Individual Heating Plants and Energy Transport

TECHNOLOGY DATA FOR ENERGY PLANTS

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1 Introduction

The present technology catalogue is published in co-operation between the Danish Energy Agency and Energinet.dk and includes technology descriptions for a number of technologies for individual heat production and energy transport.

The primary objective of the technology catalogue is to establish a uniform, commonly accepted and up-to-date basis for the work with energy planning and the development of the energy sector, including future outlooks, scenario analyses and technical/economic analyses.

The technology catalogue is thus a valuable tool in connection with energy planning and assessment of climate projects and for evaluating the development opportunities for the energy sector's many technologies, which can be used for the preparation of different support programmes for energy research and development.

The publicationof the technology catalogue should also be viewed in the light of renewed focus on strategic energy planning in municipalities etc. In that respect, the technology catalogue is considered to be an important tool for the municipalities in their planning efforts.

The technology catalogue is in English so that it can be used also in a Nordic and international perspective.

The technology catalogue has been prepared by COWI, TI and DGC in the period October 2011 to March 2012.

In addition to this technology catalogue, the Danish Energy Agency and Energinet.dk also publish a technology catalogue for larger (decentralised and central) electricity and heat generating technologies "Technology Data for Energy Plants. Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion".

2 Introduktion på dansk

Dette teknologikatalog er udgivet i et samarbejde mellem Energistyrelsen og Energinet.dk og indeholder teknologibeskrivelser for en række teknologier til brug for individuel opvarmning samt energitransport.

Et hovedformål med teknologikataloget er at sikre et ensartet, alment accepteret og aktuelt grundlag for arbejdet med energiplanlægning samt udvikling af energisektoren, herunder fremskrivninger, scenarie-analyser og tekniske/økonomiske analyser.

Teknologikataloget er således tænkt som nyttigt redskab i forbindelse med energiplanlægning og vurdering af klimaprojekter samt til at vurdere udviklingsmulighederne for energisektorens mange teknologier til brug for tilrettelæggelsen af støtteprogrammer inden for energiforskning og -udvikling.

Udarbejdelsen af teknologikataloget skal også ses i lyset af, at der er kommet fokus på den strategiske energiplanlægning i kommuner m.m. Teknologikataloget vurderes i den forbindelse at kunne udgøre et vigtigt værktøj for kommunerne i deres planlægningsindsats.

Teknologikataloget er udarbejdet på engelsk og vil dermed også kunne anvendes i såvel nordisk som international sammenhæng.

Teknologikataloget er udarbejdet af COWI, TI og DGC i perioden oktober 2011 til marts 2012.

Foruden dette teknologikatalog udgiver Energistyrelsen og Energinet.dk også et teknologikatalog for større (centrale og decentrale) el- og varmeproduktionsteknologier "Technology Data for Energy Plants. Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion".

3 Guidelines and manual

3.1 Introduction

This chapter serves to assist readers in understanding and assessing the presented information.

Each technology is described by a separate technology sheet following the same overall format as explained below.

3.2 Qualitative description

One to three pages give the key characteristics of the technology. Typical paragraphs are:

Brief technology description

Brief description on how the technology works and for which purpose.

Input

The main raw materials, primarily fuels, consumed by the technology.

Output

The forms of generated energy, i.e. electricity, heat, bio-ethanol etc.

Typical capacities

The stated capacities are for a single unit or, in case of e.g. solar heating, for a typical system size.

Regulation ability

Description of how the unit can regulate, e.g. a gas boiler is very flexible whereas a solar heating system depends on the solar radiation.

Advantages/disadvantages

Specific advantages and disadvantages relative to equivalent technologies. Generic advantages are ignored; e.g. renewable energy technologies mitigate climate risk and enhance security of supply.

Environment

Particular environmental characteristics are mentioned, e.g. special emissions or the main ecological footprints.

The ecological footprints cannot be used to compare technologies. For example, photovoltaic cells have few and small footprints, one of the major ones being radioactive waste. However, this does not mean that there is more radioactive waste from solar electricity than coal-fired electricity. It only means that radioactive waste is one footprint from photovoltaic cells which is more important than other footprints from the same technology.

The energy payback time or energy self-depreciation time may also be mentioned. This is the time required by the technology for the production of energy equal to the amount of energy that was consumed during the production of the technology.

Research and development

This is a very brief listing of the most important current challenges, often from a Danish perspective.

Examples of best available technology

A brief mentioning of recent technological innovations in full-scale commercial operation.

Additional remarks

References.

3.3 Quantitative description

To enable comparative analyses between different technologies, it is imperative that data are actually comparable. As an example, economic data must be stated at the same price level. Also, it is important to compare technologies at equal footing, e.g. either gross generation capacity or net capacity (gross minus own consumption).

It is essential that data are given for the same years. Year 2015 is the base for the present status of the technologies (best available technology commissioned in 2015), whereas data for expectations to future developments are given for the years 2020, 2030 and 2050.

Below is shown a typical data sheet, containing all parameters used to describe the specific technologies. For several technologies and in particular the technologies regarding energy transport, the data sheets have been adjusted to suit the specific characteristics.

Table 3.1 Typical datasheet for individual heat production technologies

Technology	**Name of technology**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)						
Expected share of space heating demand covered by unit (%)						
Expected share of hot tap water demand covered by unit (%)						
Total efficiency, annual average, net (%)						
Technical lifetime (years)						
Environment						
SO_2 (g per GJ fuel)						
NO_X (g per GJ fuel)						
CH_4 (g per GJ fuel)						
N_2O (g per GJ fuel)						
Particles (g per GJ fuel)						
Financial data						
Specific investment (1000€/kW)						
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)						
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/kW/year)						
Variable O&M (€/GJ)						

References:

1
2

Notes:
A

All data in the data sheets are referenced by a number in the utmost right column (Ref), referring to source specifics below the table.

Please be aware, before using the data, that essential information may be found in the notes below the table.

3.3.1 Energy/technical data

Heat production capacity for one unit

The stated capacities are for a single unit or, in case of solar heating, for a typical system size.

The capacity is given as net generation capacity in continuous operation, i.e. gross capacity minus own consumption (if any).

In general, the unit kW is used for both heat capacity, electric capacity (e.g. consumption in heat pumps) and fuel capacity.

Energy efficiencies

The total fuel efficiency for heat production technologies equals the net delivery of heat divided by the fuel consumption. The efficiency is stated in per cent at ambient conditions; air 15 °C and water 10 °C. For heat pumps, a fuel efficiency of e.g. 300 % represents a COP of 3.

If nothing else is stated in the technology description, the fuel efficiency reflects the total fuel efficiency covering both space heating and hot tap water.

The efficiencies reflect annual average efficiencies as experienced by the consumer, assuming that the heat installations are installed correctly. The boundary of annual efficiency is shown in the figure below.

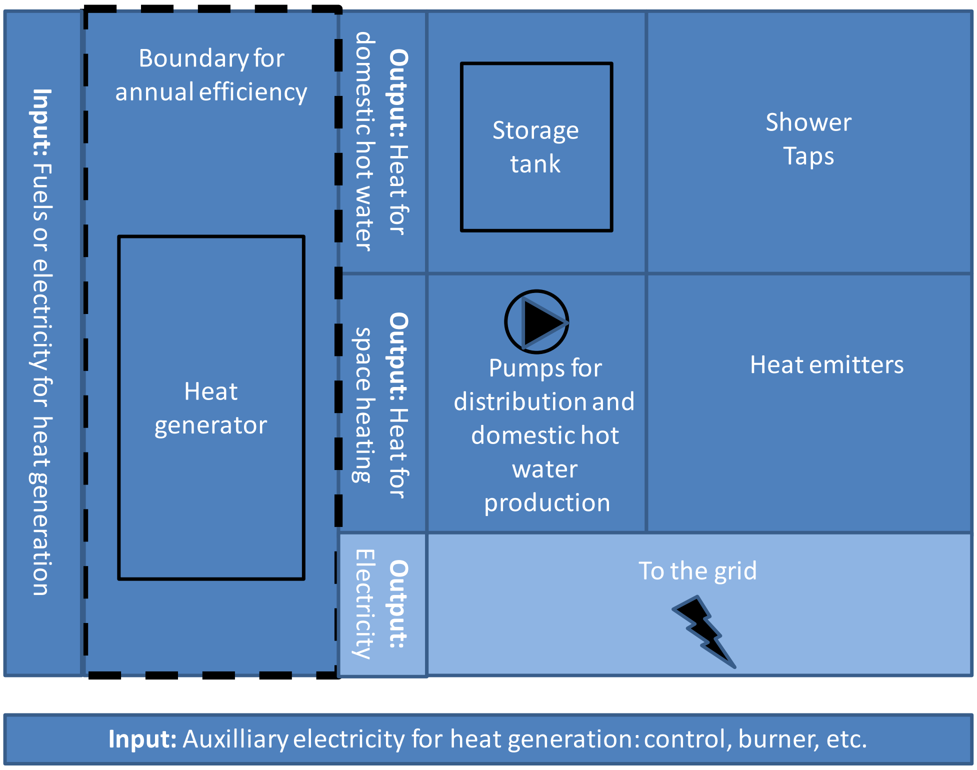

Figure 3.1 Boundary for annual efficiency

For energy transport technologies, the network loss is stated instead of the fuel efficiency.

3.3.2 Environment

CO_2 values are not stated, as these only depend on fuel, not on the technology.

SO_x: grams per GJ fuel input.

NO_x: grams per GJ fuel input. NO_x equals NO_2 + NO, where NO is converted to NO_2 in weight-equivalents.

Greenhouse gases: CH_4 and N_2O in grams per GJ fuel input.

The emissions of CH_4 and N_2O can be converted to CO_2-equivalents by multiplying the CH_4 emission by 21 and the N_2O emission by 310.

Aspects related to the technologies' possible use of rare minerals/metals (when manufactured) as well as the overall environmental footprint of the technologies have not been included in detail in the technology descriptions.

3.3.3 Financial data

Financial data are all in Euro (€) and in fixed 2011 prices.

Several data originate in Danish references. For those data, a fixed exchange rate of 7.42 DKK per € has been used.

For conversion of prices from one year to another, the general inflation rate as published by the Danish Energy Agency is used[1].

Investment costs

The investment costs include the total costs for the consumer of establishing the technology. Where possible, the investment cost has been divided (in percentage) on equipment cost and installation cost.

Where relevant, also a line with possible additional specific investment costs have been included. This is for instance relevant in connection with fluid-to-water heat pumps in city areas where it is necessary to establish vertical tubes (by use of drilling holes) instead of horizontal tubes.

The investment costs reflect consumer prices, e.g. the price for a household of establishing a new gas boiler. The prices are excluding VAT, subsidies and taxes.

An overall assumption in the catalogue is that the technologies described are of a "reasonable quality". The cheapest and non-serious boilers and heat pumps that also exist on the market are not included.

Regarding the forecast of investment costs, it has been assumed that mature technologies without an expected technology leap have the same investment cost during the period. This is based on an assumption

[1] Forudsætninger for samfundsøkonomiske analyser på energiområdet. Energistyrelsen. April 2011. / Assumptions for socio-economic analyses within the energy area. The Danish Energy Agency. April 2011

that costs of materials (e.g. steel prices) are also the same during the period (in fixed prices). If the costs of materials develop in one or another direction, it will most likely influence the technology costs.

Operation and maintenance (O&M) costs

The *fixed* share of O&M (€/kW/year) includes all costs that are independent of how the unit is operated, e.g. administration, operational staff, property tax, insurance, and payments for O&M service agreements. Re-investments within the stated lifetime are also included.

The *variable* O&M costs (€/GJ heat production) include consumption of auxiliary materials (water, lubricants, fuel additives), spare parts, and repairs (however not costs covered by guarantees and insurance).

If it is not possible to differ between fixed and variable costs, the total O&M cost is stated instead.

Fuel costs are not included in the O&M costs. Furthermore, electricity consumption for heat pumps and for electric heating is not included.

It should be taken into account that O&M costs often develop over time. The stated O&M costs are therefore average costs during the entire lifetime of the technology.

4 Definitions

4.1 Building types and heat demand

Some of the individual technologies are described for different unit sizes and/or for existing and new buildings, respectively. This is shown in the table below:

Table 4.1 Technology descriptions - relevant combinations technology and building

	Existing buildings		New buildings	
	One-family houses	Apartment complex	One-family houses	Apartment complex
Oil boiler (including bio oil)	X	X	X (bio oil)	X (bio oil)
Gas boiler	X	X	X	X
District heating substation	X	X	X	X
Biomass boiler, automatic stoking	X	X	X	X
Biomass boiler, manual stoking	X		X	
Wood stove	X		X	
Electric heat pump, air to air	X		X	
Electric heat pump, air to water	X	X	X	X
Electric heat pump, brine to water	X	X	X	X
Electric ventilation heat pump			X	X
Solar heating system	X	X	X	X
Electric heating			X	X
Micro CHP - natural gas fuel cell	X		X	
Micro CHP - hydrogen fuel cell	X		X	
Micro/Mini CHP - Stirling engine	X	(X)[2]	X	X
Micro/Mini CHP - Gas engine	X	X	X	X

[2] The highest heat capacity among the commercial products on the market is 15 kW. Even though it is possible to install several units, a Stirling engine is mainly found relevant for one family houses and for new apartment complexes with a relatively low heat demand (where the number of units can be limited).

As year 2015 is the base for the present status of the technologies, new buildings are considered to comply with the building code expected in 2015.

- An existing one-family house is defined to have an annual heat demand of 16.8 MWh and a peak demand of 7 kW.
- A new one-family house is defined to have an annual heat demand of 6.0 MWh[3] and a peak demand of 3 kW
- An existing housing block is defined to have an annual heat demand of 120 to 1,800 MWh and a peak demand of 50 to 750 kW.
- A new housing block is defined to have an annual heat demand of 40 to 600 MWh and a peak demand of 20 to 300 kW.

The size of buildings, the annual heat consumption and the peak-load demand is shown in the table below. New one-family houses are expected to have an average size of 150 m^2 (including terraced houses), whereas the average size of existing one-family houses is around 140 m^2.

Table 4.2 Annual heat consumption and peak load "an radiator"

	One-family house - existing building	Apartment complex - existing building	One-family house - new building	Apartment complex - new building
Size, m^2	140	1,000 - 15,000	150	1,000 - 15,000
Annual heat consumption, MWh	16.8	120 - 1,800	6.0	40 - 600
Peak load, kW	7	50 - 750	3	20 - 300

The heat demands are based on a demand in existing buildings of 120 kWh/m^2 (hereof 25 kWh/m^2 for hot tap water including losses) and a heat demand in new buildings of 40 kWh/m^2 (hereof 20 kWh/m^2 for hot tap water including losses). The reason why the heat demand for hot tap water in new buildings is lower than in existing buildings is an expectation of more technical insulation etc. in new buildings. It can be seen from the figures that the hot tap water makes up app. 18 % of the total heat demand in existing buildings and 50 % of the total heat demand in new buildings.

The estimated peak loads are based on a peak load of 50 W/m^2 in existing buildings and 20 W/m^2 in new buildings.

By dimensioning heat production technologies, the capacity should be higher than the estimated peak load in the table above. For instance, oil and gas boilers should have a capacity of at least 10 kW for one-family houses to make sure that they can produce hot tap water fast enough - also depending on the

[3] It should be noted that practical experiences have shown that new buildings - even though they have been designed according to the building code 2015 - can also have a higher heat demand.

size of the hot-water tank. For heat pumps which often have a larger hot-water tank, a smaller installed capacity than for oil and gas boilers may be sufficient.

The figures in the table above can be used for some rough estimates of the annual heat consumption and peak demand. However, in each specific project, the annual heat consumption and peak demand should be estimated more precisely, depending on the specific types of buildings and sizes.

4.2 Technologies and scope of investment

The catalogue is intended to work as a tool for energy planners including municipalities in their assessment, comparison and identification of future energy solutions for heat production in households etc. Hence, it is important to stress that the specific technical and economic data for each technology presented in the catalogue are not in all cases directly comparable, as data/figures cover different aspects of the energy supply of a building and the needed investment costs, respectively.

The table below includes the technologies, the scope of the technology definition used within the catalogue and direct and accompanying investment costs. The aim is to outline the different elements that have to be taken into consideration when using the catalogue data for a fair comparison of technologies

Table 4.3 Overview of investment costs included in technology data sheets and necessary accompanying investment costs

	Abolition of prior heat production system/unit	Necessary improvements of building envelope	Necessary accompanying heat supply installations	**Installation of primary heat production technology - elements incl. in the technology descriptions**	Installation of secondary heat production technology
Oil boiler	Often necessary in existing buildings e.g. • dismantling of existing boiler, • removal of oil tank, etc.	Existing buildings: not directly needed but in many cases recommendable	• Water based heat supply system • Oil tank • Chimney/flue	**Investment /installation costs of boiler incl. pumps, hot tap water production and storage.**	
Gas boiler	Often necessary in existing buildings e.g. • dismantling of existing boiler, • removal of oil tank, etc.	Existing buildings: not directly needed but in many cases recommendable	• Water based heat supply system • Chimney/flue	**Investment /installation costs of boiler incl. pumps, hot tap water production and storage, service gas pipe and meter.**	
District heating unit	Often necessary in existing buildings e.g. • dismantling of existing boiler, • removal of oil tank, etc.	Existing buildings: not directly needed but in many cases recommendable	• Water based heat supply system	**Investment /installation costs of DH unit incl. pumps, hot tap water production and storage and service DH pipe and meter.**	
Biomass boiler	Often necessary in existing buildings e.g. • dismantling of existing boiler, • removal of oil tank, etc.	Existing buildings: not directly needed but in many cases recommendable	• Water based heat supply system • Chimney/flue • Fuel storage facility	**Investment /installation costs of boiler incl. pumps, hot tap water production and storage.**	
Wood stove			• Fuel storage facility • Chimney/flue	**Investment /installation costs of stove (and water tank)**	• Supplementary heat supply •hot tap water production and storage depending on water tank
Heat pumps – air to air/ ventilation	Often necessary in existing buildings e.g. • dismantling of existing boiler, • removal of oil tank, etc.	Existing buildings: energy saving measures often needed in order to optimise heat pump installation	• Existing buildings : measures to reduce radiator temperatures often needed	**Investment /installation costs of heat pump, back-up electrical heater**	• Back up heat e.g. electrical radiators • hot tap water supply needed
Heat pumps – air/fluid to water	Often necessary in existing buildings e.g. • dismantling of existing boiler, • removal of oil tank, etc.	Existing buildings: energy saving measures often needed in order to optimise heat pump installation	• Existing buildings :measures to reduce radiator temperatures often needed • Water based heat supply system	**Investment /installation costs of heat pump incl. pipes, pumps, back-up electrical heater and hot tap water production and storage.**	
Solar heating		In some cases improvement of roof construction		**Investment /installation costs of panel incl. pipes, pumps and hot tap water storage.**	• Heat production facility • Supplementary hot tap water production
Electrical heating		Existing buildings: not directly needed but in many cases recommendable		**Investment /installation costs of electric radiators and hot tap water production and storage.**	
Micro CHP incl. fuel cells	Often necessary in existing buildings e.g. • dismantling of existing boiler, • removal of oil tank, etc.	Existing buildings: not directly needed but in many cases recommendable	• Water based heat supply system • Chimney/flue	**• Investment /installation costs of CHP/ fuel cell unit incl. pumps, meter, hot tap water production and storage. • Fuel cell (H2); hydrogen storage, electrolyser and back-up electrical heater • Fuel cell (NG); service gas pipe and back-up gas burner • Stirling and gas engine; service gas pipe and back-up gas burner**	

As can be seen from the table, there are several elements related to the installation of a particular new heating technology in a building that are not directly reflected in the investment cost and descriptions of the different technologies following this chapter.

The following table shows some of the general costs of needed accompanying investment cost, which potentially could be added when comparing the different technology solutions.

Table 4.4 Cost of accompanying investments

Accompanying element		Costs (EUR 2011)
Dismantling of existing boiler	Single family houses:	
	Wall hung natural gas fired boiler: 2,000 DKK ex. VAT	270 EUR
	Floor standing oil fired boiler: 3,000 DKK ex. VAT	400 EUR
Removal of oil tank	Single family houses:	
	1,200 liter tank (standing tank) including removal of old oil: 4,000 DKK ex. VAT	540 EUR
	Underground tank, removal of old oil, sealing of connections (no removal): 4,000 DKK ex. VAT	540 EUR
Building envelope improvements	Costs depend on the building standard etc. More information and tools to estimate costs can be found at e.g. www.byggeriogenergi.dk (The Danish Knowledge Centre for Energy Savings in Buildings).	
Water based heat supply system in building	Existing single family house (140 m^2):	
	Radiator system: 50,000 DKK ex. VAT	6,700 EUR
	New single family house (150 m^2):	
	Radiator system: 45,000 DKK ex. VAT	6,000 EUR
	Floor heating (in concrete slap): 35,000 DKK ex. VAT	4,700 EUR
	Floor heating (with diffusion plates): 45,000 DKK ex. VAT	6,000 EUR
	All prices include manifolds, piping, insulation, heat emitters/surfaces, thermostats and man hours.	
Additional radiator surface	2.2 DKK ex. VAT pr Watt (standard radiators, 300-1,000 Watt)	
	Radiators installed including thermostats:	
	Existing single family house (140 m^2): 5,000 DKK ex. VAT	670 EUR
	New single family house (150 m^2): 4,000 DKK ex. VAT	540 EUR
Oil tank	1,200 liter standing tank including installations: 8,000 DKK ex. VAT	1,100 EUR
Flue	Single family houses:	
	5 meter stainless steel flue including fittings: 7,000 DKK ex. VAT	940 EUR
	5 meter vertical flue, balanced coaxial split installed in existing chimney: 4,000 DKK ex. VAT	540 EUR

5 Technology sheets

5.1 Oil-fired boiler

Brief technology description

Oil-fired boilers are made for hot water and steam production. In the following, only hot water boilers are considered. The boilers are made in a power range from 15 kW to several MW. The oil qualities considered are:

1 Domestic mineral fuel oil.

2 Domestic oil with added bio-oil up to 10 % (fatty acid methyl ester, FAME).

3 Raw bio oil, e.g. rapeseed oil.

The complete oil-fired system includes a boiler, a burner, an oil tank and a chimney or an exhaust system. In the case of a condensing boiler, a floor drain for the condensate should be available.

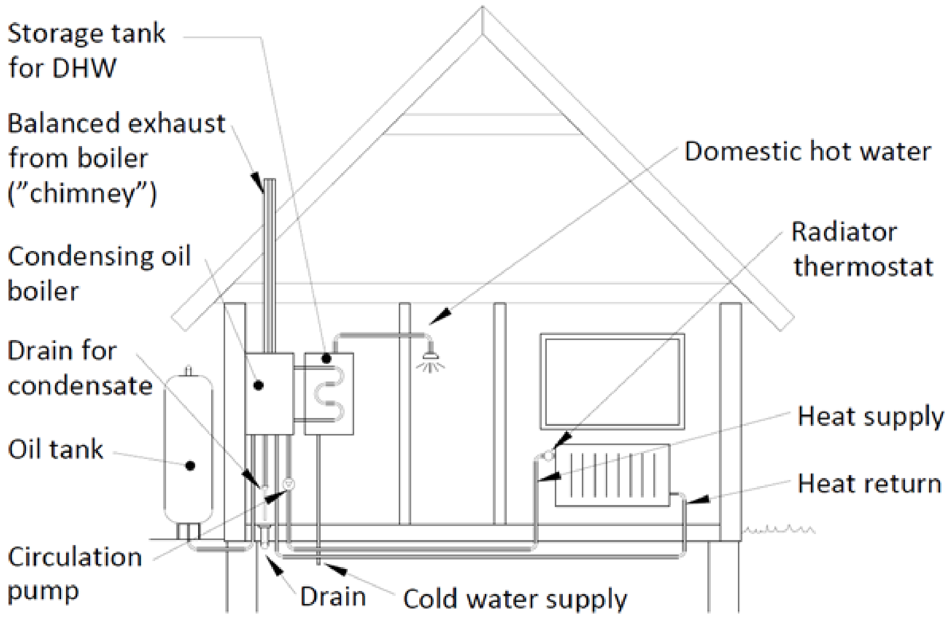

Figure 5.1 A typical installation of a condensing oil-fired boiler in a single-family house

The burner technology is atomisation by a high-pressure oil nozzle for minor boilers. For very large boilers, other technologies are available, for instance atomisation by a rotating cup. Some advanced recently developed small boilers are also using some rotating cup technology, which allows for modulating burner control. The burners may be *yellow flame* burners giving a small emission of soot or *blue flame* burners without soot emission but with a tendency to emit CO instead of soot. For the different fuels, the burner technologies are somewhat different - e.g. some fuels require preheating of the oil.

The boilers for all oil types are of almost similar design: a water-cooled combustion chamber and an integrated convection part. The materials are steel, cast iron or stainless steel. Modern boilers can be delivered with a corrosion resistant flue gas cooler that allows for condensation of the water vapour in the flue gas.

Small domestic boilers (15-100 kW)

The small boilers are used for domestic heating. The 15 kW boiler heats up to 200-300 m^2 of building area under Danish climate conditions. Very often, the boilers are built with an integrated hot water system, normally a tank of 80-150 l for the domestic tap water.

Larger boilers (100 kW - 1 MW)

These boilers are used in blocks of flats, institutions etc. and are constructed in steel or cast iron. If the connected heating system can deliver return temperatures below 45 °C, a condensing flue gas cooler will often be added. Units with integrated condensing flue gas cooler are also available. The efficiency is given by the flue gas temperature - in best cases only few degrees higher than the return temperature. In large boilers, the heat loss from the boiler can be reduced to only a fraction of a percent.

In the range of 250,000 oil-fired boilers are installed in Denmark, the largest part in single-family houses in areas where natural gas or district heating are not available.

Oil-fired boilers can have efficiency in the range of 100 %, if the return temperature from the heating system is sufficiently low, say lower than 48 °C, ref. 1, 2 and 3.

Input

Domestic fuel oil is more or less the same as diesel. Bio oil (FAME) can be added up to approximately 10 % without severe problems. Today, there are burners for pure bio oil on the market, operating with acceptable levels of problems, even if some enthusiasm may be needed though. The reliability and the maintenance (regular cleaning of the burner as an example) are not to be compared with burning of mineral oil ref. 10. Some research and development are needed in case pure liquid bio fuels shall be used widespread. The problems mostly concern practical issues with components (rubber gaskets), storage, sensibility to ambient temperature variations, preheating of oil, electricity consumption of the burner etc. These are all problems that most probably can be solved.

For large plants - in MW size - burning of bio oil gives no problems. For domestic use, some problems still remain.

Output

Heat for central heating and for domestic hot water.

Typical capacities

The heat output range from 15 kW to 1 MW.

Regulation ability

The ability to reduce the heat output is excellent for most modern boilers. It should be emphasised that a boiler with a nominal heat output of 15 kW is able to operate at much lower heat output, many types down to almost zero heat output with a very high efficiency. The reason for this is that the heat loss from the boiler can be reduced by *insulation and by low-temperature operation.*

Advantages/disadvantages

The oil-fired boiler is simple reliable technology, operating with a high thermal efficiency. The need for service is limited to once per year as stated in the regulations. In fact, one per two years will be sufficient for many installations.

Environment

A boiler fired with modern domestic fuel oil with very low content of sulphur and nitrogen will - except from the CO_2 - gives very little pollution, almost corresponding to the pollution from natural gas. The pollution components are

- Unburnt hydrocarbon (only traces)
- CO (less than 100 ppm in the flue)
- NO_X (less than 110 mg/kWh ~ 30 g/GJ)
- Soot (Soot number 0 – 1), see Ref. 9.

In Denmark, the oil-fired boilers have to be inspected once a year for flue gas loss, soot and CO (for blue flame burners)

In Denmark, boilers with an input energy larger than 100 kW must fulfil "Luftvejledningen", Ref. 7, which includes "OML" calculation of imissions (The pollution concentration in the landscape around the plant).

Research and development

The R&D in 60 years in combustion of mineral oil has resulted in very efficient, cheap and simple technology. Burner/boiler combinations with very small emissions and efficiency close to the thermodynamic limits are common standard on the market. Better burner/boiler combinations for the more difficult bio fuels can be developed.

Examples of best available technology

The best modern boilers operates with efficiency in the range of 100 % (lower calorific value), dependent on the heating system to which the boiler is connected. At the same time, the boiler/burner can be chosen with very low emissions of pollution. Combined heat and power units with a diesel engine and a flue gas cooler are on the market. That type of system needs to be cheaper and possibly also some problems with soot and NO_x. New types of bio oils are coming up, e.g., hydrotreated vegetable oil (HVO), cf. ref. 12. This type of oil can be produced in a quality very close to domestic mineral fuel oil. They are, however, not available on the Danish market yet.

