50 HEAT PUMPS

Brief description
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 ambient (input heat) and convert the heat to a higher temperature (output heat) through a closed process; either compressor heat pumps (using electricity) or absorption heat pumps (using heat; e.g. steam, hot water or flue gas).

Heat pumps serve different purposes, e.g. industrial purposes, individual space heating, heat recovery and district heat production. Today all small heat pump systems used for individual space heating are driven by electricity. Large heat pump systems are primarily dimensioned from an appraisal of the actual demand.

With low temperature levels of the heat source and the delivered heat, the heat output will be 2 to 5 times (the coefficient of performance) the drive energy. It is not possible to make general formulas for calculating the coefficient of performance (COP) since the efficiency of the systems can vary significantly depending on the compressor type etc. The theoretical COP is given by the temperature of the input and output heat:

$$COP = \frac{Heat\ output}{Energy\ input} = \frac{T_{hot}}{T_{hot} - T_{cold}}$$

both temperatures given in degrees Kelvin (^{o}K = °C + 273.15)

For example, with a hot temperature of 80°C and a cold temperature of 10°C the theoretical COP is 5.0. In all practical appliances the COP will be lower because of losses in the system, typically around 50-65% of the theoretical COP.

In Denmark the heat source is primarily renewable energy, i.e. accumulated solar heat in top soil layers, in ambient air, in lakes, streams or sea water. Also waste heat from industrial processes can directly or in connection with heat recovery be utilized as heat source.

Absorption heat pumps can in principle deliver temperatures up to 94 ^{o}C, but to avoid instability the temperature should not exceed 85-87 ^{o}C (ref. 4).

Input
A heat source (e.g. ambient air, water or ground, or waste-heat from an industrial process) and energy to drive the process. Typical Danish temperatures are 0-18 °C as ground temperature and 5-10 $^{\circ}$C as groundwater temperature. Compressor heat pumps are driven by electricity or engines, whereas absorption heat pumps are driven by heat; e.g. steam, hot water or flue gas, but also consume a small amount of electricity.

Output
Heat.

Typical capacities
The capacity of small heat pumps is 0.5 to 25 kJ/s heat output. Large heat pumps are available from 25 kW to 3-5 MJ/s heat output. Larger heat pumps than 3-5 MJ/s will typically be a number of heat pump units in a serial connection.

Regulation ability
The use of heat pumps can be beneficial for the overall electricity system in converting electricity to heat at high efficiencies in times of surplus electricity generation. This feature becomes increasingly valid, when more intermittent renewable energy generators are present in the power system.

Small heat pumps have previously been operated in on/off-mode, but recently some air/air and liquid/water heat pumps have been introduced with regulation ability; typically 30-150% (i.e. up to 50% above rated capacity). In ten years time, a regulation of 10-200% is expected. Regulating up to 150-200% is only possible for shorter intervals, but could be used for peak demand. However, operation above rated capacity shortens the lifetime of the heat pumps.

Large heat pumps are usually regulated continuously and instantly. In starting from cold, electricity consumption is full load instantly.

Research and development
The phasing out of the ozone depleting refrigerants CFC and HCFC from the heat pump market has been agreed internationally. The heat pump industry has introduced refrigerants, which are not ozone depleting. These are among others hydrocarbons (propane, butane and iso-butane), carbon dioxide, ammonia, and water. The use of these refrigerants does not decrease the energy efficiency, on the contrary if anything. It is primarily the so called HFC refrigerants that have been developed to replace the CFC and HCFC refrigerants, but the HFC's contribute to global warming and therefore work has been initiated in order to make sure that these also are phased out. From 2007 it is not allowed to use more than 10 kg of synthetic refrigerant in cooling or heat pump installations in Denmark. Therefore, natural refrigerants must be used in larger heat pump installations. Ammonia is limited to a maximum temperature of 70 °C. For higher temperatures CO_2 is the only option at the current stage of technological development.