Additional remarks

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Data sheets:

Table 5.1 Oil burner - one-family house, existing building

Technology	Oil burner (mineral oil fired, <10 % FAME) One-family house, existing building					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	15-30	15-30	15-30	15-30	A	
Expected share of space heating demand covered by unit (%)	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100		
Total efficiency, annual average, net (%)	100	100	100	100		1, 2, 3, 4
Technical lifetime (years)	20	20	20	20		4
Environment						
SO_2 (g per GJ fuel)	0.5	0.5	0.5	0.5	B, E	
NO_X (g per GJ fuel)	30	30	30	30	C	
CH_4 (g per GJ fuel)	0	0	0	0		
N_2O (g per GJ fuel)	0	0	0	0		
Particles (g per GJ fuel)	0.03	0.03	0.03	0.03	D	5, 6
Financial data						
Specific investment (1000€/kW)						
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)	6.6 70 30	6.6 70 30	6.6 70 30	6.6 70 30	F	
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/year)	270	270	270	270	F	
Variable O&M (€/GJ)						

References:

1 Study "Eco-design of Boilers and Combi-boilers http://www.ecoboiler.org/ . 2006-2007 by Van Holsteijn en Kemna (VHK) for the European Commission, DG Transport and Energy (DG TREN).

2 RECENT PROGRESS (AND APPLICATION) ACHIEVED IN THE WAY TO ESTIMATE REAL PERFORMANCES OF DOMESTIC BOILERS ONCE INSTALLED Jean Schweitzer, Christian Holm Christiansen Danish Gas Technology Centre, Denmark Martin Koot Gastec, Holland Otto Paulsen DTI, Denmark. SAVE Workshop Utrecht 2000.

3 BOILSIM

4 Sparolie.dk with a list of high efficiency oil-fired boilers and with a list of the status for existing oilfired boilers.

5 Bekendtgørelse om kontrol, rensning og justering af oliefyrsanlæg. BEK nr 785 af 21/08/2000 (Gældende). Lovgivning som forskriften vedrører: LOV Nr. 485 af 12/06/1996.

6 http://www.blauer-engel.de/_downloads/publikationen/erfolgsbilanz/ Erfolgsbilanz_Heiztechnologien.pdf (Rules for NOX).

7 Luftvejledningen fra Miljøstyrelsen. http://www2.mst.dk/udgiv/publikationer/2001/87-7944-625-6/pdf/87-7944-625-6.pdf.

8 Rapsolie til opvarmning,Teknik, økonomi og miljø. Videncentret for biomasse 2001.

9 Miljøstyrelsens vejledning nummer 3 1976. Gives a correspondence between soot number and soot concentration.

10 Jørn Bødker & Torben Hansen Technological Institute: Personly communication. Torben Hansen runs OR, an organization for installers. Jørn Bødker has for the "Energistyrelsen" investigated bio fuel.

11 Paulsen, O.:Calculation of electricity consumption of small oil and gasfired boilers – based on Laboratory test data. Annex F in Schweitzer, Jean: SAVE report 2005: http://www.boilerinfo.org/infosystem_el/webelproject/wp_reports/WP1.pdf.

12 http://www.biofuelstp.eu/downloads/SAE_Study_Hydrotreated_Vegetable_Oil_HVO_as_a_Renewable_Diesel_Fuel.pdf.

Notes:

A The minimum heat output for a pressure atomisation burner is in the range of 15 kW.

B 10 ppm sulphur in oil. Domestic fuel oil can be desulphoried to lower than 10 ppm sulphur.

C The last limit for NOx for Blaue Engel were 110 mg/kWh. The value is based on this. In Practise the value can be lower.

D Based on Soot number 0 - 1, which is the average value in DK.

E Data for Sulphur content can be found at the homepages for the oil companies.

F Installation prices given by Weishaupt, Denmark.

G Non-condensing boiler assumed above 400 kW. If condensing boiler is used, the efficiency is 100 % or even more if the heating system is dimensioned for low temperatures, e.g. if floor heating systems.

Table 5.2 Oil burner - apartment complex, existing building

Technology	Oil burner (mineral oil fired, <10 % FAME) Apartment complex, existing building					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	400	400	400	400		
Expected share of space heating demand covered by unit (%)	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100		
Total efficiency, annual average, net (%)	96	96	96	96	G	1, 2, 3, 4
Technical lifetime (years)	20	20	20	20		4
Environment						
SO_2 (g per GJ fuel)	0.5	0.5	0.5	0.5	B, E	
NO_X (g per GJ fuel)	30	30	30	30	C	
CH_4 (g per GJ fuel)	0	0	0	0		
N_2O (g per GJ fuel)	0	0	0	0		
Particles (g per GJ fuel)	0.03	0.03	0.03	0.03	D	5, 6
Financial data						
Specific investment (1000€/kW)						
Specific investment (1000€/unit)	32	32	32	32	F	
- hereof equipment (%)	70	70	70	70		
- hereof installation (%)	30	30	30	30		
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/year)	500	500	500	500	F	
Variable O&M (€/GJ)						

References:

Same as under the first table, i.e. "One-family houses, existing building".

Notes:

Same as under the first table, i.e. "One-family houses, existing building".

Table 5.3 Oil burner (bio oil) - one family house, new building

Technology	**Oil burner (bio oil) One-family house, new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	25	25	25	25	A	
Expected share of space heating demand covered by unit (%)	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100		
Total efficiency, annual average, net (%)	100	100	100	100		1, 2, 3, 4
Technical lifetime (years)	20	20	20	20		4
Environment						
SO_2 (g per GJ fuel)	0	0	0	0	B, E	
NO_X (g per GJ fuel)	> 30	> 30	> 30	> 30	C	
CH_4 (g per GJ fuel)	0	0	0	0		
N_2O (g per GJ fuel)	0	0	0	0		
Particles (g per GJ fuel)					D	5, 6
Financial data						
Specific investment (1000€/kW)						
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)	12 70 30	12 70 30	12 70 30	12 70 30	F	
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/year)	500	500	500	500	F	
Variable O&M (€/GJ)						

References:

Same as under the first table, i.e. "One-family houses, existing building".

Notes:

Same as under the first table, i.e. "One-family houses, existing building".

Table 5.4 Oil burner (bio oil) - apartment complex, new building

Technology	**Oil burner (bio oil) Apartment complex, new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	400	400	400	400	A	
Expected share of space heating demand covered by unit (%)	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100		
Total efficiency, annual average, net (%)	100	100	100	100		1, 2, 3, 4
Technical lifetime (years)	20	20	20	20		4
Environment						
SO_2 (g per GJ fuel)	0	0	0	0	B, E	
NO_X (g per GJ fuel)	> 30	> 30	> 30	> 30	C	
CH_4 (g per GJ fuel)	0	0	0	0		
N_2O (g per GJ fuel)	0	0	0	0		
Particles (g per GJ fuel)	-	-	-	-	D	5, 6
Financial data						
Specific investment (1000€/kW)						
Specific investment (1000€/unit) - 400 kW unit	40	40	40	40	F	
- hereof equipment (%)	70	70	70	70		
- hereof installation (%)	30	30	30	30		
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/year)	1000	1000	1000	1000	F	
Variable O&M (€/GJ)						

References:

Same as under the first table, i.e. "One-family houses, existing building".

Notes:

Same as under the first table, i.e. "One-family houses, existing building".

5.2 Natural gas boiler

Brief technology description

What is a gas boiler?

In a gas fired boiler, gas is burnt in a combustion section. It may be a traditional flame or via specially designed low NO_X combustors. Heat is transferred to water through water cooled walls and through a water tube heat exchanger after the combustion section. Gas boilers can be wall hung or floor standing.

The hot water from the gas boiler is circulated in the radiators of the house (a pump is therefore required on the installation or in the boiler).

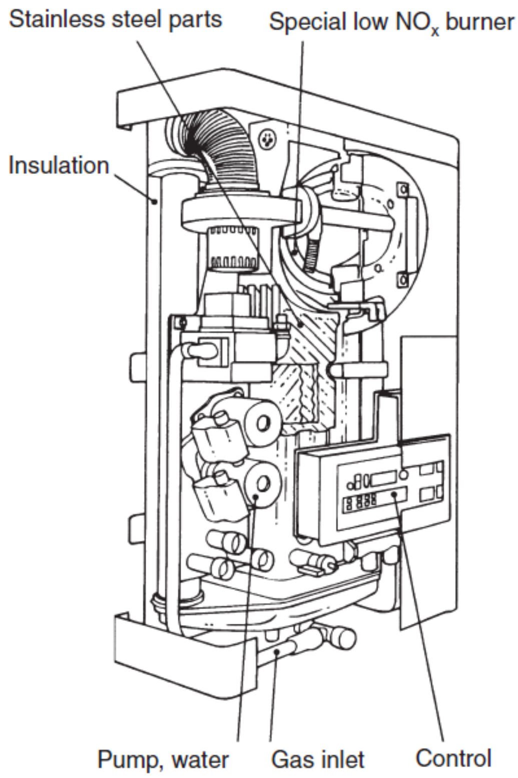

Figure 5.2 A wall hung gas boiler for single family houses (Source: VarmeStåbi®, Nyt Teknisk Forlag)

A gas boiler is often called a "central heating (CH) boiler", as it is one of the elements of a central heating installation including boiler(s), a heat distribution system, heat emitters (radiators, convectors etc.) and a control system for the appliances.

What is a condensing boiler?

A condensing boiler is a boiler designed for low-temperature operation including recovering low-temperature heat and the latent heat from water vapour produced during the combustion of the fuel.

The condensing boilers include two stages of heat collection, compared to traditional boilers (non-condensing boilers), which only include one stage. In the condensing boiler, a second heat exchanger is placed before the flue gas exit to collect the latent heat contained in the flue. Most gas-fired boilers also allow for condensation in the combustion chamber.

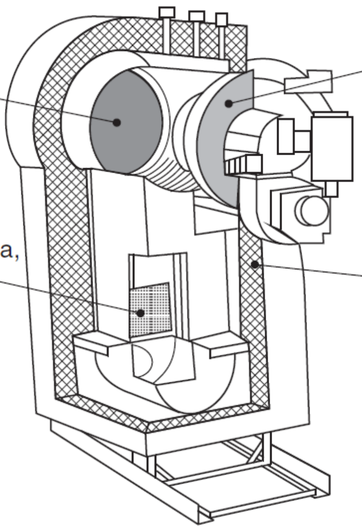

Figure 5.3 A floor standing medium size condensing gas boiler for apartment blocks etc. (Source: VarmeStåbi®, Nyt Teknisk Forlag)

Condensing flue gas recovery heat exchangers can be installed as auxiliary equipment after the boiler.

Traditional gas boilers (= non-condensing) can no longer be installed in Danish houses/buildings (Requirements of the new building regulations, BR 10).

Gas combustion

In a gas boiler, the combustion often takes place by using specially designed burners for gas and the necessary combustion air. Most appliances will accommodate a large variety of natural gas compositions or LPG's with slight technical changes to the burner.

Use of gas boilers for heating and hot water production

Gas boilers are often used for heating and sanitary hot water production. For the latter, hot water storage is used mostly (in Denmark), but it is also possible to have appliances producing hot water instantaneously.

Efficiency of gas boilers

Gas boilers' efficiency is mainly depending on water temperature. The newest condensing boilers on the market are often able to achieve more than 100 % efficiency (based on net calorific value) also in real installations. The improved insulation of boilers and new burner technologies make it possible to come close to the theoretically achievable efficiency. Efficiency in the range of 98-104 % as annual efficiency is now possible [b] [c].

Annual efficiency referred to in the section "natural gas boilers" is calculated with BOILSIM [c], [d] and includes heating and hot water production based on Danish average houses.

Hybrid systems and new technologies

Hybrid systems are mixing different technologies:

- Gas boilers can be used in combination with solar thermal energy, and dedicated and adapted products are found on the market.

- Gas boilers can also be used in combination with electrical heat pumps [e] and provide heat when for example the electrical heat pump is not able to work efficiently (e.g. because of low external air temperature). Packages with electrical heat pumps and gas boilers are on the market already. The combination is quite attractive due to the good complementarity that can achieve high system efficiency.

New technologies of gas boilers are also on the way:

- Gas heat pump [f] and micro cogeneration (mCHP) [g] are emerging technologies that have no significant market share yet, but are attracting increasing interest. Some micro CHP products are market ready, some are under development/tests (e.g. fuel cells).

- Gas heat pumps open for cooling/air conditioning function and mCHP for the decentralized electricity production.

Input

Natural gas boilers are using natural gas as fuel. They can also use LPG gases (in general with minor burner changes). Biogas can be used as well. It can be injected to the gas grid and mixed with natural gas or used directly (this requires major CO_2 removal from the gas to have a calorific value close to CH_4).

Output

The form of energy generated by gas boilers is heat transferred to heated water. So the output is hot water either used for heating or directly for sanitary hot water.

Typical capacities

For the domestic market, most of the gas boilers (single units) have a nominal heat output of about 20 kW and are modulating (see next section) down to 1 kW for very new technologies.

The 20 kW are needed to cover the *sanitary hot water production* (especially in the case of boilers without water tank), whereas for *heating* 10 kW or less would be sufficient for most of the domestic houses.

In general, gas boilers are produced as a series of similar appliances having different capacities. Examples of nominal capacities are 10, 20, 30 and 50 kW.

For apartment blocks and other large buildings, where the heat demand is larger than for single-family houses, larger boilers are used, but also the combination of several domestic appliances connected in so-called "cascade" is a possible solution. In that case, the number of appliances in operation is determined by the heat demand.

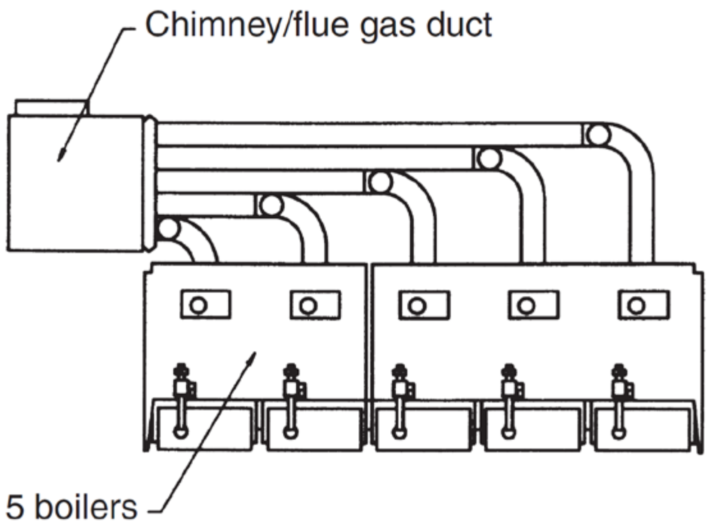

Figure 5.4 Cascade installation of boilers. (Source: VarmeStåbi®, Nyt Teknisk Forlag)

Regulation ability

Boilers are generally sold with controls that enable the optimal matching between the user demand and the appliance's heat production and the actual hot water demand. For example, in case the user needs hot water, the control system will give production priority to that demand. The control systems are able to communicate with components such as external temperature sensor or pump. The control system will also adapt to other control elements such as radiator thermostat etc.

Some control systems are auto-adaptive: they will learn from the recent past to optimize the control of the boiler.

Most of the boilers on the present market are so-called "modulating" boilers. This feature allows the appliance to deliver reduced heat output without stopping the burner (the gas and air flows to the burner are reduced). Modulating ranges from 4 to 20 kW are typical, and technologies allowing very low minimum range are developed (starting from 1 kW). The modulation feature reduces the too frequent start-stop of the boiler and improves the user's comfort and the lifetime of the appliance.

Advantages/disadvantages

Advantages of gas boilers:

- Gas boilers offer an efficient way to use directly primary energy in homes. Modern condensing boilers have very small energy losses and are designed to cover the entire heat and hot water need of end users.
- CO_2- and NO_x-emissions of gas boilers are the lowest compared to any other fossil fuel boilers.
- The transport of natural gas to the houses through the gas grid is less "energy costly" than the transport of oil.
- Opposite to district heating, there are no network losses related to the transportation of gas in the grid.

Disadvantages of gas boilers:

- In the commercial sector[4], gas boilers are very competitive. However, in the domestic sector, the relative cost of central heating installations is getting too high compared to the low energy need of modern and well insulated houses. Gas boilers are therefore decreasingly suitable for new small-size buildings or houses with low energy demand.

Environment

Emissions

Gas boilers have low NO_x emissions (lower than oil boilers, due to the nature of the fuel), very little unburned hydrocarbon (older burner technologies had some) and low CO emissions.

Like other fossil fuel boilers, gas boilers have a net emission of CO_2.

Research and development

R&D in the area is mainly dedicated to:

- Low-NO_X burners.

- Combustion controls enabling appliances to self-adapt to variations in gas composition.

But most of the research is dedicated to the development of new technologies that might replace conventional gas boilers:

- Domestic gas heat pump.

- Micro CHP units

These new technologies are not covered by this technology description of gas boilers.

Examples of best available technology

A typical example of BAT would be a modulating, condensing boiler with a range of 5 to 20 kW. The efficiency is constant over the range of modulation, and NO_x emission is low thanks to the NO_x burner technology. Most of the condensing boilers on the market have now reached the highest achievable efficiency (with this technology) and can be considered to be BAT.

As a new technology, Robur gas heat pump can be mentioned (mostly for apartment blocks due to the size range 30 to 40 kW) [f].

Additional remarks

Only condensing boiler technology is allowed for new installations in Denmark.

References

- [a] Study "Eco-design of Boilers and Combi-boilers http://www.ecoboiler.org/ . 2006-2007 by Van Holsteijn en Kemna (VHK) for the European Commission, DG Transport and Energy (DG TREN).

[4] In general, the gas market is divided into two groups: the domestic market (one-family houses, apartments) and the commercial market (shops, hospitals etc.).

- [b] RECENT PROGRESS (AND APPLICATION) ACHIEVED IN THE WAY TO ESTIMATE REAL PERFORMANCES OF DOMESTIC BOILERS ONCE INSTALLED Jean Schweitzer, Christian Holm Christiansen Danish Gas Technology Centre, Denmark Martin Koot Gastec, Holland Otto Paulsen DTI, Denmark. SAVE Workshop Utrecht 2000.

- [c] Test of more than gas 100 boilers tested in laboratory at DGC. Application of BOILSIM model.

- [d] BOILSIM http://www.boilsim.com/.

- [e] Example of hybrid technology: manufacturer: Gloworm; Product: Clearly Hybrid: http://www.glow-wormheating.co.uk/clearly-hybrid/clearly-hybrid.php.

- [f] Gas heat pump. Example of manufacturer. Robur http://www.robur.com/.

- [g] Micro CHP manufacturers on the market, e.g. Remeha and Baxi.

Data sheets:

Table 5.5 Natural gas boiler - one-family house, existing building

Technology	**Natural gas boiler One-family house, existing and new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	5-20	3-20	2-20	1-20		
Expected share of space heating demand covered by unit (%)	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100		
Total efficiency, annual average, net (%)	100-104	100-104	100-104	100-104	A	1
Electricity consumption (kWh/year)	80-200	40-120	20-80	?		
Technical lifetime (years)	22	22	22	22	B, C	2
Environment						
SO_2 (g per GJ fuel)	~0	~0	~0	~0		5
NO_X (g per GJ fuel)	20	10	5	?	D, E	4
CH_4 (g per GJ fuel)	2	1	0.5	?		5
N_2O (g per GJ fuel)	~0	~0	~0	~0		
Particles (g per GJ fuel)	~0	~0	~0	~0		
Financial data						
Specific investment (1000€/kW)						
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)	5 45 55	5 45 55	5 45 55	5 45 55	G	
Possible additional specific investment (1000€/unit)	2	2	2	2	K	6
Fixed O&M (€/kW/year)	4	4	4	4	H	
Variable O&M (€/GJ)	2	2	2	2	I	

References:

1 Annual efficiency calculation method for domestic boilers. SAVE Contract XVII/4.1031/93-008.

2 Internal note on HNG Statistics on replacement of gas boilers.

3 Study "Eco-design of Boilers and Combi-boilers (VHK) for the European Commission, DG Transport and Energy (DG TREN). Task 4 Section 3.1.

4 Study "Eco-design of Boilers and Combi-boilers (VHK). Task 4 Section 3.1.

5 Start stop emissions of domestic appliances. H. Hüppelshäuser and F. Jansen. Ruhrgas. IGRC 1998.

6 HMN: http://salg.naturgas.dk.

Notes:

A Annual efficiency calculated with input test data carried out at DGC and using the model BOILSIM [1].

B Technical lifetime (years). We consider that the lifetime is defined as the time where 50% of the appliances are not working anymore.

C The lifetime is based on [2] and averaged on selected recent technologies.

D ECO design limit for gas boilers = 70 mg/kWh = 70/3.6 = approx. 20 g/GJ fuel based on Hs.

E We consider that NOx emission will decrease as an average. The level proposed for 2030 is already achievable today.

F Ref [5] gives 5 mg/kWh, This is less than 2 g/GJ.

G HMN standardsinstallation, 37,500 kr.

H HMN serviceordning 2011.

I HNG servicestatistik 2006.

J HMN energirådgivning.

K Installation of a gas service line (grid connection). The price may change depending on the marketing of the gas distribution companies. For non-domestic appliances, the same price as for domestic is assumed. Only to be paid if the natural gas is not yet supplied to the house.

Table 5.6 Natural gas boiler - apartment complex, existing building

Technology	**Natural gas boiler** **Apartment complex, existing and new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	20-750	20-750	20-750	20-750		
Expected share of space heating demand covered by unit (%)	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100		
Total efficiency, annual average, net (%)	100-104	100-104	100-104	100-104		
Electricity consumption (kWh/year)	400	300	200	100		
Technical lifetime (years)	25	25	25	25		
Environment						
SO_2 (g per GJ fuel)	~0	~0	~0	~0		
NO_X (g per GJ fuel)	20	10	5	5		
CH_4 (g per GJ fuel)	2	1	0.5	0.5		
N_2O (g per GJ fuel)	~0	~0	~0	~0		
Particles (g per GJ fuel)	~0	~0	~0	~0		
Financial data						
Specific investment (1000€/kW)						
Specific investment (1000€/unit)	5-40	5-35	5-30	5-30	J	
- hereof equipment (%)	50-85	50-85	50-85	50-85		
- hereof installation (%)	15-50	15-50	15-50	15-50		
Possible additional specific investment (1000€/unit)	2	2	2	2	K	6
Fixed O&M (€/kW/year)	4	4	4	4		
Variable O&M (€/GJ)	2	2	2	2		

References:

Same as under the first table, i.e. "One-family houses, existing building".

Notes:

Same as under the first table, i.e. "One-family houses, existing building".

5.3 District heating substation

Brief technology description

District heating is a hydraulic system of pipes with the purpose of distributing thermal heat to end user of space heating and domestic hot water mainly. The thermal heat comes from of a number of sources including heat from combined heat and power production (CHP), surplus heat from industry, and heat from waste incineration and biomass boilers. More than 60% of Danish households are supplied with district heating by more than 400 district heating networks. In major cities, typically more than 95% of the end users are connected.

The district heating substation is placed at the end user with the purpose of preparing domestic hot water and delivering heat for the space heating system based on district heating. Each building with a district heating substation is supplied from a branch pipe connecting the building to the overall distribution network.

The substation is equipped with a domestic hot water heater based on either a storage tank or a heat exchanger without storage, e.g. a plate heat exchanger. In some cases, a combination of an external heat exchanger and a storage tank is seen. The space heating is delivered by direct supply of district heating water or by a heat exchanger placed in between the district heating water (primary side) and the space heating water (secondary side). Further, the substation includes all valves, controllers, filters, pumps, etc. that are necessary for the operation.

Figure 5.5 shows a sketch with typical components included in a substation for single-family houses [1], Figure 5.6 shows the district heating substation installed in a single-family house.

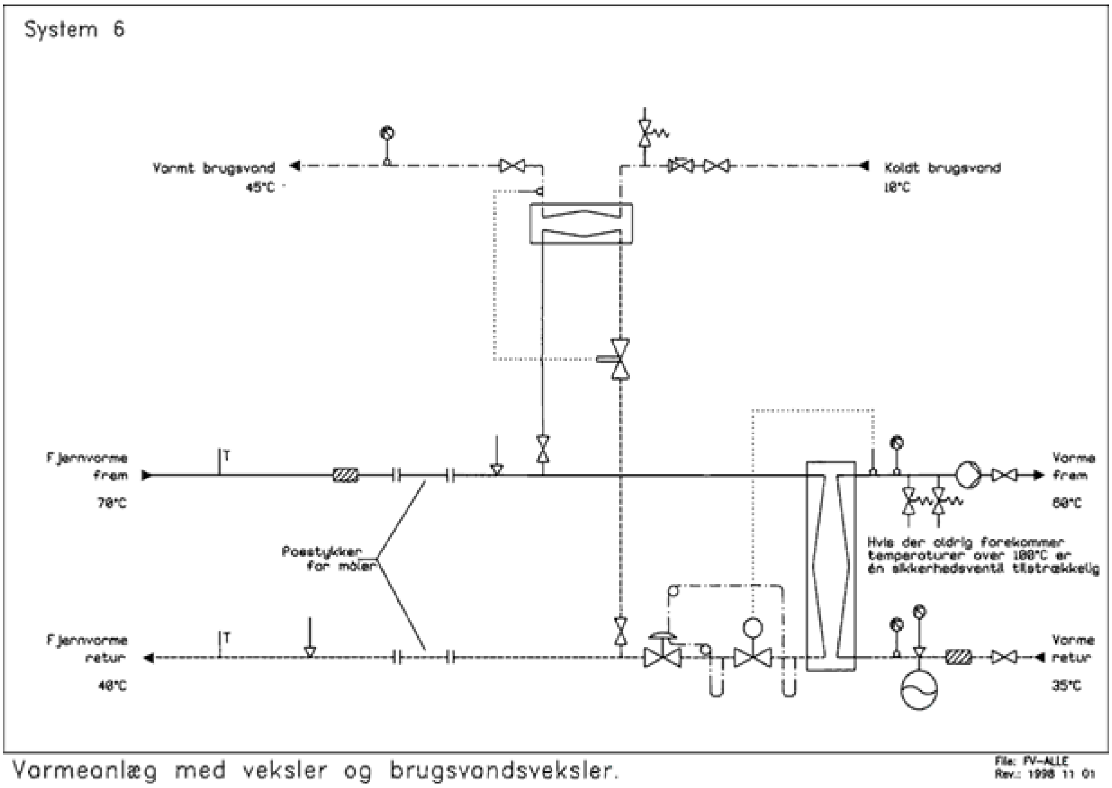

Figure 5.5 District heating substation with domestic hot water heater and heat exchanger for space heating in a one family house. A branch pipe is connecting the building with the district heating network.

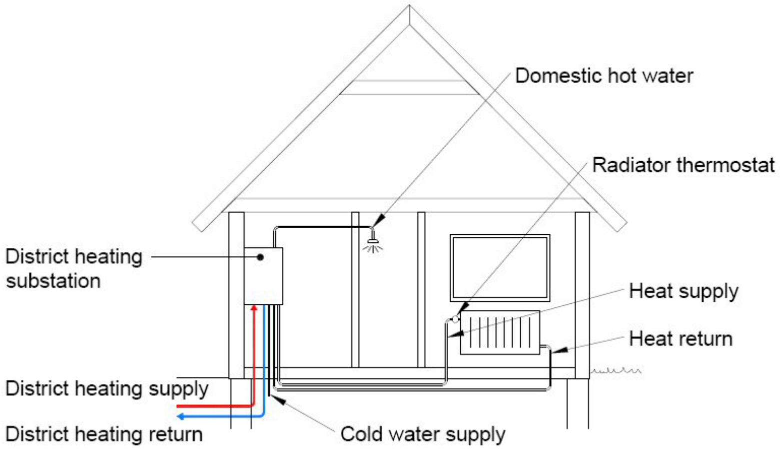

Figure 5.6 District heating substation with domestic hot water heater and heat exchanger for space heating

In large buildings, the substation can be placed centrally, or small substations, the so-called flat stations, can be placed in each flat.

Input

Heat (district heating).

Output

Heat (space heating and domestic hot water).

Typical capacities

The substation space heating capacity is determined based on district heating temperatures and maximum allowable pressure drop.

In single-family houses, the space heating capacity is typically set at 10 kW for district heating temperatures 70°C/40°C and a maximal allowable pressure drop of 0.3 bar.

For large buildings, the capacities typical range from 70 kW to 250 kW for standardised wall-hung products. Above 250 kW, the substations will be individually designed and manufactured. Figure 5.7 shows and example of a substation. The capacities of large buildings refer to district heating temperatures 70°C/40°C in the following.

Figure 5.7 District heating substation for large buildings [2]

Regulation ability

The district heating substations can regulate the heat to comply with any heat demand required within the dimensioned heat demand. On component level, the design criteria include ability to control domestic hot tap water temperature, flow temperature to the heating system, pressure loss and ability to maintain a low return temperature.

Advantages/disadvantages

Basically, the substation itself cannot be compared with individual heating options like gas boilers or heat pumps. In order to make a comparison, the whole district heating system must be taken into consideration, including distribution network and heat source.

Advantages/disadvantages are here considered in relation to the individual building. Some of the advantages of district heating are:

- Compact design - small installation space requirements
- Low maintenance costs
- Very low noise level
- No pollution produced locally.

Disadvantages are mainly related to the establishment of the district heating network. The laying of the branch pipe requires some extra construction work compared to other heating technologies. Capital costs and distribution network losses of the district heating system may be barriers that prevent district heating companies from providing district heating to customers in areas with low heat density.

Environment

The environmental characteristics are dependent on the heat input to the specific district heating network. Therefore, no such characteristics are presented. Environmental declarations exist for district heating networks, e.g. the declaration for the Greater Copenhagen district heating system.

Research and development

Research and development are mainly taking place in the following areas:

- Plate heat exchanger design.
- Control strategies.
- Low-temperature operation (< 55^{o}C district heating flow temperature).
- Reduction of standby losses (primarily in new single-family houses).
- Integration or combination with other technologies (mainly outside Denmark). In Denmark, low temperature district heating combined with electric immersion heating elements or heat pumps for hot water production eventually combined with smart grids are new research areas.

Examples of best available technology

Some district heating utilities are working on decreasing the district heating supply temperature and have set new requirements for district heating substations [6].

Such low-temperature district heating substations have been demonstrated in the low-energy buildings of Dept. 34 of the housing association "Boligforeningen Ringgården". The substations incorporate efficient plate heat exchanger technology and are able to supply domestic hot tap water at 47°C with a district heating supply temperature of 50°C and return temperatures below 25°C [3].

In low-energy houses, low standby losses of technical installations are essential to comply with the Danish building code. An example of a very efficient insulation of a substation is seen in Figure 5.8 (note that only the back insulation panel is shown on the photo, the front insulation has been removed).

Figure 5.8 District heating substation with full body insulation for a single-family house [4]

Also new electronically controlled water heaters have entered the market and are expected to improve efficiency and comfort further [5].

Additional remarks

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References

1 Forslag til Forskrifter for godkendte standardunits, Teknologisk Institut, 2005.

2 Communication with Gemina Termix, www.termix.dk.

3 Delrapport 2 - DEMONSTRATION AF LAVENERGIFJERNVARME TIL LAVENERGIBYGGERI I BOLIGFORENINGEN RINGGÅRDENS AFD. 34 I LYSTRUP. Energistyrelsen - EUDP 2008-II, 2011.

4 Communication with Danfoss Redan, www.redan.danfoss.com.

5 www.metrotherm.dk.

6 Krav til fjernvarmeunits I VarmeTransmission Aarhus, December 2011.

7 Prices from different providers of substation maintenance.

Data sheet:

Table 5.7 District heating substation - one family house, existing and new building

Technology	**District heating substation One-family house, existing and new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	10	10	10	10	H	
Expected share of space heating demand covered by unit (%)	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100		
Total efficiency, annual average, net (%)	98	98	98	98	B	
Technical lifetime (years)	20	20	20	20		
Environment						
SO_2 (g per GJ fuel)	-	-	-	-		
NO_X (g per GJ fuel)	-	-	-	-		
CH_4 (g per GJ fuel)	-	-	-	-		
N_2O (g per GJ fuel)	-	-	-	-		
Particles (g per GJ fuel)	-	-	-	-		
Financial data						
Specific investment (1000€/kW)						
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)	1.5-3.5 20-25 75-80	1.5-3.5 20-25 75-80	1.5-3.5 20-25 75-80	1.5-3.5 20-25 75-80	C	2, 3, 4
Possible additional specific investment (1000€/unit)	3	3	3	3	D	
Fixed O&M (€/unit/year)	150	150	150	150	F	7
Variable O&M (€/GJ)						

References:

1 Forslag til Forskrifter for godkendte standardunits, Teknologisk Institut, 2005.

2 Communication with Gemina Termix, www.termix.dk.

3 Delrapport 2 - DEMONSTRATION AF LAVENERGIFJERNVARME TIL LAVENERGIBYGGERI I BOLIGFORENINGEN RINGGÅRDENS AFD. 34 I LYSTRUP. Energistyrelsen - EUDP 2008-II, 2011.

4 Communication with Danfoss Redan, www.redan.danfoss.com.

5 www.metrotherm.dk.

6 Krav til fjernvarmeunits I VarmeTransmission Aarhus, December 2011.

7 Prices from different providers of substation maintenance.

Notes:

A The generating capacity for one substation is set at the space heating capacity at typical district heating flow/return temperatures of 70°C/40°C. The size of the water heater capacity is estimated based on the number of apartments that the substation can supply with space heating.

B The only losses related to the district heating substation are the standby heat losses. For large well-insulated substations, these are considered negligible – 100% efficiency. However, substations for single-family houses will have a heat loss during summer that cannot be considered useful. Applying best available technology, this is considered to be about 2%, resulting in 98% efficiency.

C The price span covers the variety of designs on the market from very simple direct connected substations with instantaneous water heater to indirect connected substations with a storage tank water heater.

D Specific investment in branch pipe and meter.

E The price span covers the variety of designs on the market from very simple direct connected substations with instantaneous water heater to indirect connected substations with storage tank water heater. The price is related to generating capacity.

F The operation and maintenance costs are based on a maintenance check every second year, but calculated per year and per installation.

G The price is given for an indirect connected substation with storage tank water heater and is related to generating capacity. A large variety of designs are on the market from very simple direct connected substations with instantaneous water heater to indirect connected substations with storage tank water heater. For the simplest solution the price can be 50 % lower than the prices given in the table.

H Note that the branch pipe should be dimensioned for the use of hot tap water. If there is not any hot water tank, the branch pipe capacity should be higher than the capacity of the DH substation.

Table 5.8 District heating substation - apartment complex, existing and new building

Technology	District heating substation Apartment complex, existing and new building					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	250	250	250	250	A	
Expected share of space heating demand covered by unit (%)	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100		
Total efficiency, annual average, net (%)	100	100	100	100	B	
Technical lifetime (years)	20	20	20	20		
Environment						
SO_2 (g per GJ fuel)	-	-	-	-		
NO_X (g per GJ fuel)	-	-	-	-		
CH_4 (g per GJ fuel)	-	-	-	-		
N_2O (g per GJ fuel)	-	-	-	-		
Particles (g per GJ fuel)	-	-	-	-		
Financial data						
Specific investment (1000€/kW)	0.07	0.07	0.07	0.07	G	2, 4
Specific investment (1000€/unit)						
- hereof equipment (%)	70	70	70	70		
- hereof installation (%)	30	30	30	30		
Possible additional specific investment (1000€/unit)	4	4	4	4	D	
Fixed O&M (€/unit/year)	1,250	1,250	1,250	1,250		7
Variable O&M (€/GJ)						

References:

Same as under the first table, i.e. "One-family houses, existing and new building".

Notes:

Same as under the first table, i.e. "One-family houses, existing and new building".

5.4 Biomass boiler, automatic stoking

Brief technology description

Wood pellets are usually applied in automatically stoking biofuel boilers. However, some boilers, especially major ones, are also designed for firing with other types of biomass such as wood chips and grain.

The fuel is conveyed via an auger feeder from the fuel supply to the burner unit. In the burner, the combustion takes place during supply of primary and secondary air. The boiler is often a steel sheet boiler with a convection unit consisting of boiler tubes or plates.

The fuel can be supplied from an external earth storage tank, storage room or similar, or it can be supplied from an integral fuel hopper that is part of the boiler unit. Fuel is available in sacks and can be added to the silo manually, or - in case of wood pellets - the fuel can be blown into the storage tank or room by a tanker.

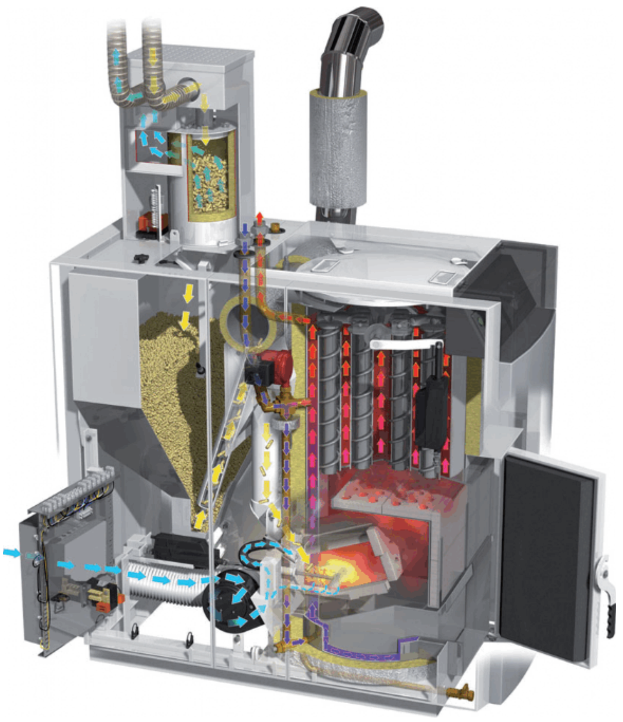

Figure 5.9 Biomass boiler, automatic stoking

Within automatic bio fuel boilers, we operate with two types: compact plants consisting of a boiler and a burner in the same unit, and boilers with a detachable burner. Detachable burners can be approved up till 70 kW and are exclusively applicable for stoking with pellets.

Heating can be done solely with an automatic biofuel boiler, but hybrid systems like solar/biomass or others are attractive to combine solar thermal technologies in summer for hot tap water, while biomass is turned off and remains the main heat source for hot tap water and space heating during the rest of the year.

Use of biofuel boilers can be a relevant option for the approx. 500,000 households found in rural areas or in areas without legal requirements of connecting to the public supply network. Biofuel boilers are common in Denmark and in the rest of Europe. Denmark is estimated to have approx. 47,000 automatically fired biofuel boilers in 2011.

Input

Wood pellets or wood chips[5]. Another possible fuel depending on the boiler type is non-woody biomass such as grain.

Output

Heat for central heating.

Typical capacities

From 8 kW to 500 kW, or even larger. Detachable pellet burners from 8 kW to 70 kW.

Regulation ability

All boilers can be regulated from less than 30% to 100% of full capacity, without violating emission requirements. The best technologies can be regulated from 10 to 120% of the nominal heat output stated by the manufacturer on the boiler plate.

Advantages/disadvantages

Considerable savings in relation to economy and CO_2 emission can be reached.

The investment in a new biomass boiler is often limited if an existing oil burner must be replaced anyway.

Biomass boilers and storage capacities require room space and an appropriate boiler room. For lager boilers, and also in case of firing with other types of fuels than pellets, the labour needed for maintenance must be considered.

Environment

Use of high fuel quality and advanced technological combustion concepts ensure that automatic combustion systems are environmentally sound and efficient residential heating technologies. The legislation requirements are easily met for the best available technologies firing with wood pellets and wood chips.

Research and development

There is still a need for R&D in the following areas:

- High-efficient and low-emission technologies

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[5] Wood pellets are small, compressed pellets made of e.g. wood shavings and sanding dust compressed under high pressure and with maximum 1% binding agents. Wood pellets have typically a diameter of 6 mm or 8 mm and a moisture content of about 6-8 %. The length varies up to 5 times the diameter.

Wood chips consist of wood pieces of 5-50 mm in the fibre direction, longer twigs (slivers), and a fine fraction (fines). There exist three types of wood chips: Fine, coarse and extra coarse. The names refer to the size distribution only, and not to the quality.

- Automation and comfort
- Fuel flexible boilers
- Boilers with less than 5 kW nominal heat output.

Examples of best available technology

Danish manufacturers of best available technology can be found on web lists at http://www.teknologisk.dk/911. The lists make use of energy and emission labelling of the boilers.

Additional remarks

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References

1 Videncenter for Halm og Flis-fyring. Træ til energiformål. 1999.

2 "Brændeovne og små kedler – partikelemissioner og reduktionstiltag, Miljøprojekt nr. 1164, 2007, Jytte Boll Illerup, DMU et al.

3 Emissioner fra træfyrede brændeovne og -kedler, Miljøprojekt nr. 1324 2010, Johnny Iversen, Thomas Capral Henriksen og Simon Dreyer, Carl Bro.

Data sheets:

Table 5.9 Biomass boiler, automatic stoking - one-family house, existing building

Technology	**Biomass boiler, automatic stoking One-family house, existing building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	6-20	5-20	4-20	4-20	A	4, 5
Expected share of space heating demand covered by unit (%)	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100		
Total efficiency, annual average, net (%)	80	87	91	95	B	5, 6
Technical lifetime (years)	20	20	20	20		7
Environment						
SO_2 (g per GJ fuel)	NA	NA	NA	NA		
NO_X (g per GJ fuel)	90	70	50	40		5
CH_4 (g per GJ fuel)	3	2	1	0		2, 5
N_2O (g per GJ fuel)	NA	NA	NA	NA		
Particles (g per GJ fuel)	10	8	6	4	C	2, 5
Financial data						
Specific investment (1000€/kW)						
Specific investment (1000€/unit) - hereof equipment (1000€/unit) - hereof installation (1000€/unit)	2.5-11 2-10 0.5-1	2.5-11 2-10 0.5-1	3-12 2.5-11 0.5-1	3-12 2.5-11 0.5-1	G	
Possible additional specific investment (1000€/unit)	1.6	1.6	1.6	1.6	D, F	
Fixed O&M (€/kW/year)	2	2	3	3	E	6
Variable O&M (€/GJ)	NA	NA	NA	NA		

References:

1 Vurdering af brændekedlers partikelemission til luften i Danmark, Miljøprojekt nr. 6 2008, Kim Winther, Teknologisk Institut.

2 Emissioner fra træfyrede brændeovne og -kedler, Miljøprojekt nr. 1324 2010, Johnny Iversen, Thomas Capral Henriksen og Simon Dreyer, Carl Bro.

3 Brændeovne og små kedler - partikelemissioner og reduktionstiltag, Miljøprojekt nr. 1164, 2007, Jytte Boll Illerup, DMU et al.

4 www.teknologisk.dk/911; Listen over godkendte biobrændselsanlæg.

5 Biomass for heating & cooling, Vision & SRA; DRAFT 08072011; Renewable heating & Cooling; European Technology Platform.

6 Energibesparelser - det behøver ikke være så svært; Energibranchen.dk, nr. 3, september 2009.

7 Lot 15: Solid fuel small combustion installations-Base Case definition.

Notes:

A Nominal heat delivery.

B Efficiency development from reference 5.

C EN303-5 measurement method.

D Prerequisite: house with central heating system.

E Contemporary value from reference 6.

F Chimney.

G Difference in price mainly due to different finish, design etc. but to some extent also due to size/capacity.

Table 5.10 Biomass boiler, automatic stoking - apartment complex, existing building

Technology	**Biomass boiler, automatic stoking** **Apartment complex, existing building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	100-1000	100-1000	100-1000	100-1000		
Expected share of space heating demand covered by unit (%)	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100		
Total efficiency, annual average, net (%)	85	87	91	95		5
Technical lifetime (years)	20	20	20	20		7
Environment						
SO_2 (g per GJ fuel)	NA	NA	NA	NA		
NO_X (g per GJ fuel)	90	70	50	40		5
CH_4 (g per GJ fuel)	3	2	1	0		2, 5
N_2O (g per GJ fuel)	NA	NA	NA	NA		
Particles (g per GJ fuel)	10	8	6	4		5
Financial data						
Specific investment (1000€/kW)	0.17	0.17	0.17	0.17		7
Specific investment (1000€/unit) - hereof equipment (1000€/unit) - hereof installation (1000€/unit)	NA NA NA	NA NA NA	NA NA NA	NA NA NA		
Possible additional specific investment (1000€/unit)	5-25	5-25	7-30	7-30	E	
Fixed O&M (€/kW/year)	6.3	6.3	7	8	F	7
Variable O&M (€/GJ)	NA	NA	NA	NA		

References:

1 Vurdering af brændekedlers partikelemission til luften i Danmark, Miljøprojekt nr. 6 2008, kim Winther, Teknologisk Institut.

2 Emissioner fra træfyrede brændeovne og -kedler, Miljøprojekt nr. 1324 2010, Johnny Iversen, Thomas Capral Henriksen og Simon Dreyer, Carl Bro.

3 Brændeovne og små kedler - partikelemissioner og reduktionstiltag, Miljøprojekt nr. 1164, 2007, Jytte Boll Illerup, DMU et.al.

4 www.teknologisk.dk/911; Listen over godkendte biobrændselsanlæg.

5 Biomas for heating & cooling, Vision & SRA; DRAFT 08072011; Renewable heating & Cooling; European Technology Platform.

6 Agricultural Chamber Styria 1998, E.V.A. 1999.

7 Lot 15: Solid fuel small combustion installations-Base Case definition.

Notes:

A Nominal heat delivery.

B Efficiency development from reference 5.

C Method VDI 2066.

D Prerequisite: house with central heating system and chimney.

E Biomass storage.

F Contemporary value from Ref.

Table 5.11 Biomass boiler, automatic stoking - one-family house, new building

Technology	**Biomass boiler, automatic stoking** **One-family house, new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	6-20	5-18	4-16	4-14	A	4, 5
Expected share of space heating demand covered by unit (%)	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100		
Total efficiency, annual average, net (%)	80	87	91	95	B	5, 6
Technical lifetime (years)	20	20	20	20		7
Environment						
SO_2 (g per GJ fuel)	NA	NA	NA	NA		
NO_X (g per GJ fuel)	90	70	50	40		5
CH_4 (g per GJ fuel)	3	2	1	0		2, 5
N_2O (g per GJ fuel)	NA	NA	NA	NA		
Particles (g per GJ fuel)	10	8	6	4	C	2, 5
Financial data						
Specific investment (1000€/kW)	NA	NA	NA	NA		
Specific investment (1000€/unit)	2.5-11	2.5-11	3-12	3-12	G	
- hereof equipment (1000€/unit)	2-10	2-10	2.5-11	2.5-11		
- hereof installation (1000€/unit)	0.5-1	0.5-1	0.5-1	0.5-1		
Possible additional specific investment (1000€/unit)	1.3	1.3	1.3	1.3	D, F	
Fixed O&M (€/kW/year)	2	2	3	3	E	6
Variable O&M (€/GJ)	NA	NA	NA	NA		

References:

1 Vurdering af brændekedlers partikelemission til luften i Danmark, Miljøprojekt nr. 6 2008, kim Winther, Teknologisk Institut.

2 Emissioner fra træfyrede brændeovne og -kedler, Miljøprojekt nr. 1324 2010, Johnny Iversen, Thomas Capral Henriksen og Simon Dreyer, Carl Bro.

3 Brændeovne og små kedler - partikelemissioner og reduktionstiltag, Miljøprojekt nr. 1164, 2007, Jytte Boll Illerup, DMU et al.

4 www.teknologisk.dk/911; Listen over godkendte biobrændselsanlæg.

5 Biomas for heating & cooling, Vision & SRA; DRAFT 08072011; Renewable heating & Cooling; European Technology Platform.

6 Energibesparelser - det behøver ikke være så svært; Energibranchen.dk, nr. 3 september 2009.

7 Lot 15: Solid fuel small combustion installations-Base Case definition.

Notes:

A Nominal heat delivery.

B Efficiency development from reference 5.

C EN303-5 measurement method.

D Prerequisite: house with central heating system.

E Contemporary value from reference 6.

F Chimney.

G Difference in price due to different finish, design etc.

Table 5.12 Biomass boiler, automatic stoking - apartment complex, new building

Technology	Biomass boiler, automatic stoking Apartment complex, new building					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	100-1000	100-1000	100-1000	100-1000		
Expected share of space heating demand covered by unit (%)	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100		
Total efficiency, annual average, net (%)	80	87	91	95		5
Technical lifetime (years)	20	20	20	20		7
Environment						
SO_2 (g per GJ fuel)	NA	NA	NA	NA		
NO_X (g per GJ fuel)	90	70	50	40		5
CH_4 (g per GJ fuel)	3	2	1	0		2, 5
N_2O (g per GJ fuel)	NA	NA	NA	NA		
Particles (g per GJ fuel)	10	8	6	4		2, 5
Financial data						
Specific investment (1000€/kW)	0.17	0.17	0.17	0.17		7
Specific investment (1000€/unit)	NA	NA	NA	NA		
- hereof equipment (1000€/unit)	NA	NA	NA	NA		
- hereof installation (1000€/unit)	NA	NA	NA	NA		
Possible additional specific investment (1000€/unit)	5-25	5-25	7-30	7-30	E	
Fixed O&M (€/kW/year)	6.3	6.3	7	8	F	7
Variable O&M (€/GJ)	NA	NA	NA	NA		

References:

1 Vurdering af brændekedlers partikelemission til luften i Danmark, Miljøprojekt nr. 6 2008, kim Winther, Teknologisk Institut.

2 Emissioner fra træfyrede brændeovne og -kedler, Miljøprojekt nr. 1324 2010, Johnny Iversen, Thomas Capral Henriksen og Simon Dreyer, Carl Bro.

3 Brændeovne og små kedler - partikelemissioner og reduktionstiltag, Miljøprojekt nr. 1164, 2007, Jytte Boll Illerup, DMU et al.

4 www.teknologisk.dk/911; Listen over godkendte biobrændselsanlæg.

5 Biomas for heating & cooling, Vision & SRA; DRAFT 08072011; Renewable heating & Cooling; European Technology Platform.

6 Lot 15: Solid fuel small combustion installations-Base Case definition.

Notes:

A Nominal heat delivery.

B Efficiency development from reference 5.

C EN303-5 measurement method.

D Prerequisite: house with central heating system and chimney.

E Biomass storage.

F Contemporary value from Ref.

5.5 Biomass boiler, manual stoking

Brief technology description

Modern manually fired boilers for stoking with solid wood have downwards draught or down-draught. The principle is that the fuel is heated, dried and degasified in the combustion chamber, after which the gases are led downwards (or down in case of down-draught) through a crevice in the bottom of the combustion chamber into the chamber where the combustion takes place during supply of secondary air. This type of boiler is often provided with an air fan for supply of combustion air or a flue gas fan.

Figure 5.10 Double duty wood log boiler (manual stoking) prepared for mounting of pellet burner (automatic stoking)

Older types of boilers are updraught boilers and do not comply with the current environmental require-ments.

Manual boilers should be installed with an accumulation tank of appropriate size.

Heating can be carried out solely with a manual biomass boiler with a well-insulated accumulation tank.

Manually fired biomass boilers are common in Denmark and in the rest of Europe. Denmark is esti-mated to have 48,000 manually fired boilers.

Input

The input is log wood of different sizes, depending on the boiler.

Output

Heat for central heating.

Typical capacities

Log wood boilers are available from a few kW up to 100 kW.

Regulation ability

The boilers are installed with a storage tank. A few log wood boilers have regulation abilities.

Advantages/disadvantages

Boilers for manual stoking must always be installed with a storage tank of suitable size. This ensures both the greatest comfort for the user, the best stoking economy and the best environmental conditions.

Environment

Examinations show that newer boilers with accumulation tank cause considerably less pollution compared to old updraught boilers.

Research and development

There is a need for R&D in the following areas:

- High-efficient and low-emission technologies
- Automation.
- Boilers with less than 5 kW nominal heat output.

Examples of best available technology

Danish manufacturers of best available technology can be found on web lists at http://www.teknologisk.dk/911. The lists make use of energy and emission labelling of the boilers.

Additional remarks

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References

1 Brændeovne og små kedler – partikelemissioner og reduktionstiltag, Miljøprojekt nr. 1164, 2007, Jytte Boll Illerup, DMU et al.

2 Emissioner fra træfyrede brændeovne og -kedler, Miljøprojekt nr. 1324 2010, Johnny Iversen, Thomas Capral Henriksen og Simon Dreyer, Carl Bro.

3 Vurdering af brændekedlers partikelemission til luften i Danmark, Miljøprojekt nr. 6 2008, Kim Winther, Danish Technological Institute.

4 Videncenter for Halm og Flis-fyring. Træ til energiformål, 1999.

5 Videncenter for Halm og Flis-fyring. Straw for Energy production, 1998.

Data sheets:

Table 5.13 Biomass boiler, manual stoking - one-family house, existing building

Technology	Biomass boiler, manual stoking One-family house, existing building					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	6-20	5-20	4-20	4-20	A	4, 5
Expected share of space heating demand covered by unit (%)	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100		
Total efficiency, annual average, net (%)	75	82	86	90		5
Technical lifetime (years)	20	20	20	20		6
Environment						
SO_2 (g per GJ fuel)	NA	NA	NA	NA		
NO_X (g per GJ fuel)	80	70	60	50		5
CH_4 (g per GJ fuel)	3	2	1	0		2, 5
N_2O (g per GJ fuel)	NA	NA	NA	NA		
Particles (g per GJ fuel)	15	12	9	6	C	5
Financial data						
Specific investment (1000€/kW)	NA	NA	NA	NA		
Specific investment (1000€/unit) - hereof equipment (1000€/unit) - hereof installation (1000€/unit)	4.5 3 1.5	4.5 3 1.5	4.5 3 1.5	4.5 3 1.5		
Possible additional specific investment (1000€/unit)	3.1	3.1	3.1	3.1	B, E	
Fixed O&M (€/kW/year)	2	2	2	2	D	6
Variable O&M (€/GJ)	NA	NA	NA	NA		

References:

1 Vurdering af brændekedlers partikelemission til luften i Danmark, Miljøprojekt nr. 6 2008, kim Winther, Teknologisk Institut.

2 Emissioner fra træfyrede brændeovne og -kedler, Miljøprojekt nr. 1324 2010, Johnny Iversen, Thomas Capral Henriksen og Simon Dreyer, Carl Bro.

3 Brændeovne og små kedler - partikelemissioner og reduktionstiltag, Miljøprojekt nr. 1164, 2007, Jytte Boll Illerup, DMU.

4 www.teknologisk.dk/911; Listen over godkendte biobrændselsanlæg.

5 Biomas for heating & cooling, Vision & SRA; DRAFT 08072011; Renewable heating & Cooling; European Technology Platform.

6 Lot 15: Solid fuel small combustion installations-Base Case definition.

Notes:

A Nominal heat delivery.

B Storage tank.

C EN303-5 measurement method.

D Prerequisite: house with central heating system.

E Chimney.

Table 5.14 Biomass boiler, manual stoking - one-family house, new building

Technology	**Biomass boiler, manual stoking One-family house, new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	6-20	5-18	4-16	4-14	A	4, 5
Expected share of space heating demand covered by unit (%)	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100		
Total efficiency, annual average, net (%)	75	82	86	90		5
Technical lifetime (years)	20	20	20	20		6
Environment						
SO_2 (g per GJ fuel)	NA	NA	NA	NA		
NO_X (g per GJ fuel)	80	70	60	50		5
CH_4 (g per GJ fuel)	3	2	1	0		2, 5
N_2O (g per GJ fuel)	NA	NA	NA	NA		
Particles (g per GJ fuel)	15	12	9	6	C	5
Financial data						
Specific investment (1000€/kW)	NA	NA	NA	NA		
Specific investment (1000€/unit) - hereof equipment (1000€/unit) - hereof installation (1000€/unit)	4.5 3 1.5	4.5 3 1.5	4.5 3 1.5	4.5 3 1.5		
Possible additional specific investment (1000€/unit)	2.8	2.8	2.8	2.8	B, E	
Fixed O&M (€/kW/year)	2	2	2	2	D	
Variable O&M (€/GJ)	NA	NA	NA	NA		

References:

1 Vurdering af brændekedlers partikelemission til luften i Danmark, Miljøprojekt nr. 6 2008, kim Winther, Teknologisk Institut.

2 Emissioner fra træfyrede brændeovne og -kedler, Miljøprojekt nr. 1324 2010, Johnny Iversen, Thomas Capral Henriksen og Simon Dreyer, Carl Bro.

3 Brændeovne og små kedler - partikelemissioner og reduktionstiltag, Miljøprojekt nr. 1164, 2007, Jytte Boll Illerup, DMU.

4 www.teknologisk.dk/911; Listen over godkendte biobrændselsanlæg.

5 Biomass for heating & cooling, Vision & SRA; DRAFT 08072011; Renewable heating & Cooling; European Technology Platform.

6 Lot 15: Solid fuel small combustion installations-Base Case definition.

Notes:

A Nominal heat delivery.

B Storage tank.

C EN303-5 measurement method.

D Prerequisite: house with central heating system.

E Chimney.

5.6 Wood stove

Brief technology description

A wood stove is an enclosed room heater used to heat the space in which the stove is situated.

Usually, the wood stove is fired with a batch of 2-3 pieces of new firewood at a time. The firing takes place when there are no more visible yellow flames from the previous basic firebed, and when a suitable layer of embers has been created.

Modern wood stoves have up to three air inlet systems in order to achieve the best possible combustion and to ensure that the glass pane in the front door does not get sooty: primary air up through the bottom of the combustion chamber, secondary air as air wash to keep the combustion alive and to maintain the glass clean, and tertiary air in the backside of the combustion chamber for after-burning of the gases.

Figure 5.11 Wood stove

Some stoves need to have the air inlet dampers manually adjusted in connection with each new fired batch (maximum 3-5 minutes after each charge); others are more or less self-regulating.

The chimney serves as the stove's motor, and is essential to the stove's functioning. The chimney draught sucks air through the air dampers to the combustion chamber.

Heat from wood stove is usually a supplement to other kinds of heat supply.

Wood stoves are widely used in Denmark, and the number of installed stoves is 750,000.

Input

Wood logs of different sorts like beech, birch and pine wood. The humidity should be of 12 to 20 %, and the size of the wood logs depends on the stove but usually about 250 to 330 mm with a weight of 700 to 1000 g.

Output
Space heating by convection and radiation.

Typical capacities
Typical capacities are 4 to 8 kW nominal output.

Regulation ability
By regulating the air dampers, the stove's capacity can be minimized or maximized within a few kW, however, this might e.g. result in an increased emission.