Besides the further development of environmentally neutral refrigerants it is expected that technology development will focus on:

- Increase the efficiencies of all types of heat pump systems.
- Use of heat pumps combined with combined heat and power production.
- Optimise the benefits for the overall electricity system of using heat pumps.
- Further development of heat pumps driven by natural gas.

Advantages/disadvantages compared to other technologies
A general advantage of heat pumps is that the heat pump is able to utilize energy at a low temperature level. Additionally the heat pump is flexible concerning use of renewable energy, waste and surplus heat. The combined utilization of a heat source at a low temperature level and the use of for example gas as driving power enables more effective resource utilization compared with conventional heat production technologies.

Compared with traditional heating technologies, heat pumps are relatively expensive in investments costs. However, this is counterbalanced with considerable savings in operating costs.

Environment
Harmless refrigerants are currently replacing the former previous refrigerants at large scale.

As heat pumps need drive energy (electricity, oil or gas) the environmental impact from using heat pumps stems from the production and use of the drive energy.

Additional remarks
The data for ‘hot’ heat pumps is based on a heat source of 35°C; otherwise the average outdoor temperature is used as heat source. If other heat sources are used e.g. in connection with decentralised CHP systems, the COP values would be considerably higher. This could be heat sources such as flue gas cooling, heat from intercooler or waste heat from gas engines.

For large compressor heat pumps the most probable refrigerants to be used in large heat pumps in the future will be NH_3 and CO_2. However, due to the condensation temperature of NH_3 (normally up to about 60°C) only CO_2 can be used for applications with higher temperatures (up to about 90^{o}C). Danish district heating systems typically employ a supply temperature of 75°C or higher. Heat pumps using NH_3 are well tested and commercially available, whereas CO_2 heat pumps are still a new technology.

A NH_3 heatpump may be 30-40% cheaper in investment (M€ per MJ/s delivered) than a CO_2 heat pump, but it cannot deliver a supply temperature much above 55^{o}C.

Concerning financial data mentioned in the data sheets, the span of investment costs and O&M costs is expected to cover the future. Investment costs are not expected to fall and O&M costs may increase slightly in the future.

The total investment cost of a CO_2 heat pump is comprised of (ref. 2):

Heat pump:	55-60%.
Container (no building):	3 %
Connections and other costs:	35-40%.

Based on a single case, the total investment cost of an absorption heat pump for flue gas condensation is comprised of (ref. 5):

Heat pump:	50%.
Pipe connections:	12%
Chimney anti-corrosion:	13%
Other costs:	25%.

In this case, there was already a steel chimney. This needed anti-corrosive protection.

Reference

1. Danish Technology Institute, 2003, 2004 & 2005
2. Advansor, 2009
3. Presentation “Varmepumper i ATES”, DONG Energy, March 2009.
4. DONG Energy, October 2009.
5. Vestforbrænding, November 2009.

Data sheets

The following types and sizes are covered in this technology sheet:

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

Technology	**Large heat pumps, electric (heat source: ambient temperature)**					
	2010	**2020**	**2030**	**2050**	**Note**	**Ref**
Energy/technical data						
Generation capacity for one unit (MJ/s heat)	**1-10**					
Coefficient of performance	2.8	2.9	3	3.2	A	1,2
Forced outage (%)						
Planned outage (weeks per year)						
Technical lifetime (years)	20	20	20	20		1,2
Construction time (years)	0.5-1	0.5-1	0.5-1	0.5-1		1,2
Environment						
Refrigerants	neutral				A	
Financial data						
Specific investment (M€ per MJ/s heat out)	0.5-0.8	0.45-0.75	0.4-0.7	0.35-0.65	C	1,2
Total O&M (€ per MJ/s heat out per year)	3500-7000	2300-4700	2300-4700	2300-4700	B	1

References:

1 Advansor 2009

2 "Varmepumper og lavtemperaturfjernvarme. Rapportering fra to workshops. Delrapportering fra EFP projekt: Effektiv fjernvarme i fremtidens energisystem" (heat pumps and low temperature heat, workshop reports in Danish), Ea Energianalyse A/S, Risø DTU, og RAM-løse edb og Dansk Fjernvarmes visionsudvalg, 2009.