Advantages/disadvantages
Wood stoves are usually independent of electricity supply.

Some stoves are assembled with a water tank, and thus they can be connected to the central heating system.

Environment
In practice, pollution from wood stoking in stoves is a correlation between a series of factors such as stoking conduct, the individual stove and chimney in relation to the surroundings.

Newer swan-labelled stoves live up to the more rigorous requirements for particles according to the current legislation.

Research and development
There is a need for continuous development of stoves with the purpose of reducing the particle emissions and decreasing the supply to low-energy houses.

Examples of best available technology
Some Danish manufacturers produce swan-labelled products, which can be found on the web lists at http://www.ecolabel.dk. The swan label is a voluntary agreement, and labelled stoves must comply with extra stringent emission requirements.

Additional remarks
-

References
1 Brændeovne og små kedler – partikelemissioner og reduktionstiltag, Miljøprojekt nr. 1164, 2007, Jytte Boll Illerup, DMU et .al.

2 Emissioner fra træfyrede brændeovne og -kedler, Miljøprojekt nr. 1324 2010, Johnny Iversen, Thomas Capral Henriksen og Simon Dreyer, Carl Bro.

Data sheets:

Table 5.15 Wood stove without water tank - one-family house, existing and new building

Technology	Wood stove without water tank One-family house, existing and new building					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	3-12	2-12	1.5-9	1.5-6		
Expected share of space heating demand covered by unit (%)	20-60	20-60	20-60	20-60	C	
Expected share of hot tap water demand covered by unit (%)	0	0	0	0	E	
Total efficiency, annual average, net (%)	65	70	75	75		
Technical lifetime (years)	24	24	24	24		2
Environment						
SO_2 (g per GJ fuel)	NA	NA	NA	NA		
NO_X (g per GJ fuel)	90	90	90	90		
CH_4 (g per GJ fuel)	320	125	100	100		1
N_2O (g per GJ fuel)	NA	NA	NA	NA		
Particles (g per GJ fuel)	50	40	30	25	A	1
Financial data						
Specific investment (1000€/kW)	NA	NA	NA	NA		
Specific investment (1000€/unit)	2.6	2.6	3.5	3.5	D	2
- hereof equipment (1000€/unit)	2	2	2.5	2.5		2
- hereof installation (%1000€/unit)	0.6	0.6	1	1		2
Possible additional specific investment (1000€/unit)	1.6	1.6	1.6	1.6	B	
Fixed O&M (€/kW/year)	0.1	0.1	0.1	0.2		
Variable O&M (€/GJ)	NA	NA	NA	NA		

References:

1 Emissioner fra træfyrede brændeovne og -kedler, Miljøprojekt nr. 1324 2010, Johnny Iversen, Thomas Capral Henriksen og Simon Dreyer, Carl Bro.

2 Lot 15: Solid fuel small combustion installations-Base Case definition.

Notes:

A DIN Plus measurement method.

B Chimney.

C The share of space heating covered by a wood stove depends on the possibility to regularly charge the stove with wood logs and of the location of the stove in the house. With regularly charging and a central location of the stove, the coverage can be up to 80 % of the heating demand in the house. Approximately 10 % larger is possible for stoves with a water tank. Taking into consideration that normally the average residents will have difficulties with regular fuel charging, the expected share of space heating covered by the wood stove without a water tank will be in the range of 20 % to 60 %.

A large coverage requires that doors between the room where wood stove is placed and the adjoining rooms are open or an air circulation system is installed.

D More automatic stoves are expected in the future.

E Only for stoves with water tank, otherwise 0%.

Table 5.16 Wood stove with water tank - one-family house, existing and new building

Technology	Wood stove with water tank One-family house, existing and new building					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	3-8	2-5	1.5-4	1.5-3		
Expected share of space heating demand covered by unit (%)	20-70	20-70	20-70	20-70	C	
Expected share of hot tap water demand covered by unit (%)	20	20	20	20	E	
Total efficiency, annual average, net (%)	65	70	75	75		
Technical lifetime (years)	24	24	24	24		2
Environment						
SO_2 (g per GJ fuel)	NA	NA	NA	NA		
NO_X (g per GJ fuel)	90	90	90	90		
CH_4 (g per GJ fuel)	320	125	100	100		1
N_2O (g per GJ fuel)	NA	NA	NA	NA		
Particles (g per GJ fuel)						1
Financial data						
Specific investment (1000€/kW)	NA	NA	NA	NA	A	1
Specific investment (1000€/unit)	2.6	2.6	3.5	3.5	D	2
- hereof equipment (%)	2	2	2.5	2.5		2
- hereof installation (%)	NA	NA	NA	NA		2
Possible additional specific investment (1000€/unit)	1.3	1.3	1.3	1.3	B	
Fixed O&M (€/kW/year)	0.1	0.1	0.1	0.2		
Variable O&M (€/GJ)	NA	NA	NA	NA		

References:

1 Emissioner fra træfyrede brændeovne og -kedler, Miljøprojekt nr. 1324 2010, Johnny Iversen, Thomas Capral Henriksen og Simon Dreyer, Carl Bro.

2 Lot 15: Solid fuel small combustion installations-Base Case definition.

Notes:

A DIN Plus measurement method.

B Chimney.

C The share of space heating covered by a wood stove depends on the possibility to regularly charge the stove with wood logs and of the location of the stove in the house. With regularly charging and a central location of the stove, the coverage can be up to 80 % of the heating demand in the house. Approximately 10 % larger is possible for stoves with a water tank. Taking into consideration that normally the average residents will have difficulties with regular fuel charging, the expected share of space heating covered by the wood stove with a water tank will be in the range of 20 % to 70 %.

A large coverage requires that doors between the room where wood stove is placed and the adjoining rooms are open or an air circulation system is installed.

D More automatic stoves are expected in the future.

E Only for stoves with water tank, otherwise 0%.

5.7 Electrical heat pump, air-to-air

Brief technology description

General for heat pumps

Heat pumps employ the same technology as refrigerators, moving heat from a low-temperature location to a warmer location. Heat pumps usually draw heat from the ambience (input heat) and convert the heat to a higher temperature (output heat) through a closed process; electrically driven compressor heat pumps.

The energy efficiency of heat pumps is normally referred to by the COP factor "Coefficient of Performance", describing the delivered heat divided by the used electricity. A COP of three means that the heat pump delivers three times as much heat as the electricity consumption, and two thirds of the delivered heat are collected through the outdoor heat exchanger.

Specifically for air-to-air heat pumps

Air-to-air heat pumps draw heat from ambient air and supply heat locally through air heat exchangers. Most air-to-air heat pumps have one outdoor unit and one indoor unit and are often referred to as "split-units". This configuration means that the heat pump can only supply heat from where the indoor unit is placed.

Air-to-air heat pumps with more than one indoor heat exchanger (multi-split units) are also available, but they are only representing a very small percentage of the installed air-to-air heat pumps today.

Many air-to-air heat pumps are reversible so that they can be used for cooling in warm periods (air-condition).

A single air-to-air heat pump normally covers between 60 % and 80 % of the space heating demand. A large coverage requires that the doors between the room where the air-to-air heat pump is placed and the adjoining rooms are open or an air circulation system is installed. The remaining space heating demand must be covered by other sources, which would normally be electrical heaters or additional air-to-air heat pumps.

The number of air-to-air heat pumps installed in Denmark is 60,000 to 80,000 (2011). A large share of this type of heat pumps is installed in summer residences. The main reasons for the large number of installed air-to-air heat pumps are low investment costs and easy installation. In buildings with electric heating, air-to-air heat pumps can be a very good investment.

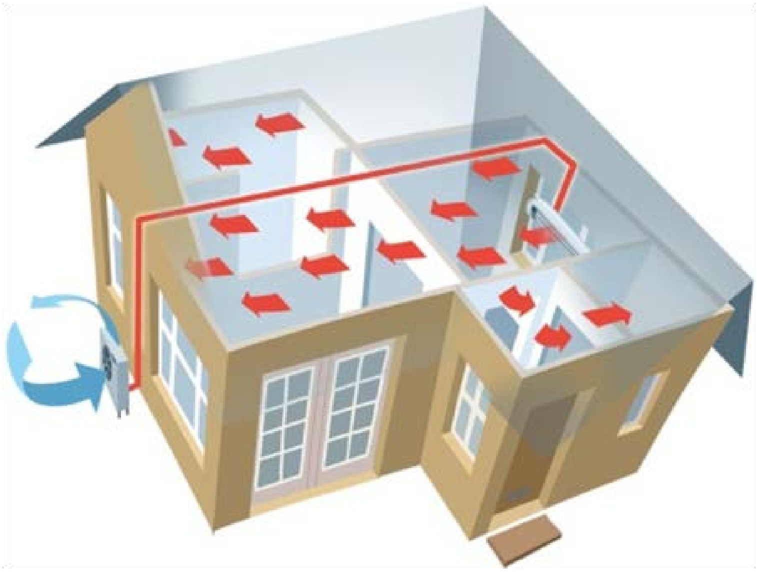

Figure 5.12 Electrical heat pump, air-to-air

Input

The input is the heat from ambient air collected by the outdoor heat exchanger and electrical energy to drive the process. The heat source is the ambient air.

Output

The output is heat for space heating delivered by heating air passing through the indoor unit.

Typical capacities

A range of capacities is available, typically from 3 kW up to 8 kW heat.

Regulation ability

Different types of regulation exist for this type of heat pumps. There is on/off regulation and capacity regulation, which is continuously variable down to about 20 % of the maximum capacity.

Capacity regulation works through a variable speed compressor where the amount of refrigerant flow through the refrigerant cycle is adapted to the demand. In on/off regulation, the compressor will work full load and stop at intervals adapted to the heat demand.

The main part of air-to-air heat pumps in the market today has capacity regulation.

Advantages / disadvantages

General for heat pumps

The general advantage of heat pump technologies is that the technology normally uses a free, low-temperature heat source.

Heat pump efficiency in general depends on the temperatures on the cold (outdoor) and the warm (in-door) side of the heat pump. Lower temperatures on the cold side as well as higher temperatures on the warm side decrease the efficiency. The heat demand is normally higher when outdoor temperatures are low. Therefore, it is important to compare the average yearly efficiency instead of the efficiency at a single working point.

Specifically for air-to-air heat pumps

Air-to-air heat pumps are especially good in rooms and buildings with electrical heating. Air-to-air heat pumps collect heat from outside air and supply it to the building by use of electricity. The ratio between delivered heat and consumed electricity on a yearly basis will be around three. This means that the yearly electricity consumption in rooms with electrical heating can be reduced to one third by installing an air-to-air heat pump.

Since the air-to-air heat pumps normally only cover 60-80% of the heating demand in the house, more air-to-air heat pumps or a multi-split system are needed if the overall electricity demand is to be reduced to one third. But one air-to-air heat pump in an electrical heated house will reduce the electricity consumption significantly under any circumstances.

A special advantage of air-to-air heat pumps is that they do not need a heat distribution system for space heating. In houses with electrical heating, there is normally no heat distribution system, but the air-to-air heat pump can reduce the energy consumption significantly without installation of radiators or floor heating.

Similarly, the outdoor installation is simple and will only need very limited outdoor space and do not need any digging in the ground.

The disadvantage of this type of installation is that the heat from the heat pump can only be delivered in the room where the indoor unit is installed (often the living room). As mentioned before, the air-to-air heat pump can cover 60-80% of the overall heat demand. Other rooms will need supplementary heating, e.g. electrical heating or another air-to-air heat pump.

In cold humid periods, ice will build up on the outdoor heat exchanger and thereby decrease the evaporation temperature and the efficiency. Therefore, de-frosting of the outdoor heat exchanger is needed during cold and humid periods, causing an increased energy consumption. There are several heat pumps suited for Nordic climates on the market today.

Noise from air-source heat pumps may also be a problem. The noise level has to be less than 35 dB(A) on the boundary to other properties. Air-to-air heat pumps of higher quality will normally have lower noise levels.

An air-to-air heat pump is normally a smaller investment than other types of heat pumps. It will cost approximately 25% of the price of a brine-to-water heat pump.

Environment

General for heat pumps

The heat pumps use F-gases (HFCs) as refrigerants. F-gases are fluorinated gases (HFCs, PFCs and SF6), which are potent greenhouse gases. They are covered by the Kyoto Protocol.

The HFCs (HydroFluoroCarbons) are the most important, and they are frequently used in the refrigeration industry as the working fluid in the refrigeration cycle.

There are many different refrigerants based on HFCs. The most important are HFC-134a (R134a) and HFC mixtures: R404A, R410A and R407A. The most common refrigerants based on HFCs have Global Warming Potentials (GWP) of about 1,500 to 4,000 compared to CO_2 which has a GWP of 1.

There are, however, some heat pumps working with natural refrigerants (including R290 – propane), but this is a minority. In the future, it will be possible to replace F-gases by natural refrigerants or other less harmful refrigerants.

Natural refrigerants are substances that can be found in nature's own cycle, e.g. ammonia, hydrocarbons, CO_2, water and air. None of the refrigerants in the group of natural refrigerants are perfect, and they all have technical limitations. Therefore, natural refrigerants have to be chosen with care, and one fluid cannot cover all applications.

Different types of heat pumps use the same types of refrigerants. The above description is therefore representative for all types of heat pumps.

The environmental impact due to the use of electricity will depend on the way the electricity is produced.

Research and development

There are a number of areas where the performance of heat pumps can be improved by performing research and development activities.

Examples of possible improvements are:

- Better control and operation strategies.
- Adoption of heat pumps as a smart grid component.
- More efficient components.
- Better integration with other systems such as ventilation, water heating, air conditioning, storages and solar thermal systems.
- Increased use of natural refrigerants instead of HFC’s in heat pumps.

Examples of best available technology

Air-to-air heat pumps of better quality normally have variable-speed compressors.

Additional remarks

New European regulation concerning energy efficiency of air-to-air heat pumps comes into force by 1 January 2013. It is likely that this regulation will affect the general energy efficiency of heat pumps in the market, ruling out the inefficient heat pumps and promoting the best heat pumps through energy labels. This can also increase the incentive to develop new technology.

References

- Potentiale for varmepumper til opvarmning af boliger med oliefyr. Ener-gistyrelsen. 2011.
- Den lille blå om varmepumper. Dansk Energi. 2011.

- Technology Roadmap, energy Efficient Buildings: Heating and cooling Equipment, OECD/IEA 2011.

- Energiløsninger til renovering af eksisterende bygninger. Videncenter for energibesparelser i bygninger. 2010.

- Stock of heat pumps for heating in all-year residences in Denmark. Project made for the Danish Energy Agency. COWI, Teknologisk Institut, Statens Byggeforskningsinstitut. 2011.

Data sheets:

Table 5.17 Heat pump, air-to-air - one-family house, existing and new building

Technology	**Heat pump, air-to-air** **One-family house, existing and new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	3-5	3-5	3-5	3-5	D	
Expected share of space heating demand covered by unit (%)	60	60	60	60	C	
Expected share of hot tap water demand covered by unit (%)	0	0	0	0		
Total efficiency, annual average, net (%)	300	320	370	400	A	1, 2, 3, 4
Technical lifetime (years)	20	20	20	20		
Environment						
SO_2 (g per GJ fuel)	For electric heat pumps, the emissions depend on how the electricity is produced. Emission factors for electricity in Denmark can for instance be found in socio-economic assumptions for energy projects published by the Danish Energy Authority (www.ens.dk → Fremskrivninger → Samfundsøkonomiske beregningsforudsætnigner).					
NO_X (g per GJ fuel)						
CH_4 (g per GJ fuel)						
N_2O (g per GJ fuel)						
Particles (g per GJ fuel)						
Financial data						
Specific investment (1000€/kW)						
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)	2,7 80 20	2,6 80 20	2,4 80 20	2,3 80 20	A	1, 2
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/unit/year)	42	42	42	42	B	2
Variable O&M (€/GJ)						

References:

1 Potentiale for varmepumper til opvarmning af boliger med oliefyr. Energistyrelsen. 2011.

2 Den lille blå om varmepumper. Dansk Energi. 2010.

3 Technology Roadmap, Energy Efficient Buildings: Heating and Cooling Equipment, OECD/IEA 2011.

4 Energiløsninger til renovering af eksisterende bygninger. Videncenter for energibesparelser i bygninger. 2010.

Notes:

A Improvement of delivered energy costs is assumed to be 25 % in 2030 and 35 % in 2050. The improvement is equally split between the efficiency and the cost. For systems used in one-family houses, the price variation depending on the size is limited and an average price is used.

B The O&M cost corresponds to an expense of 135 EUR each third year.

C A large coverage requires that the doors between the room where the air-to-air heat pump is placed and the adjoining rooms are open or an air circulation system is installed.

D The heat production capacity is assumed to be respectively 5 kW in existing one family houses and 3 kW in new one family houses.

5.8 Electrical heat pump, air-to-water

Brief technology description

General for heat pumps

Heat pumps employ the same technology as refrigerators, moving heat from a low-temperature location to a warmer location. Heat pumps usually draw heat from the ambience (input heat) and convert the heat to a higher temperature (output heat) through a closed process.

The energy efficiency of heat pumps is normally referred to by the COP factor "Coefficient Of Performance", describing the delivered heat divided by the used electricity. A COP of three means that the heat pump delivers three times as much heat as the electricity consumption, and two thirds of the delivered heat is collected through the outdoor heat exchanger.

Specifically for air-to-water heat pumps

Air-to-water heat pumps draw heat from ambient air and use a water-based heating system to supply the heat to the building. The heat pump can also produce the hot water for domestic use.

Air-to-water heat pumps are normally designed to cover between 95 and 98 % of the heating demand. The remaining heat demand is covered by electrical heating. It is possible to supplement the heat pump by a solar heating system.

Air-to-water heat pump is normally chosen where there is not enough available outdoor area for ground heat collectors, but where there is a water-based heat distribution system in the building. Air-to-water heat pumps cannot deliver water temperatures higher than 55˚C, which means that the radiators have to be able to cover the heat demand with temperatures below this.

In order to obtain these sufficient low supply temperatures, it is in many cases necessary to install a larger heat capacity of the heat emission system, e.g. by installing larger radiators and/or by improving the insulation level of the building envelope. In section 4.2, some examples are given for the cost of installing larger radiators. In many cases, however, the improvement of the building envelope may be an economic profitable option anyway, and for new buildings it will be a necessity due to requirements in the building regulations.

Some air-to-water heat pumps are designed specifically for supplying only hot tap water. This type of air-to-water heat pumps is used in a number of summer residences, especially if there is a large consumption of hot tap water. The data sheets presented by the end of this chapter show data for heat pumps covering both space heating and hot tap water.

The number of installations in Denmark of air-to-water heat pumps today is estimated to be approximately 10,000 - 15,000 (2011).

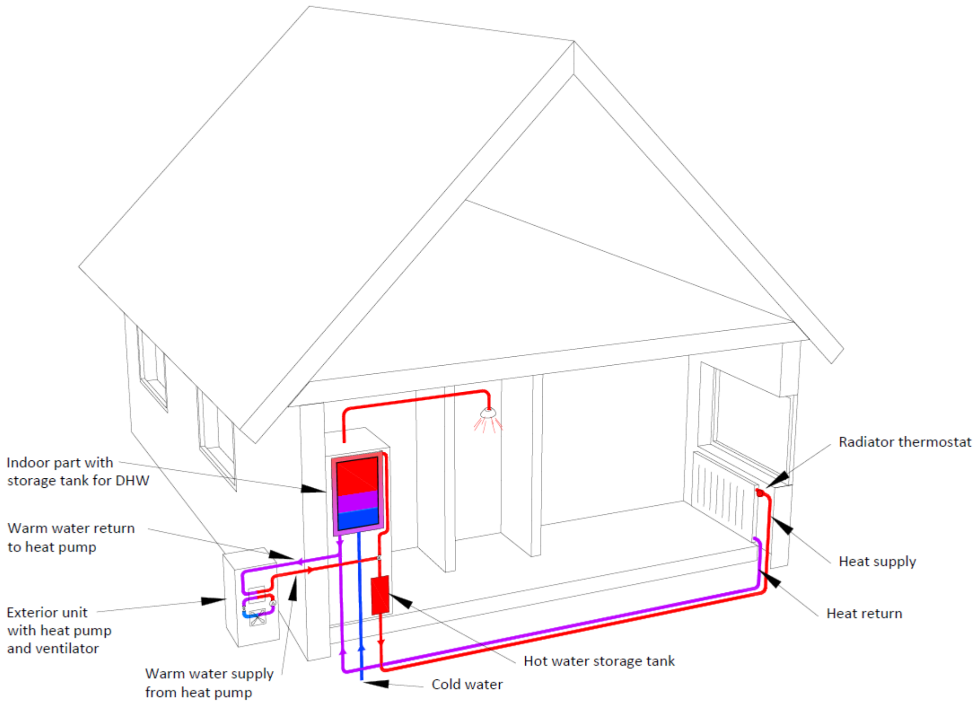

Figure 5.13 Electrical heat pump, air-to-water

Input

The input is heat from ambient air collected by the outdoor air heat exchanger and electrical energy to drive the process. The heat source is the ambient air.

Output

The output is heat for primarily space heating and/or domestic hot water.

Typical capacities

The size of air-to-water heat pumps ranges from approximately 4 kW up to several hundred kW heating capacity, covering the needs for both space heating and domestic hot water in both low-energy buildings and large buildings.

Regulation ability

As for other heat pumps, there are two main types of regulation for air-to-water heat pumps. There is on/off regulation and capacity regulation which is continuously variable down to about 20 % of the maximum capacity. Capacity regulation works through a variable-speed compressor where the amount of refrigerant flow through the refrigerant cycle is adapted to the demand. In on/off regulation, the compressor will work full load and stop at intervals adapted to the heat demand.

About 20 % of the air-to-water heat pumps in the market today have capacity regulation.

The best efficiency is obtained with a capacity regulation ensuring that the supply temperature to the heat distribution system does not increase unnecessarily when the heat pump is running, because the heat pump efficiency will increase with lower temperatures.

If the heat pump is on/off regulated and has a small storage tank, the heat pump can start and stop often, which will lower the efficiency. A sufficiently large storage tank is therefore important with on/off regulation.

Advantages/disadvantages

General for heat pumps

The general advantage of heat pump technologies is that they normally use a free low-temperature heat source.

Heat pump efficiency in general depends on the temperatures on the cold (outdoor) and the warm side (indoor) of the heat pump. Lower temperatures on the cold side as well as higher temperatures on the warm side decrease the efficiency. The heat demand is normally higher when outdoor temperatures are low. Therefore, it is important to compare the average yearly efficiency instead of the efficiency at a single working point.

For heat pumps supporting a water based heat distribution system, the supply temperature plays an important role for the efficiency. Lower supply temperature gives higher efficiencies, and therefore heat pumps for floor-heating (35˚C) have better efficiency compared to heat pumps for radiators (55 ˚C).

Specifically for air-to-water heat pumps

An air-to-water heat pump can deliver heat through the heating system in several rooms, and it is possible to regulate the heat transfer individually in each room, which is an advantage compared to air-to-air heat pumps.

Compared to brine-to-water heat pumps, the air-to-water heat pump is less efficient because the air temperature to the outdoor heat exchanger will be lower than the ground temperature when there is a large demand for heating. Moreover, ice will build up on the outdoor heat exchanger and thereby decrease the evaporation temperature and the efficiency. Therefore, defrosting of the outdoor heat exchanger is needed during cold and humid periods, causing increased energy consumption.

The main reason for choosing an air-to-water heat pump instead of a brine-to-water heat pump is an easier and cheaper outdoor installation. The outdoor unit will only need a very limited outdoor space, and no digging is needed.

The overall costs are equally reduced. An air-to-water heat pump will be 20-30% cheaper in investments than a brine-to-water heat pump.

Noise may be a problem since the noise level has to be below 35 dB(A) on the boundary to other properties. In densely built-up areas, it is sometimes not possible to install air-to-water heat pumps due to this problem.

Environment

General for heat pumps

The heat pumps use F-gases (HFCs) as refrigerants. F-gases are fluorinated gases (HFCs, PFCs and SF6), which are potent greenhouse gases. They are covered by the Kyoto Protocol.

The HFCs (HydroFluoroCarbons) are the most important, and they are frequently used in the refrigeration industry as the working fluid in the refrigeration cycle.

There are many different refrigerants based on HFCs. The most important are HFC-134a (R134a) and HFC mixtures: R404A, R410A and R407A. The most common refrigerants that are based on HFCs have Global Warming Potentials (GWP) from about 1500 to 4000 compared to CO_2, which has a GWP of 1.

There are, however, some heat pumps working with natural refrigerants (including R290 – propane), but this is a minority. In the future, it will be possible to replace F-gases by natural refrigerants or other less harmful refrigerants.

Natural refrigerants are substances that can be found in nature's own cycle, e.g. ammonia, hydrocarbons, CO_2, water and air. None of the refrigerants in the group of natural refrigerants are perfect, and they all have technical limitations. Therefore, natural refrigerants have to be chosen with care, and one fluid cannot cover all applications.

Different types of heat pumps use the same types of refrigerants. The above description is therefore representative for all types of heat pumps.

The environmental impact due to the use of electricity will depend on the way the electricity is produced.

Research and development

There are a number of areas where the performance of heat pumps can be improved by performing research and development activities. This counts for most types of heat pumps.

Examples of possible improvements are:

- Better control and operation strategies.
- Adoption of heat pumps as a smart grid component.
- More efficient components.
- Better integration with other systems such as ventilation, water heating, air conditioning, storages and solar thermal systems.
- Increased use of natural refrigerants instead of HFC's in heat pumps.

Examples of best available technology

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Additional remarks

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References

- Potentiale for varmepumper til opvarmning af boliger med oliefyr. Energistyrelsen. 2011.

- Den lille blå om varmepumper. Dansk Energi. 2011.
- Technology Roadmap, Energy Efficient Buildings: Heating and cooling Equipment, OECD/IEA. 2011.
- Energiløsninger til renovering af eksisterende bygninger. Videncenter for energibesparelser i bygninger. 2010.
- Stock of heat pumps for heating in all-year residences in Denmark. Project made for the Danish Energy Agency. COWI, Teknologisk Institut, Statens Byggeforskningsinstitut. 2011.

Data sheets:

Table 5.18 Heat pump, air-to-water - one-family house, existing building

Technology	**Heat pump, air-to-water One-family house, existing building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	10	10	10	10		
Expected share of space heating demand covered by the heat pump unit (%)	100	100	100	100	C	
Expected share of hot tap water demand covered by the heat pump unit (%)	100	100	100	100	C	
Total efficiency, annual average, net (%)	300	330	370	400	A,B	1, 2, 3, 4, 6, 7
Technical lifetime (years)	20	20	20	20		
Environment						
SO_2 (g per GJ fuel)	For electric heat pumps, the emissions depend on how the electricity is produced. Emission factors for electricity in Denmark can for instance be found in socio-economic assumptions for energy projects published by the Danish Energy Authority (www.ens.dk → Fremskrivninger → Samfundsøkonomiske beregningsforudsætnigner).					
NO_X (g per GJ fuel)						
CH_4 (g per GJ fuel)						
N_2O (g per GJ fuel)						
Particles (g per GJ fuel)						
Financial data						
Specific investment (1000€/kW)						
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)	13 85 15	12 85 15	12 85 15	11 85 15	A, B, E	1, 2, 5
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/unit/year)	135	135	135	135	D	2
Variable O&M (€/GJ)						

References:

1 Potentiale for varmepumper til opvarmning af boliger med oliefyr. Energistyrelsen. 2011.

2 Den lille blå om varmepumper. Dansk Energi. 2011.

3 Technology Roadmap, Energy Efficient Buildings: Heating and Cooling Equipment, OECD/IEA 2011.

4 Energiløsninger til renovering af eksisterende bygninger. Videncenter for energibesparelser i bygninger. 2010.

5 Prisanalyse fra "Skrot-dit-oliefyr". Confidential data for 2010.

6 Personal correspondence with Claus Schøn Poulsen, Heat of Center for Refrigeration and Heat Pump Technology. 2011.

7 Energimærkning og Minimumskrav for varmepumper i forbindelse med Ecodesign direktivet. Studie udført for Energistyrelsen, december 2012.

Notes:

A Size of heating emitters corresponds to a new system.

B Improvement of delivered energy costs is assumed to be 25 % in 2030 and 35 % in 2050. The improvement is equally split between the efficiency and the cost.

C The heat pump unit described consists of a heat pump including an electrical backup. The total unit covers 100 % of the heat demand as described and with the efficiency as described. It is assumed that the heat pump will deliver 95 % of the heat demand and the electrical backup will deliver 5 % of the heat demand.

D The O&M cost corresponds to an expense of 135 EUR each yuear for one family houses and three times more for apartment buildings.

E An air-to-water heat pump will work in combination with a hot water storage tank. The price of the tank is not included in this price. An air-to-water heat pump will often replace an oil-fired boiler or a natural gas boiler where there already is a storage tank installed.

Table 5.19 Heat pump, air-to-water - apartment complex, existing building

Technology	**Heat pump, air-to-water** **Apartment complex, existing building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	50-750	50-750	50-750	50-750		
Expected share of space heating demand covered by the heat pump unit (%)	100	100	100	100	C	
Expected share of hot tap water demand covered by the heat pump unit (%)	100	100	100	100	C	
Total efficiency, annual average, net (%)	300	330	370	400	A,B	1, 2, 3, 4, 6, 7
Technical lifetime (years)	20	20	20	20		
Environment						
SO_2 (g per GJ fuel)	For electric heat pumps, the emissions depend on how the electricity is produced. Emission factors for electricity in Denmark can for instance be found in socio-economic assumptions for energy projects published by the Danish Energy Authority (www.ens.dk → Fremskrivninger → Samfundsøkonomiske beregningsforudsætnigner).					
NO_X (g per GJ fuel)						
CH_4 (g per GJ fuel)						
N_2O (g per GJ fuel)						
Particles (g per GJ fuel)						
Financial data						
Specific investment (1000€/kW)	1	1	0.9	0,9	A, B	1, 2, 5
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)						
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/unit/year)	400	400	400	400	D	2
Variable O&M (€/GJ)						

References:

Same as under the first table, i.e. "One-family houses, existing building".

Notes:

Same as under the first table, i.e. "One-family houses, existing building".

Table 5.20 Heat pump, air-to-water - one-family house, new building

Technology	**Heat pump, air-to-water One-family house, new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	5	5	5	5		
Expected share of space heating demand covered by unit (%)	100	100	100	100	C	
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	C	
Total efficiency, annual average, net (%)	300	330	370	400	A,B	1, 2, 3, 4, 6, 7
Technical lifetime (years)	20	20	20	20		
Environment						
SO_2 (g per GJ fuel)	For electric heat pumps, the emissions depend on how the electricity is produced. Emission factors for electricity in Denmark can for instance be found in socio-economic assumptions for energy projects published by the Danish Energy Authority (www.ens.dk → Fremskrivninger → Samfundsøkonomiske beregningsforudsætnigner).					
NO_X (g per GJ fuel)						
CH_4 (g per GJ fuel)						
N_2O (g per GJ fuel)						
Particles (g per GJ fuel)						
Financial data						
Specific investment (1000€/kW)						
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)	10,5 80 20	10,1 80 20	9,3 80 20	8,9 80 20	A, B	1, 2, 5
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/unit/year)	133	133	133	133	D	2
Variable O&M (€/GJ)						

References:

Same as under the first table, i.e. "One-family houses, existing building".

Notes:

Same as under the first table, i.e. "One-family houses, existing building".

Table 5.21 Heat pump, air-to-water - apartment complex, new building

Technology	**Heat pump, air-to-water Apartment complex, new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	20-300	20-300	20-300	20-300		
Expected share of space heating demand covered by unit (%)	100	100	100	100	C	
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	C	
Total efficiency, annual average, net (%)	300	330	370	400	A,B	1, 2, 3, 4, 6, 7
Technical lifetime (years)	20	20	20	20		
Environment						
SO_2 (g per GJ fuel)	For electric heat pumps, the emissions depend on how the electricity is produced. Emission factors for electricity in Denmark can for instance be found in socio-economic assumptions for energy projects published by the Danish Energy Authority (www.ens.dk → Fremskrivninger → Samfundsøkonomiske beregningsforudsætnigner).					
NO_X (g per GJ fuel)						
CH_4 (g per GJ fuel)						
N_2O (g per GJ fuel)						
Particles (g per GJ fuel)						
Financial data						
Specific investment (1000€/kW)	1	1	0.9	0,9	A, B	1, 2, 5
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)						
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/unit/year)	400	400	400	400		2
Variable O&M (€/GJ)						

References:

Same as under the first table, i.e. "One-family houses, existing building".

Notes:

Same as under the first table, i.e. "One-family houses, existing building".

5.9 Electrical heat pump, brine-to-water (ground source heat pump)

Brief technology description

General for heat pumps

Heat pumps employ the same technology as refrigerators, moving heat from a low-temperature location to a warmer location. Heat pumps usually draw heat from the ambience (input heat) and convert the heat to a higher temperature (output heat) through a closed process.

The energy efficiency of heat pumps is normally referred to by the COP factor "Coefficient of Performance" describing the delivered heat divided by the used electricity. A COP of three means that the heat pump delivers three times as much heat as the electricity consumption, and two thirds of the delivered heat is collected through the outdoor heat exchanger.

Specifically for brine-to-water heat pumps

Most brine-to-water heat pumps draw heat from the ground through a ground source heat collector. Normally, this type of heat pumps has horizontal pipes about a meter down in the ground with anti-freeze brine collecting the heat from the ground. This type is also called a ground source heat pump. Instead of horizontal pipes, it is also possible to use vertical pipes places with depth up to 250 m.

The heat pumps are normally designed to cover between 95 % and 98 % of the heating demand. The remaining heat demand is covered by direct electrical heat sources. It is possible to supplement the heat pump by a solar heating system.

Brine-to-water heat pumps have a high average efficiency over the year due to the more stable temperatures in the ground. Brine-to-water heat pumps cannot deliver water temperatures higher than 55˚C, which means that the radiators have to be able to cover the heat demand of the house with temperatures below 55˚C.

In order to obtain these sufficient low supply temperatures, it is in many cases necessary to install a larger heat capacity of the heat emission system, e.g. by installing larger radiators and/or by improving the insulation level of the building envelope. In section 4.2, some examples are given for the cost of installing larger radiators. In many cases, however, the improvement of the building envelope may be an economic profitable option anyway, and for new buildings it will be a necessity due to requirements in the building regulations.

The number of installations in Denmark of this type of heat pumps is estimated to be 15,000 to 20,000 (2011).

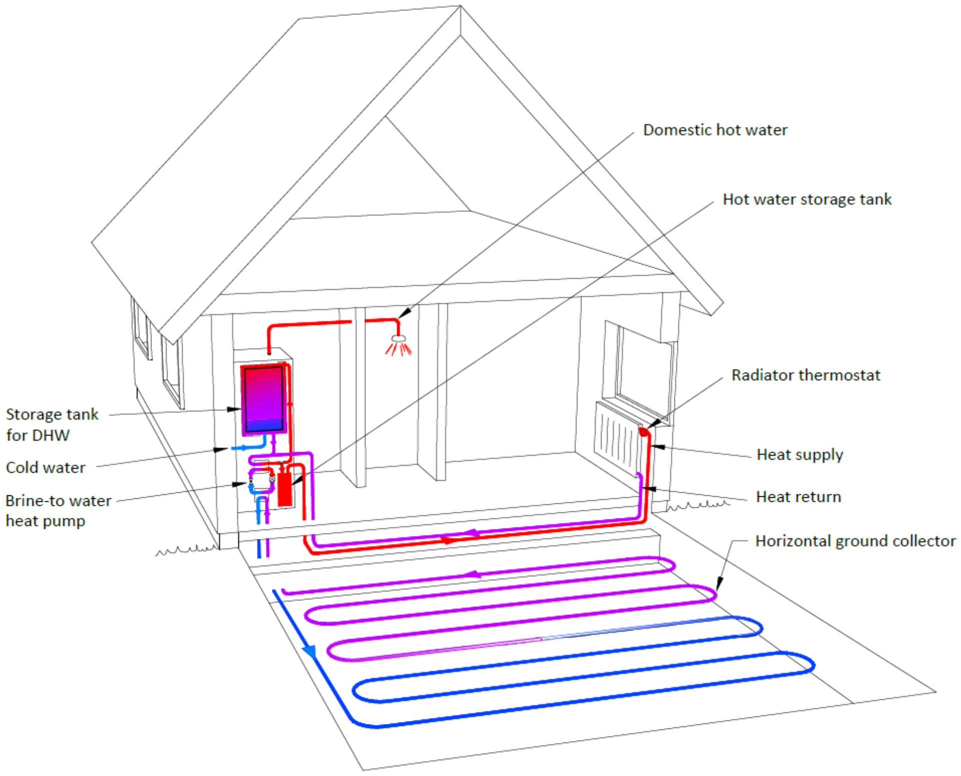

Figure 5.14 Electrical heat pump, brine-to-water

Input

The input is heat from an available heat source and electrical energy to drive the process. The heat source is most commonly the top soil (horizontal ground collector), but can also be the ground (vertical ground collector), water (lake, streams or sea water) or ambient energy absorbers (placed outdoors or roof integrated). Ambient energy absorbers can be considered as a kind of solar collector.

Output

The output is heat for primarily space heating and possible domestic hot water.

Typical capacities

There is a range of capacities available, ranging from 1.5 kW up to several hundred kW covering the needs for both space heating and domestic hot water in both low-energy buildings and large buildings.

Regulation ability

For brine-to-water heat pumps as well as other types of heat pumps, there are two main types of regulation. There is on/off regulation and capacity regulation, which is continuously variable down to about 20 % of the maximum capacity.

Capacity regulation works through a variable speed compressor where the amount of refrigerant flow through the refrigerant cycle is adapted to the demand. In on/off regulation, the compressor will work full load and stop at intervals adapted to the heat demand.

Brine-to-water heat pumps with capacity regulation do exist on the market today, but is a special feature and not very common yet.

The best efficiency is obtained with a capacity regulation ensuring that the supply temperature to the heat distribution system does not increase unnecessarily when the heat pump is running, because the heat pump efficiency will increase with lower temperatures.

If the heat pump is on/off regulated and has a small storage tank, the heat pump may start and stop often, which will lower the efficiency. A sufficiently large storage tank is therefore important with on/off regulation.

Advantages/disadvantages

General for heat pumps

The general advantage of heat pump technologies is that the technology normally uses a free low-temperature heat source.

Heat pump efficiency in general depends on the temperatures on the cold (outdoor) and the warm (indoor) side of the heat pump. Lower temperatures on the cold side as well as higher temperatures on the warm side decrease the efficiency. The heat demand is normally higher when outdoor temperatures are low. Therefore, it is important to compare the average yearly efficiency instead of the efficiency at a single working point.

For heat pumps supporting a water based heat distribution system, the supply temperature plays an important role for the efficiency. Lower supply temperature gives higher efficiencies, and therefore heat pumps for floor-heating (35˚C) have better efficiency than heat pumps for radiators (55 ˚C).

Specifically for brine-to-water heat pumps

The specific advantage of the ground source heat pump (using the top soil or the ground) is that it has a better performance than other types of heat pumps because of the higher heat source temperature during the heating season.

The brine-to-water heat pump has the same advantage as the air-to-water heat pump, where the heat is distributed to different rooms supplying different heat demands. The need for hot water production can also be supplied with this heat pump.

A disadvantage is that the ground heat source involves digging in the ground or other arrangements to retrieve the necessary heat. The most common solution, which is horizontal ground collectors, needs available ground area corresponding to a maximal consumption of 40 kWh/m^2 per year where the area is the horizontal area. The investments can be counterbalanced by the reduced costs of energy. A brine-to-water heat pump will be approximately 15 % more efficient than an air-to-water heat pump. The overall price including digging and pipes is about 20-30% more than for air-to-water heat pumps.

Moreover, there is no noise problems when the heat pump is running, which can make it the only possible solution in densely built areas.

Vertical pipes can be used instead of horizontal pipes if there is not enough available ground area. This is a more expensive solution, but is being used more often than previous, which can lower the prices in the future.

Environment

General for heat pumps

The heat pumps use F-gases (HFCs) as refrigerants. F-gases are fluorinated gases (HFCs, PFCs and SF6), which are potent greenhouse gases. They are covered by the Kyoto Protocol.

The HFCs (HydroFluoroCarbons) are the most important, and they are frequently used in the refrigeration industry as the working fluid in the refrigeration cycle.

There are many different refrigerants based on HFCs. The most important are HFC-134a (R134a) and HFC mixtures: R404A, R410A and R407A. The most common refrigerants that are based on HFCs have Global Warming Potentials (GWP) from about 1500 to 4000 compared to CO_2, which has a GWP of 1.

There are, however, some heat pumps working with natural refrigerants (including R290 – propane), but this is a minority. In the future, it will be possible to replace F-gases by natural refrigerants or other less harmful refrigerants.

Natural refrigerants are substances that can be found in nature's own cycle, e.g. ammonia, hydrocarbons, CO_2, water and air. None of the refrigerants in the group of natural refrigerants are perfect, and they all have technical limitations. Therefore, natural refrigerants have to be chosen with care, and one fluid cannot cover all applications.

Different types of heat pumps use the same types of refrigerants. The above description is therefore representative for all types of heat pumps.

The environmental impact due to the use of electricity will depend on the way the electricity is produced.

Research and development

There are a number of areas where the performance of heat pumps can be improved by performing research and development activities.

Examples of possible improvements are:

- Better control and operation strategies.
- Adoption of heat pumps as a smart grid component.
- More efficient components.
- Better integration with other systems as ventilation, water heating, space conditioning, storages and solar thermal systems.
- Increased use of natural refrigerants instead of HFC's in heat pumps.

Examples of best available technology

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Additional remarks

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References

- Potentiale for varmepumper til opvarmning af boliger med oliefyr. Energistyrelsen. 2011.

- Den lille blå om varmepumper. Dansk Energi. 2011.

- Technology Roadmap, Energy Efficient Buildings: Heating and cooling Equipment, OECD/IEA. 2011.

- Energiløsninger til renovering af eksisterende bygninger. Videncenter for energibesparelser i bygninger. 2010.

- Stock of heat pumps for heating in all-year residences in Denmark. Project made for the Danish Energy Agency. COWI, Teknologisk Institut, Statens Byggeforskningsinstitut. 2011.

Data sheets:

Table 5.22 Heat pump, brine-to-water - one-family house, existing building

Technology	**Heat pump, brine-to-water One-family house, existing building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	10	10	10	10		
Expected share of space heating demand covered by unit (%)	100	100	100	100	C	
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	C	
Total efficiency, annual average, net (%)	330	350	400	450	A, B	1, 2, 3, 4, 6, 7
Technical lifetime (years)	20	20	20	20		
Environment						
SO_2 (g per GJ fuel)	For electric heat pumps, the emissions depend on how the electricity is produced. Emission factors for electricity in Denmark can for instance be found in socio-economic assumptions for energy projects published by the Danish Energy Authority (www.ens.dk → Fremskrivninger → Samfundsøkonomiske beregningsforudsætnigner).					
NO_X (g per GJ fuel)						
CH_4 (g per GJ fuel)						
N_2O (g per GJ fuel)						
Particles (g per GJ fuel)						
Financial data						
Specific investment (1000€/kW)						
Specific investment (1000€/unit)	17	16	15	14	A, B, D, E, G	1, 2, 5
- hereof equipment (%)	70	70	70	70		
- hereof installation (%)	30	30	30	30		
Possible additional specific investment (1000€/unit)	6	6	6	6	D	
Fixed O&M (€/unit/year)	135	135	135	135	F	2
Variable O&M (€/GJ)						

References:

1 Potentiale for varmepumper til opvarmning af boliger med oliefyr. Energistyrelsen. 2011.

2 Den lille blå om varmepumper. Dansk Energi. 2011.

3 Energiløsninger til renovering af eksisterende bygninger. Videncenter for energibesparelser i bygninger. 2010.

4 Technology Roadmap, Energy Efficient Buildings: Heating and cooling Equipment, OECD/IEA. 2011.

5 Prisanalyse fra "Skrot dit oliefyr". Confidential data from 2010.

6 Personal correspondence with Claus Schøn Poulsen, Head of Center for Refrigeration and Heat Pump Technology. 2011.

7 Energimærkning og minimumskrav for varmepumper i forbindelse med Ecodesign direktivet. Studie udført for Energistyrelsen. 2011.

Notes:

A Size of heat emitters corresponds to a new system.

B Improvement of delivered energy cost is assumed to be 25 % in 2030 and 35 % in 2050. The improvements are equally split between the efficiency and the cost.

C The heat pump unit described consists of a heat pump including an electrical backup. The total unit covers 100 % of the heat demand as described and with the efficiency as described. It is assumed that the heat pump will deliver 97 % of the heat demand and the electrical backup will deliver 3 % of the heat demand.

D A vertical heat collection can be used instead of horizontal heat collectors. This will reduce the need for digging up the ground but increase the costs.

E A brine-to-water heat pump will work in combination with a hot water storage tank. The price of the tank is not included in this price. Brine-to-water heat pumps will often replace an oil-fired or natural gas boiler, where there is already a storage tank installed.

F The O&M cost corresponds to an expense of 135 EUR each year for one-family houses and three times more for apartment buildings.

G The investment cost is considered as a typical investment cost based on practical experiences. It should be noted that the investment cost can vary a lot from unit to unit.

Table 5.23 Heat pump, brine-to-water - apartment complex, existing building

Technology	**Heat pump, brine-to-water Apartment complex, existing building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	50-750	50-750	50-750	50-750		
Expected share of space heating demand covered by unit (%)	100	100	100	100	C	
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	C	
Total efficiency, annual average, net (%)	330	350	400	450	A,B	1, 2, 3, 4, 6, 7
Technical lifetime (years)	20	20	20	20		
Environment						
SO_2 (g per GJ fuel)	For electric heat pumps, the emissions depend on how the electricity is produced. Emission factors for electricity in Denmark can for instance be found in socio-economic assumptions for energy projects published by the Danish Energy Authority (www.ens.dk → Fremskrivninger → Samfundsøkonomiske beregningsforudsætnigner).					
NO_X (g per GJ fuel)						
CH_4 (g per GJ fuel)						
N_2O (g per GJ fuel)						
Particles (g per GJ fuel)						
Financial data						
Specific investment (1000€/kW)	1,1	1,1	1	0,9	A,B	1, 2, 5
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)						
Possible additional specific investment (1000€/kW)	0.67	0.67	0.67	0.67	D	
Fixed O&M (€/unit/year)	400	400	400	400	F	2
Variable O&M (€/GJ)						

References:

Same as under the first table, i.e. "One-family houses, existing building".

Notes:

Same as under the first table, i.e. "One-family houses, existing building".

Table 5.24 Heat pump, brine-to-water - one-family house, new building

Technology	**Heat pump, brine-to-water One-family house, new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	5	5	5	5		
Expected share of space heating demand covered by unit (%)	100	100	100	100	C	
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	C	
Total efficiency, annual average, net (%)	330	350	400	450	A,B	1, 2, 3, 4, 6, 7
Technical lifetime (years)	20	20	20	20		
Environment						
SO_2 (g per GJ fuel)	For electric heat pumps, the emissions depend on how the electricity is produced. Emission factors for electricity in Denmark can for instance be found in socio-economic assumptions for energy projects published by the Danish Energy Authority (www.ens.dk → Fremskrivninger → Samfundsøkonomiske beregningsforudsætnigner).					
NO_X (g per GJ fuel)						
CH_4 (g per GJ fuel)						
N_2O (g per GJ fuel)						
Particles (g per GJ fuel)						
Financial data						
Specific investment (1000€/kW)						
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)	14 75 25	13 75 25	12 75 25	12 75 25	A, B, D, E	1, 2, 5
Possible additional specific investment (1000€/unit)	6	6	6	6	D	
Fixed O&M (€/unit/year)	135	135	135	135	F	2
Variable O&M (€/GJ)						

References:

Same as under the first table, i.e. "One-family houses, existing building".

Notes:

Same as under the first table, i.e. "One-family houses, existing building".

Table 5.25 Heat pump, brine-to-water - apartment complex, new building

Technology	**Heat pump, brine-to-water Apartment complex, new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	20-300	20-300	20-300	20-300		
Expected share of space heating demand covered by unit (%)	100	100	100	100	C	
Expected share of hot tap water demand covered by unit (%)	100	100	100	100	C	
Total efficiency, annual average, net (%)	330	350	400	450	A, B	1, 2, 3, 4, 6, 7
Technical lifetime (years)	20	20	20	20		
Environment						
SO_2 (g per GJ fuel)	For electric heat pumps, the emissions depend on how the electricity is produced. Emission factors for electricity in Denmark can for instance be found in socio-economic assumptions for energy projects published by the Danish Energy Authority (www.ens.dk → Fremskrivninger → Samfundsøkonomiske beregningsforudsætnigner).					
NO_X (g per GJ fuel)						
CH_4 (g per GJ fuel)						
N_2O (g per GJ fuel)						
Particles (g per GJ fuel)						
Financial data						
Specific investment (1000€/kW)	1,1	1,1	1	0,9	A, B, D, E	1, 2, 5
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)						
Possible additional specific investment (1000€/kW)	0.67	0.67	0.67	0.67	D	
Fixed O&M (€/kW/year)	400	400	400	400	F	2
Variable O&M (€/GJ)						

References:
Same as under the first table, i.e. "One-family houses, existing building".

Notes:
Same as under the first table, i.e. "One-family houses, existing building".

5.10 Electrical heat pump, ventilation

Brief technology description

General for heat pumps

Heat pumps employ the same technology as refrigerators, moving heat from a low-temperature location to a warmer location. This is done by a closed process driven by an electrical compressor.

The energy efficiency of heat pumps is normally referred to by the COP factor "Coefficient of Performance", describing the delivered heat divided by the used electricity. A COP of three means that the heat pump delivers three times as much heat as the electricity consumption, and two thirds of the delivered heat is collected through the outdoor heat exchanger.

Specifically for ventilation heat pumps

Ventilation heat pumps draw heat from ventilation exhaust air and uses it for heating up the air intake in the ventilation system. This type of heat pumps is also called exhaust air heat pumps.

The air can be heated to a level providing more heat than the ventilation heat loss, and thereby compensate for the transmission loss to some extent. But a ventilation heat pump will always need a supplementary heating system to cover the heat demand all year around and to make individual room regulation possible.

The heat pump can be combined with a heat exchanger that can exchange part of the heat from exhaust air to the intake air without any electrical input (other than electricity for the ventilators) since the exhaust air is warmer than the intake air. This will decrease the specific energy efficiency for the heat pump, but from a system perspective the efficiency will increase.

Some heat pumps also use the exhaust air heat for heating hot utility water. In this solution, the hot water production has first priority.

The number of exhaust air to water heat pumps is difficult to estimate. It is expected that the number corresponds to the number of air to water heat pumps which is estimated to be 10,000 to 15,000 (2011).

Figure 5.15 Electrical heat pump, ventilation

Input

The input is the exhaust air from the building and electrical energy to drive the refrigerant cycling process.

Output

The output from ventilation heat pumps is heat for the air intake and in combined heat pumps also heat for domestic hot water.

Typical capacities

The ventilation heat pumps range from 1.5 kW to several hundred kW in large office buildings. In private households, the capacity is normally up to 3 kW.

Regulation ability

Different types of regulation exist for this type of heat pumps. There is on/off regulation and capacity regulation which is continuously variable down to about 20 % of the maximum capacity. The best efficiency is obtained by a capacity regulation due to the lower supply temperature to the heat emitting system when the heat pump is running.

Advantages/disadvantages

The general advantage of the ventilation heat pump is that it uses the heat which would otherwise be lost to the surroundings through the exhaust air. Likewise, the heat pump is implemented in a system delivering fresh air in the building, which will improve the indoor climate.

A ventilation system is necessary to implement the technology. In old houses with large uncontrolled ventilation due to air infiltration, the technology will not be applicable. In new and more airtight houses ventilation systems are often applied, and here ventilation heat pumps will be a very good idea.

The disadvantage of ventilation heat pumps is that the heat input for the intake air is limited by the heat that can be drawn from the exhaust air. Because a building will have a larger heat loss than what is caused by ventilation (e.g. transmission heat loss) the heat pump will not be able to cover all of the heat demand, and a second heating system is normally needed.

Environment

General for heat pumps

The heat pumps use F-gases (HFCs) as refrigerants. F-gases are fluorinated gases (HFCs, PFCs and SF6), which are potent greenhouse gases. They are covered by the Kyoto Protocol.

The HFCs (HydroFluoroCarbons) are the most important, and they are frequently used in the refrigeration industry as the working fluid in the refrigeration cycle.

There are many different refrigerants based on HFCs. The most important are HFC-134a (R134a) and HFC mixtures: R404A, R410A and R407A. The most common refrigerants based on HFCs have Global Warming Potentials (GWP) from about 1500 to 4000 compared to CO_2, which has a GWP of 1.

There are, however, some heat pumps working with natural refrigerants (including R290 – propane), but this is a minority. In the future, it will be possible to replace F-gases by natural refrigerants or other less harmful refrigerants.

Natural refrigerants are substances that can be found in nature's own cycle, e.g. ammonia, hydrocarbons, CO_2, water and air. None of the refrigerants in the group of natural refrigerants are perfect, and they all have technical limitations. Therefore, natural refrigerants have to be chosen with care, and one fluid cannot cover all applications.

The refrigerants used earlier have been replaced by types which have a modest influence on the environment. But still there will be a pressure on replacing the use of F-gases (HFCs), which are common today, with even more environmental friendly refrigerants with less impact on global warming.

Different types of heat pumps use the same type of refrigerants. The above description is therefore representative for all types of heat pumps.

The environmental impact of the drive energy due to the use of electricity will depend on the way the electricity is produced.

Research and development

There are a number of areas where the performance of heat pumps can be improved by performing research and development activities.

Examples of possible improvements are:

- Better control and operation strategies.
- Adoption of heat pumps as a smart grid component.
- More efficient components.
- Better integration with other systems as ventilation, water heating, space conditioning, storages and solar thermal systems.

Examples of best available technology

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Additional remarks

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References

- Den lille blå om varmepumper. Dansk Energi. 2011.
- Technology Roadmap, energy Efficient Buildings: Heating and cooling Equipment, OECD/IEA. 2011.
- Energiløsninger til renovering af eksisterende bygninger. Videncenter for energibesparelser i bygninger. 2010.
- Stock of heat pumps for heating in all-year residences in Denmark. Project made for the Danish Energy Agency. COWI, Teknologisk Institut, Statens Byggeforskningsinstitut. 2011.

Data sheets:

Table 5.26 Heat pump, ventilation - one family house, new building

Technology	Heat pump, ventilation One-family house, new building					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	2	2	2	2		
Expected share of space heating demand covered by unit (%)	40	40	40	40	A	
Expected share of hot tap water demand covered by unit (%)	0	0	0	0	B	
Total efficiency, annual average, net (%)	300	310	340	350		1, 2, 4
Technical lifetime (years)	20	20	20	20		4
Environment						
SO_2 (g per GJ fuel)	For electric heat pumps, the emissions depend on how the electricity is produced. Emission factors for electricity in Denmark can for instance be found in socio-economic assumptions for energy projects published by the Danish Energy Authority (www.ens.dk → Fremskrivninger → Samfundsøkonomiske beregningsforudsætnigner).					
NO_X (g per GJ fuel)						
CH_4 (g per GJ fuel)						
N_2O (g per GJ fuel)						
Particles (g per GJ fuel)						
Financial data						
Specific investment (1000€/kW)						
Specific investment (1000€/unit)	2,5	2,4	2,2	2,1	C, D	2, 4
- hereof equipment (%)	90	90	90	90	D	
- hereof installation (%)	10	10	10	10	D	
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/unit/year)	44	44	44	44	E	2
Variable O&M (€/GJ)						

References:

1 Den lille blå om varmepumper. Dansk Energi. 2011.

2 Technology Roadmap, Energy Efficient Buildings: Heating and Cooling Equipment, OECD/IEA. 2011.

3 Energiløsninger til renovering af eksisterende bygninger. Videncenter for energibesparelser i bygninger. 2010.

4 Data from manufactures.2011.

Notes:

A According to Danish building regulation, buildings cannot be heated by ventilation air alone. An additional heat distribution system is required.

B Many ventilation heat pumps have hot tap water heating. This will decrease the heating of the ventilation intake air during colder hours, because of limitations in the heat pump capacity and because these types of heat pumps have hot water priority.

C The number represents the additional cost by including a ventilation heat pump in a new ventilation system with a passive heat exchanger. The price of the complete system including passive heat exchanger ducts and installation will be about 10.000 €, where the installation costs will amount to approximately 4.000 €.

D The installation part of the price is the added cost by having a ventilation heat pump in the system instead of just a ventilation system with passive heat exchange.

E The O&M cost corresponds to an expense of 135 EUR each third year for one-family houses and three times more for apartment buildings.

Table 5.27 Heat pump, ventilation - apartment complex, new building

Technology	**Heat pump, ventilation Apartment complex, new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	14-200	14-200	14-200	14-200		
Expected share of space heating demand covered by unit (%)	40	40	40	40	A	
Expected share of hot tap water demand covered by unit (%)	0	0	0	0		
Total efficiency, annual average, net (%)	300	310	340	350		1, 2, 4
Technical lifetime (years)	20	20	20	20		4
Environment						
SO_2 (g per GJ fuel)	For electric heat pumps, the emissions depend on how the electricity is produced. Emission factors for electricity in Denmark can for instance be found in socio-economic assumptions for energy projects published by the Danish Energy Authority (www.ens.dk → Fremskrivninger → Samfundsøkonomiske beregningsforudsætnigner).					
NO_X (g per GJ fuel)						
CH_4 (g per GJ fuel)						
N_2O (g per GJ fuel)						
Particles (g per GJ fuel)						
Financial data						
Specific investment (1000€/kW)	1	1	0,9	0,9	C	2, 4
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)						
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/unit/year)	135	135	135	135	E	2
Variable O&M (€/GJ)						

References:

Same as under the first table, i.e. "One-family house, new building".

Notes:

Same as under the first table, i.e. "One-family house, new building".

5.11 Solar heating system

Brief technology description

Solar energy for domestic hot water and space heating is usually based on the principle of pumping a heat transfer liquid from an array of roof mounted solar collectors to one or more storage tanks. Solar heating for dwellings has mainly been developed for coverage of the entire hot water demand during the summer period, and to a minor degree for space heating. Because of the mismatch between demand for space heating and available solar heat, there is need of seasonal energy storage if solar energy should be the only supply. Such storage systems are only feasible at very large scale, and therefore solar heating for individual dwellings must be combined with other heating systems, e.g. gas boilers or heat pumps.

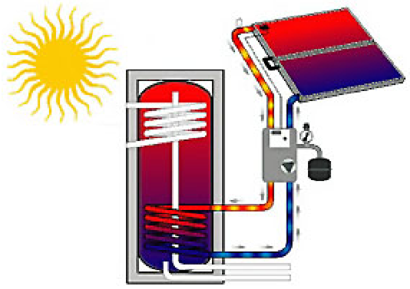

Figure 5.16 Small solar heating system for domestic hot water. Auxiliary heat is supplied to the upper heat exchanger coil

Today, solar heating plays a very little role in the Danish energy supply, but the potential is enormous [2]. In recent years, the dominating market has shifted from individual systems to large-scale systems for district heating due to economy of scale benefits. However, with the increasing demand for energy efficiency of new buildings, individual solar heating plants are becoming more and more common.

The international solar thermal industry is one of the fastest growing sectors, with 20-30% annual growth rates [2]

Input

The primary energy input is solar radiation, of which a part can be converted to thermal energy in the absorber plate. The amount of energy reaching the absorber depends on geographical site and orientation of the collector as well as possible shadows and ground reflectance. The only non-solar energy input to a solar heating system is the electric energy needed for the pump, controller and optional electric back-up heater. This amounts to 5 % of the delivered energy in a typical system.

Output

The output is thermal energy at medium temperature, typically 20-80 °C, depending on operation conditions and collector type. Higher temperatures are possible with special double-glazed solar collectors for district or industrial heating, but they are hardly relevant for DHW and space heating. In combination with heat pumps, it is possible to use very simple and inexpensive solar collectors operating at low temperature. These are typically made of polymers.

It is very important to mention that the actual performance of a solar heating system is highly dependent on the energy consumption and its distribution on time. A high consumption per m^2 collector is favourable for the efficiency, because it tends to lower the operational temperature, but it also results in a low solar fraction i.e. the part of the heating demand that is covered by the solar heating system.

Typical capacities

Traditionally, the system size is given in m^2 collector surface. For single-family homes the typical range is from 4 m^2 in case of a small DHW system to 15 m^2 for a combined space heating and DHW system. In order to compare with other technologies, IEA has decided that 0.7 kW of nominal thermal power can be used as an equivalent to 1 m^2 collector surface, but of course this is a somewhat imprecise figure because collectors and operating conditions may be very different. [5]

Regulation ability

The thermal power is largely determined by the solar irradiance and the actual operating temperature relative to ambient temperature. As the temperature increases, efficiency drops, so in a sense solar collectors are self-regulating and will stop producing heat when it reaches the so-called stagnation temperature. The regulation system in a solar heating plant can switch the available solar energy to be used for hot water or space heating and in some cases to a heat dump in order to avoid boiling or temperature induced damages.

Advantages/disadvantages

Advantage: No pollution. The solar collector can be integrated in the urban environment and may substitute a part of the building envelope. Large energy savings are often possible if the existing heater can be completely switched off during the summer so that standby losses can be substantially reduced.

Disadvantages: Relatively expensive installation, except for large systems. Mismatch between heating demand and solar availability. Requires sufficient area on the roof with appropriate orientation. May compete with photovoltaic systems for the same area.

Environment

A solar heating system mainly contains metals and glass that require energy in manufacturing. It is estimated that the energy payback time is 1-3 years [4] for a well-functioning system in Denmark. Almost all the materials can be recycled.

The special selective surface used on most solar collectors is made in a chemical process that in some cases involves chromium. It is important that the process control is adequate to avoid any pollution from this process. The fluid used in most solar heating systems shall be disposed as low-toxic chemical waste.

Research and development

The most relevant R&D needed for further development of solar thermal systems is:

- Advanced and cost effective storage systems for thermal energy.
- More cost-effective solar collectors, either by increased performance or improved low-cost manufacturing processes.
- Self-adjusting control systems that are easily adapted to the existing heating system.
- Completely new system designs, e.g. air-based wall solar collectors combined with heat pump.
- Improved architectural design and smooth integration in buildings.

Examples of best available technology

The sector is characterized by step-by-step improvements, and the most important improvements in the last 10 years are probably:

- Perfection of stratified storage tanks.
- Hot water heat exchanger modules for Legionella prevention.
- Large-scale solar collectors for district heating and other applications.
- Energy saving pumps for less electricity consumption.
- Flexible and pre-insulated installation pipework.
- Improved design and integration in roof windows (e.g. Velux).

Additional remarks

This technology description is limited to traditional solar heating systems without exchange of energy with other buildings than the one where the solar collectors are installed. Only domestic hot water and space heating are considered, not solar cooling.

References

1 Solvarme faktablade, www.altomsolvarme.dk.

2 Solvarme handlingsplan, Jan Erik Nielsen, okt. 2011.

3 Energiteknologier – tekniske og øko-nomiske udviklingsperspektiver, Teknisk baggrundsrapport til Energistrategi 2025, 2005.

4 Bygningsintegreret energiproduktion. Det økologiske råd, juni 2011.

5 Recommendation : Converting solar thermal collector area into installed capacity (m^2 to kW_{th}) .Technical note, IEA SHC 2004.

Data sheets:

Table 5.28 Solar heating system - one family house, existing building

Technology	Solar heating system One-family house, existing building					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Typical size per unit (m^2)	6	6	6	6	A	1
Typical size per unit (kW)	4.2	4.2	4.2	4.2	A	
Expected share of space heating demand covered by unit (%)	10	10	12	12	B	2, 6
Expected share of hot tap water demand covered by unit (%)	65	65	70	70	B	
Total efficiency, annual average, net (%)						
Technical lifetime (years)	20	25	30	30	C	1
Environment						
SO_2 (g per GJ fuel)	0	0	0	0	G	
NO_X (g per GJ fuel)	0	0	0	0		
CH_4 (g per GJ fuel)	0	0	0	0		
N_2O (g per GJ fuel)	0	0	0	0		
Particles (g per GJ fuel)	0	0	0	0		
Financial data						
Specific investment (1000€/m^2)	0.9	0.85	0.8	0.6	D	1, 8, 9, 10
Specific investment (1000€/unit)	5.4	5.1	4.6	3.7		1, 8, 9, 10
- hereof equipment (%)	60-70	60-70	60-70	60-70		9, 1
- hereof installation (%)	30-40	30-40	30-40	30-40		8
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/unit/year)	40	40	40	40	E	
Variable O&M (€/unit/year)	22	22	22	22	F	

References:

1 Solvarme/faktablad, www.altomsolvarme.dk.

2 Solvarme handlingsplan, Jan Erik Nielsen, okt. 2011.

3 Energiteknologier – tekniske og øko-nomiske udviklingsperspektiver, Teknisk baggrundsrapport til Energistrategi 2025, 2005.

4 Bygningsintegreret energiproduktion. Det økologiske råd, juni 2011.

5 INSPIRATIONSKATALOG Forsynings- og infrastruktur-teknologier for bæredygtig byudvikling, COWI januar 2011.

6 Komponentkrav, konkurrence og eksport. En kortlægning af innovation i byggekomponenter, DTU februar 2011.

7 Solar Heat Worldwide 2011 statistics. IEA Solar Heating and Cooling programme.

8 Tænk, december 2009.

9 www.batec.dk.

10 www.sonnenkraft.dk.

Notes:

A Fixed average size but increasing efficiency is assumed. Typical range is from 3-15 m^2 in one-family houses. 1 m^2 is equivalent with 0.7 kW.

B Annual yield 500 kWh/m^2. Highest figures for new buildings. General improvements and better storage technology assumed.

C Increase due to better materials/fluids.

D Depends on existing heating system. Savings if tank should be changed anyway. For new buildings solar system costs are lower.

E Service checks, liquid etc., 40 EUR/year in average for small systems and 100 EUR/year for large systems.

F Electricity for solar pump and control.

G Pollution associated with the small amount of electricity needed for operation is neglected.

Table 5.29 Solar heating system - apartment complex, existing building

Technology	Solar heating system Apartment complex, existing building					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Typical size per unit (m^2)	200	200	200	200	A	
Typical size per unit (kW)	140	140	140	140	A	
Expected share of space heating demand covered by unit (%)	10	10	12	12	B	
Expected share of hot tap water demand covered by unit (%)	65	65	70	70	B	
Total efficiency, annual average, net (%)						
Technical lifetime (years)	20	25	30	30	C	
Environment						
SO_2 (g per GJ fuel)	0	0	0	0	G	
NO_X (g per GJ fuel)	0	0	0	0		
CH_4 (g per GJ fuel)	0	0	0	0		
N_2O (g per GJ fuel)	0	0	0	0		
Particles (g per GJ fuel)	0	0	0	0		
Financial data						
Specific investment (1000€/m^2)	0.5	0.5	0.5	0.5	D	
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)	90 60-70 30-40	90 60-70 30-40	90 60-70 30-40	90 60-70 30-40		9, 1 8
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/unit/year)	100	100	100	100	E	
Variable O&M (€/unit/year)	500	500	500	500	F	

References:
Same as under the first table, i.e. "One-family houses, existing building".

Notes:
Same as under the first table, i.e. "One-family houses, existing building".

Table 5.30 Solar heating system - one family house, new building

Technology	Solar heating system One-family house, new building					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Typical size per unit (m^2)	6	6	6	6	A	1
Typical size per unit (kW)	4.2	4.2	4.2	4.2	A	
Expected share of space heating demand covered by unit (%)	40	40	50	60	B	2, 6
Expected share of hot tap water demand covered by unit (%)	65	65	70	70		
Total efficiency, annual average, net (%)						
Technical lifetime (years)	20	25	30	30	C	1
Environment						
SO_2 (g per GJ fuel)	0	0	0	0	G	
NO_X (g per GJ fuel)	0	0	0	0		
CH_4 (g per GJ fuel)	0	0	0	0		
N_2O (g per GJ fuel)	0	0	0	0		
Particles (g per GJ fuel)	0	0	0	0		
Financial data						
Specific investment (1000€/m^2)	0.68	0.64	0.60	0.45	D	1, 8, 9, 10
Specific investment (1000€/unit)	4.1	3.8	3.5	2.8		1, 8, 9, 10
- hereof equipment (%)	60-70	60-70	60-70	60-70		9, 1
- hereof installation (%)	30-40	30-40	30-40	30-40		8
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/unit/year)	40	40	50	60	E	
Variable O&M (€/unit/year)	22	22	22	22	F	

References:
Same as under the first table, i.e. "One-family houses, existing building".

Notes:
Same as under the first table, i.e. "One-family houses, existing building".

Table 5.31 Solar heating system - apartment complex, new building

Technology	Solar heating system Apartment complex, new building					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Typical size per unit (m^2)	200	200	200	200	A	
Typical size per unit (kW)	140	140	140	140	A	
Expected share of space heating demand covered by unit (%)	40	40	50	60	B	
Expected share of hot tap water demand covered by unit (%)	65	65	70	70	B	
Total efficiency, annual average, net (%)						
Technical lifetime (years)	20	25	30	30	C	
Environment						
SO_2 (g per GJ fuel)	0	0	0	0	G	
NO_X (g per GJ fuel)	0	0	0	0		
CH_4 (g per GJ fuel)	0	0	0	0		
N_2O (g per GJ fuel)	0	0	0	0		
Particles (g per GJ fuel)	0	0	0	0		
Financial data						
Specific investment (1000€/kW)	0.38	0.38	0.38	0.38	D	
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)	68 60-70 30-40	68 60-70 30-40	68 60-70 30-40	68 60-70 30-40		 9, 1 8
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/unit/year)	100	100	100	100	E	
Variable O&M (€/unit/year)	500	500	500	500	F	

References:

Same as under the first table, i.e. "One-family houses, existing building".

Notes:

Same as under the first table, i.e. "One-family houses, existing building".

5.12 Electric heating

Brief technology description

Electric radiators are mounted in each room. The bathrooms are equipped with electric floor heating systems.

The hot tap water is made by a hot water tank with an electric heating coil. In the case the distance to a secondary tapping point is large, an instantaneous water heater may be applied.

The radiators are equipped with internal thermostats, but more refined systems are available, making it possible to programme a temperature schedule individually for each room.

Electric heating can be a supplement or be a complete system.

Electric heating can be controlled by external systems, as an example Lauritz Knudsens IHC system including night set back. Also remote internet control is possible.

The installation will normally include a group switch per one or two rooms, making central control very simple to install.

Input

The input is electricity.

Output

The output is room heating and heating of tap water.

Typical capacities

Typical capacities for one-family buildings and apartment complex are 5 to 400 kW.

Regulation ability

The control is very flexible and the capacity can be regulated fast from 0 to 100 % and vice versa. It should be noted that the heat output is only dependent on the installed nominal power. In most cases, use of night setback or other forms of periodic heating is very efficient, as the reheating of the rooms can be very rapid. Furthermore, adding extra capacity is cheap.

Electric radiators can be built as storage heaters with some energy storage. For such radiators, electricity can be turned off for a period but heat is still emitted from the radiator. This ability can be used to e.g. fit time varying electricity tariffs in future.

Advantages/disadvantages

The advantages are the low installation prices, ref 6., the very high flexibility, the very efficient reheating after night setback, the very precise room temperature control and easy possibility of remote control. For the hot water, periodic disinfection of tap water is easily done regularly without any loss of energy.

Furthermore, distribution heat losses are saved compared to water based heating systems.

The disadvantage is the high energy price and the thermodynamic loss of "exergy". If widespread used, the power need can be critical in some areas.

Environment

The environmental impact due to the use of electricity will depend on the way the electricity is produced.

Research and development

Research concerning the future use of direct electrical heating in a smart grid may lead to positive results for this technology. It shall be taken into account that electrical heating historically often showed unexpected low energy consumptions, ref. 2. As a curiosity, the statistics shows that the average electric heated house has a lower electricity consumption than the average heat pump heated house, ref. 2.

Examples of best available technology

A modern electric heating system is an intelligent system, see ref 5. Each room can be controlled individually, and the consumption per room can be displayed for the consumer. The bathrooms are heated with floor heating and the rooms with panels. The hot water tank is a 'smart tank' including self-learning controls to maintain the lowest average temperature, while still controlling the risk of Legionella. Storage heaters are used in case of varying electricity tariffs.

Additional remarks

The prices below include a complete system for space heating and domestic hot water in each living unit.

References

1 Forsyningskatalog 1988.

2 Dansk Elforsyningsstatistik 2008.

3 1975 – 1990 Publikationer fra DEFU Concerning electric heating. Here are also reports on storage heaters.

4 http://www.dimplex.co.uk/products/domestic_heating/installed_ heating/storage_heaters/index.htm.

5 http://www.lk.dk/Lauritz+Knudsen/privat/det-intelligente-hjem/det-intelligente-hjem.page?

6 Peter Strøm from “EL-Strøm A/S”, personal communication.

Data sheets:

Table 5.32 Electric heating - one family house, new building

Technology	**Electric heating One-family house, new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	5	5	5	5		
Expected share of space heating demand covered by unit (%)	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100		
Total efficiency, annual average, net (%)	100	100	100	100	A	
Technical lifetime (years)	30	30	30	30		
Environment						
SO_2 (g per GJ fuel)	For electric heating, the emissions depend on how the electricity is produced. Emission factors for electricity in Denmark can for instance be found in socio-economic assumptions for energy projects published by the Danish Energy Authority (www.ens.dk → Fremskrivninger → Samfundsøkonomiske beregningsforudsætnigner).					
NO_X (g per GJ fuel)						
CH_4 (g per GJ fuel)						
N_2O (g per GJ fuel)						
Particles (g per GJ fuel)						
Financial data						
Specific investment (1000€/kW)						
Specific investment (1000€/unit)	4	4	4	4	D	6
- hereof equipment (%)	70	70	70	70		6
- hereof installation (%)	30	30	30	30		6
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/kW/year)	10	10	10	10	C	
Variable O&M (€/GJ)						

References:

1 Forsyningskatalog 1988.

2 Dansk Elforsyningsstatistik 2008.

3 1975 – 1990 Publikationer fra DEFU Concerning electric heating. Here are also reports on storage heaters.

4 http://www.dimplex.co.uk/products/domestic_heating/installed_ heating/storage_heaters/index.htm.

5 http://www.lk.dk/Lauritz+Knudsen/privat/det-intelligente-hjem/det-intelligente-hjem.page?

6 Peter Strøm from “EL-Strøm A/S”, personnaly communication.

Notes:

A Annual efficiency based on 100 % space heating efficiency and hot water efficiency. In addition, distribution heat losses compared to water based heating systems are saved, typically in the range of 5-10 %.

B Assuming 150 apartments.

C Assuming change of heating elements in the hot water tank every 10 years.

D The price includes the complete system including room heaters and hot tap water preparation.

Table 5.33 Electric heating - apartment complex, new building

Technology	Electric heating Apartment complex, new building					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	400	400	400	400	B	
Expected share of space heating demand covered by unit (%)	100	100	100	100		
Expected share of hot tap water demand covered by unit (%)	100	100	100	100		
Total efficiency, annual average, net (%)	95	95	95	95	A	
Technical lifetime (years)	30	30	30	30		
Environment						
SO_2 (g per GJ fuel)	For electric heating, the emissions depend on how the electricity is produced. Emission factors for electricity in Denmark can for instance be found in socio-economic assumptions for energy projects published by the Danish Energy Authority (www.ens.dk → Fremskrivninger → Samfundsøkonomiske beregningsforudsætnigner).					
NO_X (g per GJ fuel)						
CH_4 (g per GJ fuel)						
N_2O (g per GJ fuel)						
Particles (g per GJ fuel)						
Financial data						
Specific investment (1000€/kW)						
Specific investment (1000€/unit)	266	266	266	266	B, D	6
- hereof equipment (%)	70	70	70	70		6
- hereof installation (%)	30	30	30	30		6
Possible additional specific investment (1000€/unit)						
Fixed O&M (€/kW/year)	10	10	10	10	C	
Variable O&M (€/GJ)						

References:

Same as under the first table, i.e. "One-family houses, existing building".

Notes:

Same as under the first table, i.e. "One-family houses, existing building".

5.13 Micro CHP - natural gas fuel cell

General for micro CHP fuel cell units

A fuel cell is a unit which produces electricity and heat through an electrochemical reaction between fuel and oxygen. The conversion factor from fuel to electricity is high and fuel cell micro CHP units have the potential to obtain electrical efficiencies higher than for other cogeneration technologies in the same power range and for the same fuel. The fuel cell technology is scalable without loss of efficiency.

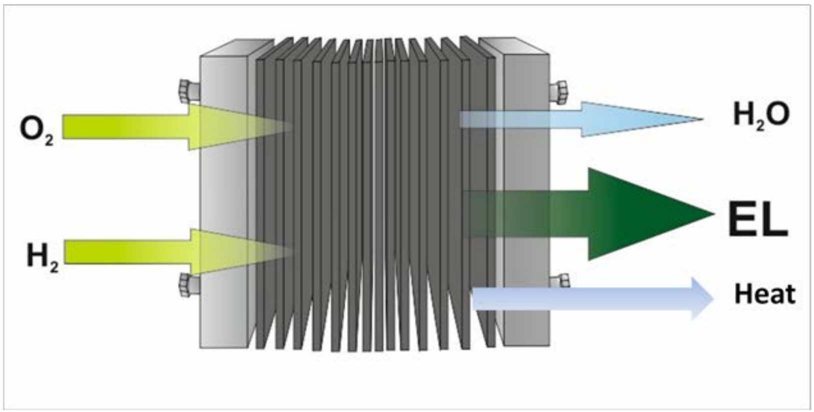

Figure 5.17 Fuel cell principle

Fuel cells can be of different types including among others PEM (Proton Exchange Membrane) and SOFC (Solid Oxide Fuel Cell) where the name refers to the electrolyte or membrane used in the fuel cell. Some types of fuel cells operate at a low temperature whereas other types of fuel cells operate at a high temperature.

Fuel cells can be used in different applications including stationary applications in households as micro CHP units, where the fuel cell produces both electricity and heat to the household. When the electricity production exceeds the consumption, it can be exported to the electrical grid. Opposite, when the electricity production is less than the consumption, additional power will be supplied from the grid.

The fuel cell micro CHP system should be equipped with a heat storage so that the capacity of the unit can be limited and the fuel cell can optimize its production taking not only the heat demand but also the electricity demand/prices into consideration.

The fuel cell produces direct current (DC) and therefore, the fuel cell system must be equipped with a DC/AC inverter changing the direct current to alternating current (AC).

Today, there are only a few micro CHP fuel cell installations in Danish households and these are all demonstration units.

Fuel cell based micro CHP units are today expensive to manufacture but the costs are expected to decrease as the development takes place. The costs are in particular expected to decrease when the technology becomes more widespread and the units can be manufactured in larger numbers.

Specifically for natural gas fuel cells

Natural gas fuel cells use natural gas as fuel and therefore they can simply be connected to the gas grid similar to e.g. natural gas boilers. However, because the fuel cell needs hydrogen as input, a natural gas fuel cell micro CHP must include a reformer (either separate component or internal reforming) which produces hydrogen from natural gas.

The figure below shows a number of natural gas fuel cells installed as micro CHPs in individual households. The fuel cells are supplied with natural gas from the natural gas network and they exchange electricity with the electrical grid. The emissions are predominantly limited to CO_2 from the reforming process of natural gas to hydrogen. In addition to this, some water production takes place from the electrochemical reaction between hydrogen and oxygen.

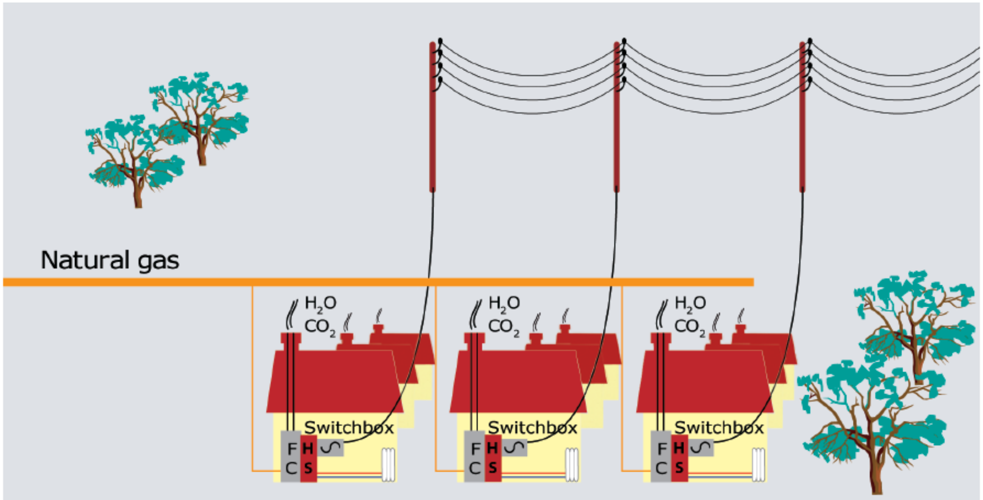

Figure 5.18 *Fuel cell micro CHPs supplied with natural gas from the gas grid and delivering surplus electricity to the electrical grid*

Input

The input to a natural gas fuel cell micro CHP unit is natural gas (which is reformed to hydrogen in a reformer before entering the fuel cell).

Output

The output is heat for domestic heating and for hot tap water as well as electricity. The produced electricity can be consumed by the building or in case the electricity production exceeds the demand it can be exported to the electrical grid.

Typical capacities

Typical capacities for natural gas fuel cell micro CHP units are 1.5-20 kW heat (including supplementary heater/boiler) and 0.7-1.5 kW electricity.

Regulation ability

Natural gas fuel cells can regulate. However, the regulation ability is limited by the dynamic characteristics of the reformer. Furthermore, the fuel cell should preferably be operated at nominal load due to own consumption/efficiency aspects and life time considerations. The regulation ability is expected to be improved in future.

Advantages/disadvantages

The main advantage of natural gas fuel cell based micro CHP units is that they produce both electricity and heat in cogeneration and with a higher electrical efficiency than for other cogeneration technologies in same power range fuelled by natural gas. Thereby, it is possible to convert individual gas boilers outside district heating areas to fuel efficient combined heat and power production (CHP).

Another advantage of natural gas fuel cells is that they produce electricity locally as "distributed generators" which can result in reduced electricity distribution losses and costs.

Depending on the regulation possibilities, natural gas fuel cells can contribute to the balancing of the power system, e.g. by pooling a large number of units into so called virtual power plants (VPP) controlled by e.g. the grid operator.

A disadvantage of natural gas fuel cells is that they are dependent of natural gas supply, i.e. a natural gas network.

Environment

The emissions from natural gas fuel cells are relatively low.

Research and development

Natural gas fuel cell micro CHP units are still under development. The development is in particular concentrated on reducing the costs of the units, increasing the lifetime and increasing the reliability.

In a later phase the research and development activities may be concentrated on how to use the units in a smart grid context so that natural gas fuel cells can optimize their operation according to dynamic electricity prices.

Examples of best available technology

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Additional remarks

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References

1 Mini- og mikrokraftvarme, Teknologi, potentialer og barrierer. Projektrapport, DGC, Oktober 2006.

Data sheets:

Table 5.34 Micro CHP, Natural gas fuel cell - One-family house, existing and new building

Technology	**Micro CHP - Natural gas fuel cell One-family house, existing and new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	1.5-20	1.5-20	1.5-20		C	1, 2, 3
Electricity generation capacity for one unit (kW)	0.7-1.5	0.7-1.5	0.7-1.5			1
Expected share of space heating demand covered by unit (%)	50-100	50-100	50-100		D	
Expected share of hot tap water demand covered by unit (%)	30/40-100	30/40-100	30/40-100		D, G, I	
Electric efficiency, annual average, net (%)	35-40	40-50	40-55		H	1
Heat efficiency, annual average, net (%)	50-60	50-55	50-55		H	1
Total efficiency, annual average, net (%)	85-90	95-100	95-102		H	1
Technical lifetime (years)	> 7	> 10	> 10			6
Environment						
SO_2 (g per GJ fuel)	0	0	0			
NO_X (g per GJ fuel)	< 2	< 2	< 2			1, 4, 7
CH_4 (g per GJ fuel)	0.5 - 2	0.5 - 2	0.5 - 2		F	1, 4, 7
N_2O (g per GJ fuel)	NA	NA	NA			
Particles (g per GJ fuel)	0	0	0			7
Financial data						
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)	7-35 80 20	4.4 80 20	2.6 80 20		A, B	1, 5
Possible additional specific investment (1000€/unit)	0.5-4.5	0.5-4.5	0.5-4.5		E	
Fixed O&M (€/kW/year)	NA	NA	NA			
Variable O&M (€/GJ)	NA	NA	NA			

References:

1 Results from tests in the project "Dansk Mikrokraftvarme"

2 www.baxi.com

3 www.hexis.ch

4 www.asue.de

5 www.sgc.se, report 228, April 2011

6 Ballard tests FCgen 1030 V3 data > 26000 h syst test

7 EUR 20681 Rapport, 2003/2010 "Fuel Cells".

Notes:

A Target cost price "Dansk Mikrokraftvarme" (Lowest costs at 10,000 units/year)

B Target price 2020 from JPN (the Enefarm project)

C A built in burner increases heat output > 1½ kW for some units (Baxi Innotec, Hexis Galileo)

D The highest number, i.e. 100 %, is due to the built in supplementary heater/burner. The micro CHP unit will cover approx. 50-70 % of the total heat demand. The remaining part is supplied from the built in supplementary heater/burner (gas burner or electric heater).

E The additional investment costs are for the supplementary heater/burner. The cost will be lowest if an electric heater is chosen and highest if a gas burner is chosen.

F Lowest value found in ref /4/

G The larger hot water tank, the higher coverage.

H All efficiencies refer to the CHP unit only and are based on lower calorific value (LCV) of the fuel. The fuel or electricity consumption in the supplementary heater/burner depends on the technology chosen.

I For existing buildings, with a higher demand for space heating than new buildings, the minimum expected share of hot tap water demand covered by the unit is 40 %. For new buildings it is 30 %.

5.14 Micro CHP - hydrogen fuel cell

General for micro CHP fuel cell units

A fuel cell is a unit which produces electricity and heat through an electrochemical reaction between fuel and oxygen. The conversion factor from fuel to electricity is high and fuel cell micro CHP units have the potential to obtain electrical efficiencies higher than for other cogeneration technologies in the same power range and for the same fuel. The fuel cell technology is scalable without loss of efficiency.

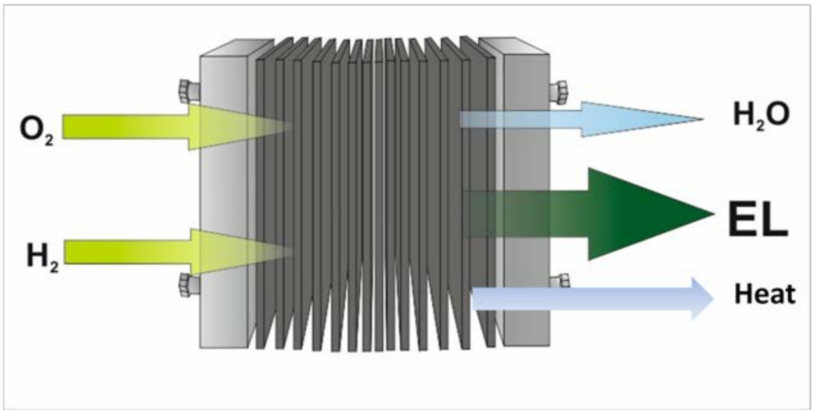

Figure 5.19 Fuel cell principle

Fuel cells can be of different types including among others PEM (Proton Exchange Membrane) and SOFC (Solid Oxide Fuel Cell) where the name refers to the electrolyte or membrane used in the fuel cell. Some types of fuel cells operate at a low temperature whereas other types of fuel cells operate at a high temperature.

Fuel cells can be used in different applications including stationary applications in households as micro CHP units, where the fuel cell produces both electricity and heat to the household. When the electricity production exceeds the consumption, it can be exported to the electrical grid. Opposite, when the electricity production is less than the consumption, additional power will be supplied from the grid.

The fuel cell micro CHP system should be equipped with a heat storage so that the capacity of the unit can be limited and the fuel cell can optimize its production taking not only the heat demand but also the electricity demand/prices into consideration.

The fuel cell produces direct current (DC) and therefore, the fuel cell system must be equipped with a DC/AC inverter changing the direct current to alternating current (AC).

Today, there are only a few micro CHP fuel cell installations in Danish households and these are all demonstration units.

Fuel cell based micro CHP units are today expensive to manufacture but the costs decrease as the development takes place. The costs are in particular expected to decrease when the technology becomes more widespread and the units can be manufactured in larger numbers.

Specifically for hydrogen fuel cells

Hydrogen fuel cells use hydrogen as fuel. One way to produce hydrogen is via an electrolyzer which produces hydrogen from electricity.

The production of hydrogen can take place either centrally or locally in each building. If the production takes place centrally, it is necessary to establish a hydrogen distribution network. If the production takes place locally in each building, each building should be equipped with a small electrolyzer and a hydrogen storage.

The figure below shows a number of hydrogen fuel cells installed as micro CHPs in individual households. In the figure, the electrolyzer is located centrally, but as mentioned, the electrolyzer can also be placed locally in each building. This makes the technology very flexible as it does not require any gas infrastructure.

There are no emissions from hydrogen fuel cells themselves - only some water production from the electrochemical reaction between hydrogen and oxygen. From a total system perspective, however, the emissions related to the use of hydrogen fuel cell systems depend on how the electricity used in the electrolyzer is produced. If the electricity is produced by wind turbines, the net emissions are zero.

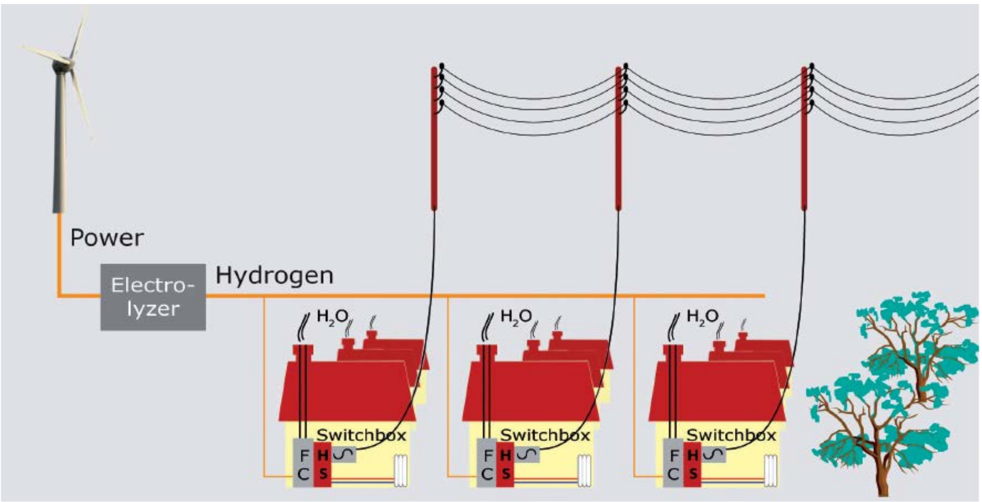

Figure 5.20 *Fuel cell micro CHPs supplied with hydrogen from an electrolyzer and delivering surplus electricity to the electrical grid. The electrolyzer can be located either centrally (as in the figure) or locally in each building.*

Due to the fact that the hydrogen fuel cell systems use electricity for producing hydrogen which is stored and used later for production of electricity and heat, the hydrogen fuel cell systems can serve as indirect electricity storages in the energy system. Thereby, hydrogen fuel cell systems can contribute to incorporating more fluctuating renewable energy sources, e.g. wind power, to the overall energy system.

One big challenge related to hydrogen fuel cell systems is however the energy losses from electricity to hydrogen and back to electricity and heat again. This is illustrated in the figure below by use of an efficiency of the electrolyzer of 85 %, an electric production efficiency of 45 % and a heat production efficiency of 45 %.

Hydrogen micro CHP system

100 units electricity → 85 units hydrogen ↗ 38,25 units electricity ↘ 38,25 units heat

Net: 61,75 electricity → 38,25 units heat

η = 62 %

Electric heater

Net: 100 units electricity → 100 units heat

η = 100 %

Figure 5.21 Example of net efficiencies, electricity to heat, in the hydrogen micro CHP solution and electric heaters

As in can be seen from Figure 5.21, the net heat efficiency of the hydrogen fuel cell system is 62 % when assuming that the electricity used in the electrolyzer has the same value as the electricity produced from the fuel cell unit. This heat efficiency can be compared to the net efficiency of an electric heater of 100 % or an even higher efficiency at heat pumps.

However, the reason why hydrogen fuel cell systems are interesting is that they can serve as indirect electricity storages and opposite to electric heaters and heat pumps fuel cell systems can also produce electricity when needed in the system.

Input

The input to a hydrogen fuel cell micro CHP unit is hydrogen produced from electricity in an electrolyzer.

Hydrogen can also be produced via industrial processes. However, for micro CHP applications with local production of hydrogen this is not relevant.

Output

The output is electricity as well as heat for domestic heating and for hot tap water production. The electricity produced can be consumed by the building or in case the electricity production exceeds the demand it can be exported to the electric grid.

Typical capacities

Typical capacities for hydrogen fuel cells as micro CHP units developed are 1-2 kW heat and 1-2 kW electricity. Hydrogen fuel cells are scalable without loss of efficiency.

Regulation ability

Most hydrogen fuel cells have a fast load response and short start/stop time. However, the fuel cell should preferably be operated at nominal load due to own consumption/efficiency aspects and life time considerations. The regulation ability is expected to be improved in the future.

Advantages/disadvantages

The main advantage of hydrogen fuel cells is that they can serve as indirect electricity storages and thereby contribute to incorporating more fluctuating renewable energy sources, e.g. wind turbines, to the system.

Another advantage of hydrogen fuel cells is that they produce electricity locally as "distributed generators" which can result in reduced electricity distribution losses and costs.

Furthermore, hydrogen fuel cells with local electrolyzers are not dependent on any gas infrastructure, as they use electricity.

Hydrogen fuel cells can contribute to the balancing of the power system, e.g. by pooling a large number of units into so called virtual power plants (VPP) controlled by e.g. the grid operator.

Hydrogen fuelled fuel cells have a high electrical efficiency compared to other cogeneration units of same power range.

A disadvantage of the hydrogen fuel cell-electrolyzer system is the relatively high losses from electricity to hydrogen and back to electricity and heat again.

Environment

There are no emissions except water from hydrogen fuel cells themselves. From a total system perspective, however, the emissions related to the use of hydrogen fuel cell systems depend on how the electricity used in the electrolyzer is produced.

Research and development

The hydrogen fuel cell micro CHP units are still under development. The development is in particular concentrated on reducing the costs of the units, increasing the lifetime and increasing the reliability.

In a later phase the research and development activities may be concentrated on how to use the units in a smart grid context so that hydrogen fuel cells can optimize their operation according to dynamic electricity prices.

Examples of best available technology

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Additional remarks

The data specified in the data tables assume that the hydrogen production takes place locally in each building. In this case, there is no need for a hydrogen distribution network.

References

1 Mini- og mikrokraftvarme, Teknologi, potentialer og barrierer. Projektrapport, DGC, Oktober 2006.

Data sheets:

Table 5.35 Micro CHP, Hydrogen fuel cell - One-family house, existing and new building

Technology	**Micro CHP - Hydrogen fuel cell One-family house, existing and new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	1.6	1.6	1.6		A	3
Electricity generation capacity for one unit (kW)	1.4	1.4	1.4			3
Expected share of space heating demand covered by unit (%)	50-70	50-70	50-70		D	
Expected share of hot tap water demand covered by unit (%)	50-70	50-70	50-70		D	
Electric efficiency, annual average, net (%)	45-50	48-53	52-57		E	1
Heat efficiency, annual average, net (%)	35-45	38-50	40-50		E	1
Total efficiency, annual average, net (%)	85-90	90-98	95-102		C, E	1
Efficiency in electrolyzer, annual average, net (%)	60-80	75-90	80-97			2, 4
Technical lifetime (years)	7	> 10	> 10		B	1
Environment						
SO_2 (g per GJ fuel)	The emissions from hydrogen fuel cell micro CHP units depend on how the electricity used for hydrogen production in the electrolyzer is produced. If the electricity is "surplus electricity" from e.g. wind power, the emissions are zero. For average Danish emissions factors for electricity, see www.ens.dk → Fremskrivninger → Samfundsøkonomiske beregningsforudsætninger.					
NO_X (g per GJ fuel)						
CH_4 (g per GJ fuel)						
N_2O (g per GJ fuel)						
Particles (g per GJ fuel)						
Financial data						
Specific investment (1000€/unit)	10.5	4.4	2.6			1
- hereof equipment (%)	65	70	70			
- hereof installation (%)	35	30	30			
Possible additional specific investment (1000€/unit)	0.5-4.5	0.5-4.5	0.5-4.5		F	
Fixed O&M (€/kW/year)	NA	NA	NA			
Variable O&M (€/GJ)	NA	NA	NA			

References:

1 Road Map, www.hydrogennet.dk.

2 Elektrolysestrategi, Partnerskabet for brint og brændselsceller, august 2009, www.hydrogennet.dk.

3 Results from "Dansk Mikrokraftvarme"

4 "Stand und Entwicklungspotenzial der wasserstoff aus regenerativen Energien", Rev 1. June 2011. Frauenhofer.

Notes:

A Built in auxiliary burner will increase heat output.

B No test data > 5 years (2012)

C Electrolyzer efficiency not included in this number. The number is for conversion of hydrogen to electricity and heat in the CHP unit.

D The micro CHP unit will cover approx. 50-70 % of the total heat demand. The remaining part should be supplied from a supplementary heater/burner.

E All efficiencies refer to the CHP unit only and are based on lower calorific value (LCV) of the fuel. The fuel or electricity consumption in the supplementary heater/burner depends on the technology chosen.

F The additional investment costs are for the supplementary heater/burner. The cost will be lowest if an electric heater is chosen and highest if a gas burner is chosen.

5.15 Micro/Mini CHP - Stirling engine

Brief technology description

Among micro CHP technologies, the products available on the market are mostly based on Stirling engines fuelled by gas (this section) or more conventional gas engines (section 5.16).

A Stirling engine is a piston engine, but opposite to traditional piston engines, the combustion takes place outside the cylinder. The engine is driven by temperature differences created by external heating and cooling sources. One part of the engine is permanently hot, while another part of the engine is permanently cold.

Inside the engine, there is a working gas, which for instance can be pressurised air or helium. The working gas is moved between the hot and the cold side of the engine by a mechanical system comprising a displacement piston coupled to a working piston. When the working gas is heated in the hot side of the engine, it expands and pushes the working piston. When the working piston moves, the displacement piston forces the working gas to the cold side of the engine, where it cools and contracts. The detailed mechanical solution and lay-out of the Stirling engine can, however, be different from one type of engine to another.

During operation the movement of the piston runs a generator which produces electricity. When the working gas cools and contracts at the cold side of the engine, it gives off heat which can be used for heating purposes. Thereby, the Stirling engine produces both heat and electricity.

Because the Stirling engine simply just converts hot air to mechanical energy, the Stirling engine is also called a hot air engine.

The Stirling engine is based on an old principle invented already in 1816. However, the engine has not yet really had its major commercial breakthrough.

The mechanical (or electrical) efficiency of a Stirling engine is for the best commercial available Stirling engine based units of approximately 25 %. However, for most small Stirling engines, the mechanical efficiency is lower, e.g. in the range of only 12 % as annual average efficiency.

The engine principle is very flexible with respect to fuels which make the engine interesting also in relation to the use of renewable energy sources. The Danish company Stirling DK manufacture a Stirling engine fuelled by biomass. However, this engine is too large for one family houses and many apartment complexes. For these applications, at least today and for the next couple of years, gas fuelled mass produced Stirling engines are considered to be the most useable/realistic options.

This technology description concerns Stirling engines fuelled by natural gas down to a size of approximately 1 kW electricity and 7-15 kW heat. A technology description of a Stirling engine fuelled by biomass and with a heat capacity of 120 kW can be found in the catalogue "Technology Data for Energy Plants" published by the Danish Energy Agency and Energinet.dk.

Input

The input is natural gas. Some mini CHP units may be delivered for LPG or biogas operation as well.

Larger Stirling engines can also be fuelled with biomass or waste (not covered by this technology description).

Output

The output is electricity as well as heat for domestic heating and hot tap water production. The produced electricity can be consumed by the building or in case the electricity production exceeds the demand it can be exported to the electrical grid.

Typical capacities

Typical heat capacities are from 7-15 kW. Typical electrical capacities are from 1-7 kW.

Regulation ability

The heat load can be changed relatively fast. The electrical output, however, can not be changed as quickly as in traditional engines.

Advantages/disadvantages

The main advantage of the Stirling engine principle is that it produces both electricity and heat and that it is flexible with respect to fuels. Regarding Stirling engines fuelled by natural gas, the advantage of Stirling engines are low emissions, few vibrations, low service requirements, long lifetime and relative low capital costs.

As for other micro and mini CHP technologies, a Stirling engine makes it possible to replace heat boilers with combined heat and power (CHP) units which increases the overall energy efficiency. Furthermore, if operated in an optimal way, there is a possibility that Stirling engines as a distributed electricity generator can lead to decreased network losses and costs in the electrical grid.

With respect to disadvantages, there are still some challenges to be solved regarding durability of the heat exchangers in the Stirling engine as well as tightening of the engine because the Stirling engine operates under a high pressure (approximately 80 bars). Furthermore, the Stirling engine has limited possibilities of operating at part load, it has a long start up time and it has a relatively high start up energy consumption.

Environment

The Stirling engine has low emissions due to the continuous combustion.

Research and development

Research and development activities take place in many countries including Denmark. One of the challenges is to increase durability of the heat exchangers and to ensure tightening of the engine since it operates at high pressure. Another challenge is to increase the mechanical (or electrical) efficiency.

Examples of best available technology

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Additional remarks

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References

1 Mini- og mikrokraftvarme, Teknologi, potentialer og barrierer. Projektrapport, DGC, Oktober 2006.

Data sheets:

Table 5.36 Micro CHP, Stirling engine - One-family house, existing building

Technology	**Micro CHP - Stirling engine One-family house, existing building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	7-12	6-10	5-6		A	
Electricity generation capacity for one unit (kW)	1	1	1			
Expected share of space heating demand covered by unit (%)	70-90	70-90	70-90		C	
Expected share of hot tap water demand covered by unit (%)	50-70	50-70	50-70		C	
Electric efficiency, annual average, net (%)	12	14	16			(4)
Heat efficiency, annual average, net (%)	75-80	75-85	75-90			(4)
Total efficiency, annual average, net (%)	87-92	89-99	91-106			(4)
Technical lifetime (years)	10	> 10	> 10			
Environment						
SO_2 (g per GJ fuel)	0	0	0			
NO_X (g per GJ fuel)	15-25	10-20	10-20		B	3
CH_4 (g per GJ fuel)	~0	~0	~0			3
N_2O (g per GJ fuel)	NA	NA	NA			
Particles (g per GJ fuel)	NA	NA	NA			
Financial data						
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)	10-14 70 30	6-8 70 30	5 70 30			1, 2
Possible additional specific investment (1000€/unit)	0.5-4.5	0.5-4.5	0.5-4.5		C	
Fixed O&M (€/kW/year)	NA	NA	NA			
Variable O&M (€/GJ)	0.5-1	0.5-1	0.5-1			3

References:

1 www.microchp.dk

2 www.dedietrich-remeha.de

3 IEA report Annex 42, subtask A FC+COGEN-SIM 2005

4 Product specification sheets

Notes:

A Heat output >7 kW is due to integrated burner

B EU-EcoDesign proposal: NO_X < 20 g/GJ

C An auxiliary burner, boiler or electrical heater may supply remaining heat

Table 5.37 Micro CHP, Stirling engine - One-family house, new building

Technology	**Micro CHP - Stirling engine One-family house, new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	7-12	6-10	5-6		A	
Electricity generation capacity for one unit (kW)	1	1	1			
Expected share of space heating demand covered by unit (%)	80-100	80-100	80-100		C	
Expected share of hot tap water demand covered by unit (%)	70-100	70-100	70-100		C	
Electric efficiency, annual average, net (%)	12	14	16			(4)
Heat efficiency, annual average, net (%)	75-80	75-85	75-90			(4)
Total efficiency, annual average, net (%)	87-92	89-99	91-106			(4)
Technical lifetime (years)	15	> 15	> 15		D	
Environment						
SO_2 (g per GJ fuel)	0	0	0			
NO_X (g per GJ fuel)	15-25	10-20	10-20		B	3
CH_4 (g per GJ fuel)	~0	~0	~0			3
N_2O (g per GJ fuel)	NA	NA	NA			
Particles (g per GJ fuel)	NA	NA	NA			
Financial data						
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)	10-14 70 30	6-8 70 30	5 70 30			1, 2
Possible additional specific investment (1000€/unit)	0.5-4.5	0.5-4.5	0.5-4.5		C	
Fixed O&M (€/kW/year)	NA	NA	NA			
Variable O&M (€/GJ)	0.5-1	0.5-1	0.5-1			3

References:

1 www.microchp.dk

2 www.dedietrich-remeha.de

3 IEA report Annex 42, subtask A FC+COGEN-SIM 2005

4 Product specification sheets

Notes:

A Heat output >7 kW is due to integrated burner

B EU-EcoDesign proposal: NO_X < 20 g/GJ

C An auxiliary burner, boiler or electrical heater may supply remaining heat

D The technical lifetime is higher in new building than in existing buildings due to lower heat consumption and thereby less annual operating hours.

Table 5.38 Micro CHP, Stirling engine - Apartment complex, new building

Technology	**Mini CHP - Stirling engine Apartment complex, (existing[6]) and new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	15	14	13		A, D, E	
Electricity generation capacity for one unit (kW)	7	7	7		A	
Expected share of space heating demand covered by unit (%)	70-90	70-90	70-90		B, C	
Expected share of hot tap water demand covered by unit (%)	30-50	30-50	30-50		B, C	
Electric efficiency, annual average, net (%)	25	27	30			1
Heat efficiency, annual average, net (%)	55	55	55			1
Total efficiency, annual average, net (%)	80	82	85			1
Technical lifetime (years)	10	> 10	> 10			
Environment						
SO_2 (g per GJ fuel)	0	0	0			
NO_X (g per GJ fuel)	20	10-20	10-20			1
CH_4 (g per GJ fuel)	<1	<1	<1			1
N_2O (g per GJ fuel)	NA	NA	NA			
Particles (g per GJ fuel)	NA	NA	NA			
Financial data						
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)	20 75 25	18 75 25	15 75 25			
Possible additional specific investment (1000€/kW)	0.2	0.2	0.2		C	
Fixed O&M (€/kW/year)	NA	NA	NA			
Variable O&M (€/GJ)	0.6-0.8	0.6-0.8	0.6-0.8			2

References:

1 SGC Report 144

[6] The highest heat capacity among the commercial products on the market today is 15 kW. Even though it is possible to install several units, a Stirling engine is mainly found relevant for one family houses and for new apartment complexes with a relatively low heat demand (where the number of units can be limited).

2 IEA Report, Annex 42, Subtask A FC+COGEN-SIM. 2005.

Notes:

A Only one commercial product is on the market in this power range

B The high number only with several units installed

C An auxiliary burner, boiler or electrical heater may supply remaining heat

D As the electric efficiency is improved over the years, the heat/power ration declines

E Several units necessary in apartment complexes to cover the heating (and power) need.

5.16 Micro/Mini CHP - gas engine

Brief technology description

Among micro and mini CHP technologies, the products available on the market are mostly based on conventional gas engines (this section) and Stirling engines fuelled by gas (section 5.15).

A conventional gas engine is a piston engine where the combustion takes place inside the cylinder. The gas engine is driven by a mix of gas and air which is compressed and then ignited. When ignited, the mix of gas and air expands and the expansion moves the piston which runs a generator producing electricity. The movement of the piston also result in the compression of the next portion of gas and air. The engine and the exhaust gas are cooled by water and the heated water can be used for heating purposes. Thereby, the gas engine produces both heat and electricity.

Gas engines used for micro and mini CHP applications are spark ignition engines using spark plugs to ignite the mix of gas and air. Spark ignition engines are commonly categorized according to the fuel/air ratio:

- In "lean burn engines" the engine runs with a low fuel/air ratio. The combustion temperature and hence the NO_X-emission is thereby reduced. Lean burn engines are normally equipped with oxidation catalysts.

- In "stoichiometric combustion engines" the amount of air equals exactly the amount of air necessary for (theoretically) complete combustion. Stoichiometric gas engines need lambda sensors and three-way catalysts to reduce emissions.

Micro and mini CHP engines are typically four-stroke water cooled engines. Some of the smallest units are with only one cylinder. An example of this is for instance a 1 kW_e micro CHP unit from Honda. These micro/mini CHP gas engines have opposite to larger engines (> 300 kW_e) normally not a turbo charger.

The gas engine technology has been used for many years. During the years, the efficiency has been steadily improved and the emissions have been reduced. The mechanical (or electrical) efficiency of a gas engine is around 20 % as annual average for micro CHP units and 28-36 % for mini CHP units.

Micro and mini CHP gas engine units are typically delivered in a noise insulated cabinet.

Input

The input is natural gas. Some mini CHP units may be delivered for LPG or biogas operation as well.

Output

The output is electricity as well as heat for domestic heating and for hot tap water production. The electricity produced can be consumed in the building or in case the electricity production exceeds the demand it can be exported to the electrical grid.

Typical capacities

Typical heat capacities for micro and mini CHP gas engines are from 3-300 kW. Typical electrical capacities are from 1-180 kW.

Gas engines are also manufactured in much larger sizes, i.e. up to around 8 MW_e. For these larger gas engines, see the catalogue "Technology Data for Energy Plants" published by the Danish Energy Agency.

Regulation ability

Gas engines can start up fast. They are able to operate at part load, however with some decrease in efficiency.

Advantages/disadvantages

The main advantage of a gas engine is that it is proven technology producing both electricity and heat. As for other micro and mini CHP technologies, a gas engine makes it possible to replace heat boilers with combined heat and power (CHP) which increases the overall energy efficiency. Furthermore, if operated in an optimal way, there is a possibility that gas engines as a distributed electricity generator can lead to decreased network losses and costs in the electrical grid.

Other advantages of gas engines are that they are based on well known technology, they are commercially available and that they have reasonable efficiencies, high durability and few high-tech components.

Disadvantages are some level of noise, a relative high level of emissions and relative high maintenance and service costs.

Environment

Gas engines have relative high emissions. When used for micro CHP applications, however, the emissions can be reduced by use of efficient catalyst systems.

Research and development

The research and development activities are focussed on improving the catalyst systems, improving the mechanical (or electrical) efficiency and to develop professional systems for installation and service.

Examples of best available technology

The product that is currently the most popular in terms of numbers sold and installed world wide is based on a Honda gas engine with a power output of approximately 1 kW and a heat output of approximately 3 kW. More than 100,000 of this type of micro CHP unit have been installed in Japan.

A Danish unit supplier is active in the gas engine based mini CHP segment.

A number of suppliers promote and sell mini CHP units for natural gas, LPG and/or biogas.

Additional remarks

-

References

1 Mini- og mikrokraftvarme, Teknologi, potentialer og barrierer. Projektrapport, DGC, Oktober 2006.

Data sheets:

Table 5.39 Micro CHP, Gas engine - One family house, existing building

Technology	**Micro CHP - Gas engine One-family house, existing building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	3.2	3.2	3.2		C	2
Electricity generation capacity for one unit (kW)	1	1	1			2
Expected share of space heating demand covered by unit (%)	60-80	60-85	60-85		A	
Expected share of hot tap water demand covered by unit (%)	40-60	40-60	40-65		A	
Electric efficiency, annual average, net (%)	20	22	25			2
Heat efficiency, annual average, net (%)	65	70	70-75			2
Total efficiency, annual average, net (%)	85	92	95-100			2
Technical lifetime (years)	10	> 10	> 10			
Environment						
SO_2 (g per GJ fuel)	0	0	0			
NO_X (g per GJ fuel)	25	15	10		B	1
CH_4 (g per GJ fuel)	< 5	< 5	< 5			1
N_2O (g per GJ fuel)	NA	NA	NA			
Particles (g per GJ fuel)	NA	NA	NA			
Financial data						
Specific investment (1000€/unit)	15	12	10			1, 2
- hereof equipment (%)	70	70	70			
- hereof installation (%)	30	30	30			
Possible additional specific investment (1000€/unit)	0.5-4.5	0.5-4.5	0.5-4.5		A	
Fixed O&M (€/kW/year)	NA	NA	NA			
Variable O&M (€/GJ)	1.0-1.2	1.0-1.2	1.0-1.2			3

References:

1 ASUE-BHKW-Kenndaten2011

2 www.bhkW-forum.info

3 IEA Report, Annex 42, Subtask A FC+COGEN-SIM. 2005.

Notes:

A An auxiliary burner, boiler or electrical heating must supply remaining heat

B EU-EcoDesign proposal: NO_X < 66 g/GJ

C As electrical efficiency is improved over the years, the heat/power ratio declines

Table 5.40 Micro CHP, Gas engine - Apartment complex, existing building

Technology	**Mini CHP - Gas engine Apartment complex, existing building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	25-300	25-300	25-300			1
Electricity generation capacity for one unit (kW)	10-180	12-200	15-220			1
Expected share of space heating demand covered by unit (%)	70-85	70-85	70-85		A	3
Expected share of hot tap water demand covered by unit (%)	50-70	50-70	50-70		A	
Electric efficiency, annual average, net (%)	28-36	30-38	32-40			(1)
Heat efficiency, annual average, net (%)	55-60	55-62	55-64			(1)
Total efficiency, annual average, net (%)	88-91	92-94	95-96			(1)
Technical lifetime (years)	10-15	10-15	10-15			
Environment						
SO_2 (g per GJ fuel)	0	0	0			
NO_X (g per GJ fuel)	20-100	10-80	10-50			
CH_4 (g per GJ fuel)	80-760	50-500	30-250			2
N_2O (g per GJ fuel)	0.4-0.8	< 0.5	< 0.5			2
Particles (g per GJ fuel)	NA	NA	NA			2
Financial data						
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)	25-120 70-80 20-30	25-120 70-80 20-30	25-120 70-80 20-30			(1)
Possible additional specific investment (1000€/kW)	0.2	0.2	0.2		A	
Fixed O&M (€/kW/year)	NA	NA	NA			
Variable O&M (€/GJ)	0.7-1.0	0.7-1.0	0.7-1.0		B	4

References:

1 ASUE-BHKW-Kenndaten2011

2 Emissionskortlægning 2010 DMU/DGC

3 www.ec-power.dk/cases

4 IEA Report, Annex 42, Subtask A FC+COGEN-SIM. 2005.

Notes:

A Supplementary boiler(s) or electrical heating must supply remaining heat

B Maintenance costs twice the number presented are seen (in 2012).

Table 5.41 Micro CHP, Gas engine - One family house, new building

Technology	**Micro CHP - Gas engine** **One-family house, new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	3.2	3.2	3		C	2
Electricity generation capacity for one unit (kW)	1	1	1			2
Expected share of space heating demand covered by unit (%)	70-90	75-95	80-100		A	
Expected share of hot tap water demand covered by unit (%)	40-70	45-80	50-100		A	
Electric efficiency, annual average, net (%)	20	22	25			
Heat efficiency, annual average, net (%)	65	70	70-75			2
Total efficiency, annual	85	92	95-100			2
Technical lifetime (years)	10	> 10	> 10			
Environment						
SO_2 (g per GJ fuel)	0	0	0			
NO_X (g per GJ fuel)	25	15	10		B	1
CH_4 (g per GJ fuel)	< 5	< 5	< 5			1
N_2O (g per GJ fuel)	NA	NA	NA			
Particles (g per GJ fuel)	NA	NA	NA			
Financial data						
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)	15 70 30	12 70 30	10 70 30			1, 2
Possible additional specific investment (1000€/unit)	0.5-4.5	0.5-4.5	0.5-4.5		A	
Fixed O&M (€/kW/year)	NA	NA	NA			
Variable O&M (€/GJ)	1.0-1.2	1.0-1.2	1.0-1.2			3

References:

1 ASUE-BHKW-Kenndaten2011

2 www.bhkW-forum.info

3 IEA Report, Annex 42, Subtask A FC+COGEN-SIM. 2005.

Notes:

A An auxiliary burner, boiler or electrical heating must supply remaining heat

B EU-EcoDesign proposal: NO_X < 66 g/GJ

C As electrical efficiency is improved over the years, the heat/power ratio declines

Table 5.42 Micro CHP, Gas engine - Apartment complex, new building

Technology	**Mini CHP - Gas engine Apartment complex, new building**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat production capacity for one unit (kW)	10-150	10-150	10-150			1
Electricity generation capacity for one unit (kW)	4-100	5-110	6-120			1
Expected share of space heating demand covered by unit (%)	75-90	75-90	75-90		A	
Expected share of hot tap water demand covered by unit (%)	50-70	50-70	50-70		A	
Electric efficiency, annual average, net (%)	24-34	26-36	28-38			(1)
Heat efficiency, annual average, net (%)	55-65	55-68	55-70			(1)
Total efficiency, annual average, net (%)	88-90	91-94	93-98			(1)
Technical lifetime (years)	10-15	10-15	10-15			
Environment						
SO_2 (g per GJ fuel)	0	0	0			
NO_X (g per GJ fuel)	20-100	10-80	10-50			1
CH_4 (g per GJ fuel)	80-760	50-500	30-250			2
N_2O (g per GJ fuel)	0.4-0.8	< 0.5	< 0.5			2
Particles (g per GJ fuel)	NA	NA	NA			2
Financial data						
Specific investment (1000€/unit) - hereof equipment (%) - hereof installation (%)	12-100 70 30	12-100 70 30	12-100 70 30			1
Possible additional specific investment (1000€/kW)	0.2	0.2	0.2		A	
Fixed O&M (€/kW/year)	NA	NA	NA			
Variable O&M (€/GJ)	0.7-1.0	0.7-1.0	0.7-1.0		B	3

References:

1 ASUE-BHKW-Kenndaten2011

2 Emissionskortlægning 2010 DMU/DGC

3 IEA Report, Annex 42, Subtask A FC+COGEN-SIM. 2005.

Notes:

A Supplementary boiler(s) or electrical heating must supply remaining heat

C Maintenance costs twice the number presented are seen (in 2012)

5.17 District heating network

Brief technology description

A district heating (DH) network is used for transportation of heat produced centrally to residential and commercial consumers. The heat can for instance be produced at a central combined heat and power plant (CHP), a central heat boiler, a central heat pump or a central solar heating unit.

The heat is most often used for space heating and hot tap water, but can also be used for industrial purposes or for producing cooling in absorption coolers. The central production of heat allows for a very efficient heat production - for instance by producing heat in cogeneration with electricity at small-scale and large-scale CHP plants.

A DH system can vary in all sizes from covering a large area as for instance the Greater Copenhagen DH system to a small area or village consisting of only a limited number of houses.

In large DH systems, the DH network may consist of both a transmission network (transporting heat at high temperature/pressure over long distances) and a distribution network (distributing heat locally at a lower temperature/pressure).

The large development of district heating in Denmark took place up through the 1980s and 1990s, and today the use of district heating is very widespread. In the large cities as for instance Copenhagen and Aarhus, the central power plants are all CHP plants producing district heating in cogeneration with electricity. Until now, the fuels used for heat production at these large plants have mainly been coal and natural gas. However, in the resent years, some of the large CHP plants have been converted to biomass, and it is expected that more of the large central CHP plant will be converted in the years to come.

Also in a large number of minor cities around Denmark, the heat supply is based on district heating. In these areas, the heat is produced at heat boilers or small-scale CHP plants, and the fuels used are mainly natural gas and biomass.

According to the latest energy statistics published by the Danish Energy Agency (ref. 1), district heating substations make up 61.7 % of the total number of heat installations in Denmark in 2010.

In line with phasing out of fossil fuels including also natural gas, there is a possibility that district heating will make up an even larger share of the total heat supply in future. However, this will depend on the competitiveness of district heating compared to individual heat solutions as well as the possibilities of e.g. using the gas infrastructure for renewable energy gases instead of natural gas.

Input

Input to the DH network is heat from e.g. a CHP plant or a heat boiler. It can also be surplus heat from an industry etc.

Output

The output from the network is heat (same as the input). The amount of heat that comes out is, however, less than the amount of heat delivered to the network due to network losses. The network loss is in particular dependent on the distance of the network and varies a lot from one system to another. Typical network losses are in the range of 15-20 % (based on ref. 2, where the average loss can be calculated to be 17%). The loss can be down to app. 7 % (ref. 2) in very large systems like in Greater Copenhagen and up to 50 % in systems of very poor conditions.

Typical capacities

The capacities of a DH network can be of all sizes depending on the size of the area. For instance, the annual heat demand in the Greater Copenhagen DH system is more than 30 PJ, whereas some small DH areas have an annual heat demand of less than 10 TJ, which is more than a factor 3,000 less.

Regulation ability

Often, in existing DH systems, the supply temperature is 60-80 °C, and the return temperature is about 40 °C. Typically, the temperatures vary a bit during the year. The regulation of the network takes place by regulating (increasing or decreasing) the flow of water.

Advantages/disadvantages

The main advantage of district heating compared to individual heat solutions is the economics of scale (economy and performance) of the production unit. Furthermore, district heating allows for producing heat in co-generation with electricity (CHP), which contributes even further to both the economy and the performance.

District heating allows for different production units in the same network, which again allows for flexible operation of the units.

District heating makes it possible to utilise waste, deep geothermal heat and surplus heat from industries - energy sources which can not be used for individual heat solutions.

If district heating is produced at CHP plants or at large heat pumps, and the DH network is connected to heat storages, district heating can give flexibility to the electricity network and help e.g. integrating more wind power. This happens already today and will be of even more importance in future as one among other Smart Grid solutions.

District heating is a flexible system in which the heat production technology can be replaced relatively easily in case of another technology being more economic or environmentally feasible etc.

Finally, district heating is a reliable technology with easy operation for the heat consumers.

The disadvantages of district heating are the relatively high costs of establishing the DH networks, the network losses and the need for electricity for pumping water through the pipes.

Environment

The establishment of DH networks allows for a very efficient heat production with relatively low fuel consumption and relatively low emissions depending on the type of fuel used.

Research and development

During the last couple of years, the concept of low-temperature district heating (LTDH) has been developed, tested and demonstrated. In these developing projects, LTDH has been defined as having a supply temperature of 50°C and a return temperature of 25-30°C at the consumer. In minor networks, these temperatures will require a supply temperature at the heat central of 52-55°C.

However, LTDH concept is not only about the district heating temperatures. It is also crucial that the whole system has an optimised design, where the network heat loss is minimised by using twin-pipe system, having small service pipes and a large insulation thickness.

The advantages of LTDH are that the network heat loss is lowered, which gives energy savings and lower fuel costs. Furthermore, the lower network temperatures make it possible to use a larger range of heat sources including more renewable energy sources and surplus heat from industrial processes etc.

If the LTDH is connected to an existing network, a mixing shunt or a heat exchanger station is required to throttle down the district heating temperature.

LTDH is not considered to be more expensive to build than conventional DH. Opposite, LTDH may be a bit cheaper.

Full-scale demonstration has proven that LTDH is suitable for low-energy houses.

Examples of best available technology

Twin pipes shall be used instead of single pipes, because this ensures lower heat losses and lower construction costs. A twin pipe consists of two service pipes, a supply and a return pipe, in the same casing.

In small dimensions (Ø14-14 - Ø40-40 mm), flexible pipes are preferable, whereas in larger dimensions (Ø27-27 - Ø219-219 mm), steel pipes will be necessary. In very large dimensions (> Ø219-219) like for transmission lines or large distribution lines, twin pipes are not available.

Flexible pipes are made of materials that make it possible easily to install the pipes within some maximum bending angles. The service pipe is typically a plastic (PEX) pipe and can be supplied with an aluminium layer to ensure diffusion tightness. Flexible twin pipes can also have a service pipe consisting of copper, and flexible single pipes are available with service pipes of (cold-rolled) steel.

Both flexible pipes and straight pipes are recommended with diffusion barrier between the insulation and the outer polyethylene (PE) casing in order to keep thermal conductivity low and unchanged over time.

An example of a steel twin pipe and a flexible twin pipe is shown in the figure below.

Figure 5.22 Example of district heating twin pipes. A steel pipe twin pipe (DN50) 60-60/225 mm (left) and a flexible pipe 14-14/110 mm

Additional remarks

The net loss is defined as the loss in percent of the heat delivered to the network. If the loss is 20 % and the heat delivered to the grid is 100 TJ, the heat at the consumer (consumption excluding network losses) is 80 TJ.

References

1 Annual Energy Statistics 2010.

2 Danish District Heating Association (Dansk Fjernvarme) Benchmarking Statistic 2010/11.

3 COWI.

Data sheets:

The data sheets are presented overleaf for the following four different combinations of DH technology and building area:

- Conventional DH network - existing building area.
- Low-temperature DH network - existing building area.
- Conventional DH network - new building area.
- Low-temperature DH network - new building area.

For all combinations, the following should be noted:

- Branch pipe[7] heat loss is included in the total heat loss.
- Branch pipe investment costs are not included in the total investment costs. These costs are included in the costs of the DH unit (see section 5.3) and are expected to be around 3,000 EUR on average per branch pipe.
- For all four combinations, it is assumed that all buildings in the area will be connected to the DH network. In practice, this is not always the case, but a main pipe should be dimensioned for that. If not all consumers are connected to the DH network, the main pipe may be oversized. However, this will not lead to significant extra costs or significantly increased heat loss unless it is consumers with large heat demands like industry or apartment houses etc. that are not connected.
- The pump energy is in MWh electricity per TJ heat **ab plant** per year.
- The investment costs are in 1,000 EUR per TJ heat **ab plant**.
- The fixed O&M costs are in EUR per TJ heat **ab plant** per year.

[7] The branch pipe is the pipe from the DH network to the building. Branch pipes are considered to be part of the DH unit, i.e. the building installation. However, with regard to losses, the branch pipe loss is included in the total DH network loss.

Conventional DH network - existing building area

This scenario is based on a conventional DH network designed to an urban area with existing buildings which have a higher heat demand than new buildings. The network heat loss is large in absolute terms, but since the heat demand is also large, the heat loss in percentage is not particularly high.

The scenario is based on a conventional DH network design, but with twin pipes. If it had been a single-pipe system, the network heat loss and the heat density ab plant could have been even higher.

Table 5.43 Conventional DH network - existing building area

Technology	Conventional DH network - existing building area					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat density an consumer (TJ/km^2 land area)	120	120	120	120	A	1
Net loss (%)	15	15	15	15	B	1
Heat density ab plant (TJ/km^2 land area)	141	141	141	141	A	1
Pump energy (MWh/TJ/year)	0.2-4	0.2-4	0.2-4	0.2-4		2
Technical lifetime (years)	30-50	30-50	30-50	30-50		3
Financial data						
Investment costs (1,000 € per TJ)	18-22	18-22	18-22	18-22	C	1
Fixed O&M (€/TJ/year)	250	250	250	250		4

References:

1 District heating system in Gentofte, 2011.

2 Based on COWI experience figures and Danish District Heating Association (Dansk Fjernvarme) Benchmarking Statistic 2010/11.

3 LOGSTOR A/S.

4 COWI experience figures.

Notes:

A Based on an area with 1400 (old and relatively large) single-family houses with a total heat demand of 229 TJ/year excluding network losses. Twin-pipe network with a total length of 17.500 m including branch pipes.

B Use of single pipes would lead to a higher heat loss.

C Excluding branch pipes. Including main network pipes (twin pipes, earthwork and pipe work).

Low-temperature DH network - existing building area

This scenario is based on a conventional DH network design to an urban area with new buildings. The heat demand in the buildings is low compared to existing buildings, so the conventional network design with higher DH temperatures gives rise to a relatively low network heat loss.

The scenario is based on a twin-pipe system.

Table 5.44 Low temperature DH network - existing building area

Technology	**Low-temperature DH network - existing building area**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat density an consumer (TJ/km^2 land area)	45-50	45-50	45-50	45-50	A	1
Net loss (%)	13-16	13-16	13-16	13-16	B	1, 2
Heat density ab plant (TJ/km^2 land area)	54-56	54-56	54-56	54-56	A	1
Pump energy (MWh/TJ/year)	1-4	1-4	1-4	1-4	C	1, 2
Technical lifetime (years)	30-50	30-50	30-50	30-50		3
Financial data						
Investment costs (1,000 € per TJ)	135-155	135-155	135-155	135-155	E	1
Fixed O&M (€/TJ/year)	1000-1200	1000-1200	1000-1200	1000-1200		4

References:

1 District heating system in Sønderby, Høje Taastrup, 2011.

Part of "Energistyrelsen - EUDP 10-II Full scale demonstration of low temperature district heating in existing buildings". Journal no.: 64010-0479. Danish Energy Agency. Project period: January 2011-December 2013.

2 District heating system in Lærkehaven II, Lystrup, 2010.

Energistyrelsen - EUDP 2008-II, CO2-reductions in low energy buildings and communities by implementation of low temperature district heating systems. Demonstration cases in EnergyFlexHouse and Boligforeningen Ringgården, Journalnr. 63011-0152. May 2011.

3 LOGSTOR A/S.

4 COWI experience figure.

Notes:

A Based on 75 single-family houses (from 1997-98) with heat demand of 3,7 TJ/year excluding network heat loss. Twin pipe network with a total length of 2.800 m including branch pipes.

B Includes only heat loss up to the mixing shunt. Heat loss in the further distribution and transmission lines could add a couple of %.

C Can vary a lot. Not many statistics are available.

D It is a small system compared to scenario "Conventional DH network - existing building area"

E Excluding branch pipes. Including main network pipes (twin pipes, earthwork and pipe work), booster pump, mixing shunt, valves, metering equipment etc.

Conventional DH network - new building area

This scenario is based on a conventional DH network design to an urban area with new buildings. The heat demand in the buildings is low compared to existing buildings, so the conventional network design with higher DH temperatures gives rise to a relatively low network heat loss.

The scenario is based on a conventional DH network design with a twin-pipe system. Please notice that single-pipes are used in large dimensions, and in some networks, single-pipes are still used also in smaller dimensions. Compared to twin-pipes, routing with single-pipes will have a higher heat loss and consequently also a higher heat density ab plant.

Table 5.45 Conventional DH network - new building area

Technology	**Conventional DH network - new building area**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat density an consumer (TJ/km^2 land area)	20-48	20-48	20-48	20-48	A	1, 2
Net loss (%)	27-37	27-37	27-37	27-37	B	1, 2
Heat density ab plant (TJ/km^2 land area)	28-72	28-72	28-72	28-72	A	1, 2
Pump energy (MWh/TJ/year)	0.5-2	0.5-2	0.5-2	0.5-2	C	1, 2
Technical lifetime (years)	30-50	30-50	30-50	30-50		3
Financial data						
Investment costs (1,000 € per TJ)	100-160	100-160	100-160	100-160	E	1, 2
Fixed O&M (€/TJ/year)	800-1,350	800-1,350	800-1,350	800-1,350		4

References:

1 District heating system in Lærkehaven II, Lystrup, 2010.

Part of "Energistyrelsen - EUDP 2008-II, CO2-reductions in low energy buildings and communities by implementation of low temperature district heating systems. Demonstration cases in EnergyFlexHouse and Boligforeningen Ringgården, Journalnr. 63011-0152. May 2011!"

2 Energistyrelsen - EFP2007 "Udvikling og demonstration af lavenergifjernvarme til lavenergibyggeri". ("Development and demonstration of low-energy district heating for low-energy buildings"). Journal no.: 033001/33033-015. Danish Energy Agency. Marts 2009.

3 LOGSTOR A/S.

4 COWI experience figure.

Notes:

A Based upon specific data for low-energy buildings. The low heat density refers to an area with 92 single-family houses with heat demand of 2.23 TJ/year. Single pipe network with a total length of 3200 m including branch pipes. The high heat density refers to a group of terraced houses (41 dwellings) with heat demand of 0,85 TJ/year. Single-pipe network with a total length of 725 m including branch pipes. Values for apartment houses and industrial areas can be very different.

B Includes only heat loss up to the mixing shunt. Heat loss in the further distribution and transmission lines could add a couple of %. Conventional network design results in a relatively high heat loss.

C May vary a lot. Not many statistics are available.

D It is a small system compared to scenario "Conventional DH network - existing building area".

E Excluding branch pipes. Including main network pipes (twin pipes, earthwork and pipe work). Low costs refer to minimum costs for the high heat density in the table. High costs refer to maximum costs for the low heat density in the table.

Low-temperature DH network - new building area

This scenario is based on a low temperature DH network design for an urban area with new buildings. The heat demand in the buildings is low compared to existing buildings, but with a low-temperature DH design, it is possible to achieve a relatively low network heat loss.

The scenario is based on a twin-pipe system.

Table 5.46 Low-temperature DH network - new building area

Technology	**Low-temperature DH network - new building area**					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Heat density an consumer (TJ/km^2 land area)	20-48	20-48	20-48	20-48	A	1, 2
Net loss (%)	15-17	15-17	15-17	15-17	B	1, 2
Heat density ab plant (TJ/km^2 land area)	25-56	25-56	25-56	25-56	A	1, 2
Pump energy (MWh/TJ/year)	2-5	2-5	2-5	2-5	C	1
Technical lifetime (years)	30-50	30-50	30-50	30-50		3
Financial data						
Investment costs (1,000 € per TJ)	120-200	120-200	120-200	120-200	E	1, 2
Fixed O&M (€/TJ/year)	1000-1550	1000-1550	1000-1550	1000-1550		4

References:

1 District heating system in Lærkehaven II, Lystrup, 2010.

Part of "Energistyrelsen - EUDP 2008-II, CO2-reductions in low-energy buildings and communities by implementation of low-temperature district heating systems. Demonstration cases in EnergyFlexHouse and Boligforeningen Ringgården, Journalnr. 63011-0152. May 2011!"

2 Energistyrelsen - EFP2007 "Udvikling og demonstration af lavenergifjernvarme til lavenergibyggeri". ("Development and demonstration of low-energy district heating for low-energy buildings"). Journal no.: 033001/33033-015. Danish Energy Agency. Marts 2009.

3 LOGSTOR A/S.

4 COWI experience figure.

Notes:

A Based upon specific data for low-energy buildings. The low heat density refers to an area with 92 single-family houses with a heat demand of 2,23 TJ/year. Twin pipe network with a total length of 3200 m including branch pipes. The high heat density refers to a group of terraced houses (41 dwellings) with heat demand of 0,85 TJ/year. Twin pipe network with a total length of 725 m including branch pipes. Values for apartment houses and industrial areas can be very different.

B Includes only heat loss up to the mixing shunt. Heat loss in the further distribution and transmission lines could add a couple of %. Conventional network design results in a relatively high heat loss.

C May vary a lot. Not many statistics are available.

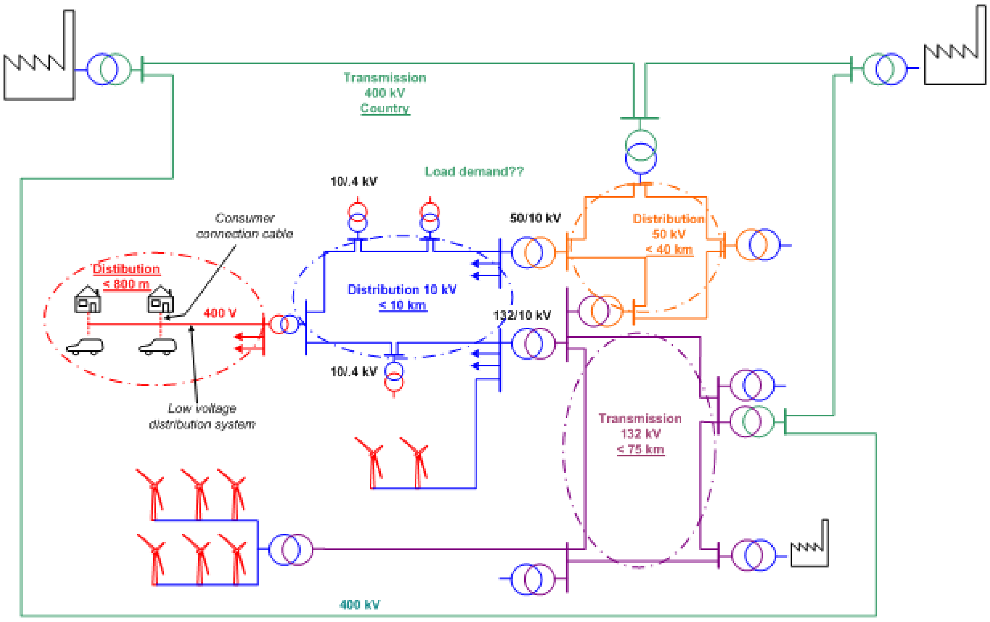
D It is a small system compared to scenario "Conventional DH network - existing building area".

E Excluding branch pipes. Including main network pipes (twin pipes, earthwork and pipe work), booster pump, mixing shunt, valves, metering equipment etc. Low costs refer to minimum costs for the high heat density in the table. High costs refer to maximum costs for the low heat density in the table.

5.18 Electrical grid

Brief technology description

The term electrical grid refers to the transmission and distribution network as shown in the figure below.



Note: The voltage levels in the figure may differ from one electrical grid to another. The voltage levels shown in the figure are the ones used in Eastern Denmark which differ from the voltage levels in Western Denmark.

Figure 5.23 Illustration of electrical grid

In a traditional system, the power is mainly generated at central units, e.g. at large central power and CHP plants. The generated power is stepped up to the relevant voltage level, e.g. 400 kV, and delivered to the transmission network.

The transmission network transports electricity over long distances within a country or between countries (cross-border interconnections). The transmission system makes it possible to make an optimal power dispatch between power generators with different characteristics, e.g. thermal power plants and hydro power. The reason why electricity is transported over long distances at a high voltage level is that the losses are lower than if transported at a lower voltage level. The transmission grid also provides a reliable power supply for the regions when local power plants are out of operation due to maintenance or breakdown.

The power is stepped down from the transmission network to a lower voltage level and distributed locally by the distribution network. When the electricity reaches the point of consumption, the voltage level is stepped down further in accordance with the requirements at the end user, e.g. to 400 V.

The stepping up and down of voltage levels is done by use of transformers. The components in the transmission and distribution network thereby mainly consist of overhead lines, cables, transformers and switch gear.

During the last decades, the Danish power system has been more and more decentralised. The introduction of small-scale CHP plants and wind turbines means that today a large part of the generated electricity is delivered to the network at a lower voltage level (transmission or distribution) than the overall transmission level. There is a possibility that the power system will be even more decentralised in future, e.g. by installing more "distributed generators" such as solar PV and micro CHP units.

Input

Input to the transmission network is electricity from e.g. large centralised power plants or large offshore wind-parks. It can also be electricity from a neighbouring transmission network, e.g. Sweden, Norway or Germany.

Input to the distribution network is electricity from the transmission network or from decentralised power generators as for instance small-scale CHP plants or wind turbines.

Output

The output from both the transmission and distribution network is electricity (same as the input). The amount of electricity that comes out is, however, less than the amount of electricity that is delivered to the grid due to network losses. In Denmark, the transmission loss is approximately 1-2 %, whereas the distribution loss is approximately 5 %.

Typical capacities

The voltage level of a transmission network is typically in the range of 132-400 kV. The voltage level of a distribution network is typically in the range of 0.4-60 kV.

The capacities in the transmission network are typically from 100 MW to around 2,000 MW. The capacities in the distribution network are typically from 50 kW to 100 MW.

Regulation ability

Transmission and distribution networks can regulate very fast, and the regulation ability in the electrical grid is therefore not limited by the regulation ability in the network. Instead, the regulation ability is limited by the regulation ability at the generators. In case of flexible demand, the consumers may contribute to increased regulation ability in the system (see also under research and development).

Advantages/disadvantages

Transmission of power through overhead lines, cables and transformer components imposes energy losses. However, the transmission network constitutes the backbone of the power system and provides supply reliability and allows an optimal power dispatch among power generators.

Environment

In future, the visual environmental impact from the transmission and distribution network will be limited to the appearance of the 400 kV overhead lines outside the cities as it has been decided to undergrounding all lines from 150 kV and below (ref. 1).

Sulphur hexafluoride (SF_6 gas) is used as insulation medium in transmission network components. If emitted, this is a very aggressive greenhouse gas. Historically, SF_6 emissions have, however, only accounted for about 0.1 % of total Danish greenhouse gas emissions calculated as CO_2 equivalents.

The risk of developing cancer as a result of magnetic field exposure from electric circuits has been discussed without any substantial conclusions.

Research and development

In Denmark and many other countries, there is a lot of research and development within "Smart Grid". There are numerous descriptions and definitions of what a Smart Grid is. A definition proposed by the 'European Technology Platform' states that Smart Grid is electricity networks that can intelligently integrate the behaviour and actions of all users connected to it - generators, consumers and those that do both - in order to efficiently deliver sustainable, economic and secure electricity supplies. A central element in the Smart Grid solution is to activate consumers so not only generators but also consumers contribute to the regulation of the electricity system. As an example, a Smart Grid component could be a local distribution network with intelligent electric meters that communicate with the overall system and ensure that e.g. electric vehicles and heat pumps consume electricity when prices are lowest, e.g. at times with large power generation from wind turbines.

Examples of best available technology

The development of cable types from paper insulated (old technology) to polymer insulated (new technology) at higher voltage levels (now up to 400 kV) has made it technologically and financially feasible to establish underground cable systems instead of overhead lines. Furthermore, the operation of underground cable systems has proven to be much more reliable than overhead lines since the impact from storms, ice and lightning phenomena is eliminated.

Additional remarks

An increase in load demand from some consumers, e.g. because of the installation of heat pumps or battery charging devices for electric vehicles will occupy capacity in both the distribution network and the transmission network and introduce a future need for network reinforcement.

Due to the complexity in planning of the distribution and transmission network, which is done by the responsible utilities, and the different conditions from one specific situation to another, it is not possible to describe any standard outline. Reinforcement and upgrading of the networks is always a successive process taking into consideration reliability, the conditions of the existing network, and long-term load forecasts in a 5-20 year planning timeframe. However, a rough indication of the costs related to reinforcement and upgrading of the network can be assessed from the standard connection fees collected by the various distribution companies. It can be assumed that these fees more or less reflect the total costs of making reinforcements in the transmission and distribution network.

References

1. Cable action plan, Energinet.dk, March 2009.

Data sheets:

Table 5.47 Electrical grid

Technology	Electrical grid					
	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Typical voltage level, transmission (kV)	132-400	132-400	132-400	132-400		
Typical voltage level, distribution (kV)	0,4-60	0,4-60	0,4-60	0,4-60		
Typical capacity, transmission (MW)	100-2,000	100-2,000	100-2,000	100-2,000		
Typical capacity, distribution (MW)	50-100	50-100	50-100	50-100		
Total network loss, transmission and distribution (%)	7	7	6	6	B	
Technical lifetime (years)	40-50	40-50	40-50	40-50		
Construction time (years)	1-5	1-5	1-5	1-5		
Financial data						
Investment costs (€/kW)	110-220	110-220	110-220	110-220	A	1
Fixed O&M (€/MW/year)	NA	NA	NA	NA		

References:

1 Web sites from DONG Energy, SEAS-NVE and EnergiMidt.

Notes:

A The stated investment cost is the grid connection fee collected by the electricity companies for 1 ampere of electricity (converted to EUR/kW). It is assumed that this fee more or less reflects the total costs of making reinforcements in the electrical grid. If a city area for instance establishes 500 heat pumps with a power consumption of up to 3 kW each, the need for additional power capacity will be up to 1,500 kW depending of the **demand factor**:

Need for additional power capacity = 500 * 3 kW * demand factor (%)

If the demand factor for instance is 50 %, the necessary additional capacity will be 500 * 3 kW * 50 % = 750 kW corresponding to a reinforcement cost of 82,500 - 165,000 EUR.

The demand factor should be evaluated depending on the specific consumption, number of unit, and depending on how the units are operated. If a certain number of units are installed (e.g. heat pumps or electric vehicles), it may be reasonable to use a demand factor of 50 % or even less. However, if for instance heat pumps are operated according to dynamic electricity prices (smart grid), they may all start when the electricity price is low, and thereby the demand factor can be high even though the number of units is also high. This is not optimal from an electrical grid perspective, but it is optimal from a generator perspective, e.g. in relation to incorporating wind power.

B In the transmission network, losses are influenced by the exchange with neighbouring countries. High levels of exchange and transit result in substantial losses. The average transmission loss (1-2 %) is expected to be more or less constant during the period. At the distribution level, there is a possibility that the share of "distributed generation" will increase in future and that this will result in a reduction in the distribution losses.