Notes:

A It is assumed that CO2 is used as refrigerant. Supply temperature about 80C.

B A typical service contract is estimated 2,000-3,000 €/year, for the larger sizes. Furthermore an overall check is needed for every 10000 hrs of operation costing approximately 1500 € per MJ/s out.

C These costs include pipes, electrical system, installation etc. It does not include buildings or storage tanks. The heat pumps alone would cost between 0.3 and 0.5 M€ per MJ/s heat out.

Technology	Large heat pumps, electric (heat source: 35 C)					
	2010	**2020**	**2030**	**2050**	**Note**	**Ref**
Energy/technical data						
Generation capacity for one unit (MJ/s heat)	**1-10**					
Coefficient of performance	3.6	3.7	3.8	3.8	A	1,2
Forced outage (%)						
Planned outage (weeks per year)						
Technical lifetime (years)	20	20	20	20		1,2
Construction time (years)	0.5-1	0.5-1	0.5-1	0.5-1		1,2
Environment						
Refrigerants	neutral				A	
Financial data						
Specific investment (M€ per MJ/s heat out)	0.45-0.85	0.4-0.8	0.35-0.75	0.3-0.7	C	1,2
Total O&M (€ per MJ/s heat out per year)	3500-7000	2300-4700	2300-4700	2300-4700	B	1

References:

1 Advansor 2009

2 "Varmepumper og lavtemperaturfjernvarme. Rapportering fra to workshops. Delrapportering fra EFP projekt: Effektiv fjernvarme i fremtidens energisystem" (heat pumps and low temperature heat, workshop reports in Danish), Ea Energianalyse A/S, Risø DTU, og RAM-løse edb og Dansk Fjernvarmes visionsudvalg, 2009.

Notes:

A It is assumed that CO2 is used as refrigerant. Supply temperature about 80C.

B Electricity consumption is excluded. A typical service contract is estimated 2,000-3,000 €/year, for the larger sizes. Furthermore an overall check is needed for every 10000 hrs of operation costing approximately 1500 € per MJ/s heat out.

C These costs include pipes, electrical system, construction etc. The heat pumps alone would cost between 0.3 and 0.5 M€ per MJ/s heat out.

Technology	Large heat pumps, absorption (flue gas condensation)					
	2010	**2020**	**2030**	**2050**	**Note**	**Ref**
Energy/technical data						
Generation capacity for one unit (MJ/s heat)	**2-15**					
Coefficient of performance	1.7	1.75	1.8	1.85	A	1+2
Technical lifetime (years)	20	20	20	20		
Construction time (years)	0.5-1	0.5-1	0.5-1	0.5-1		
Environment						
Refrigerants	Ammonia - LiBr					
Financial data						
Specific investment (M€ per MJ/s heat out)	0.35-0.40					3+4
Total O&M (€ per MJ/s heat out per year)	15-20000				B	4

References:

1 Vestforbrænding presentation, Danish Committee for Waste (DAKOFA) conference, December 2007.

2 DONG Energy, October 2009.

3 "Total udnyttelse af energien i Bjerringbro" (total energy utilization in Bjerringbro; in Danish), Fjernvarmen (Danish periodical for district heating), no. 1, 2008.

4 Vestforbrænding, November 2009.

Notes:

A Heat pumps used in connection with flue gas condensation to increase overall efficiency of MSW and biomass plants. Condensation heat from the flue gas is used as heat input to raise the district heating temperature from 40-60 C to about 80 C.

B 5% of initial investment per year. Almost all O&M cost is for for discharging the condensate water. However, at Vestforbrænding (incinerator) this cost is zero, since all condensate water is reused in an acid scrubber for flue gas cleaning (ref. 4). Cost of cleaning the condensate water before discharge is not included. Manpower to operate the heatpump is insignificant.

Costs for steam to drive the heat pump and electricity for pumps etc. are not included.
The electricity consumption for internal pumps is about 1-2 % of the heat extracted from the heat source by the evaporator (ref: 2+4).

Technology	Large heat pumps, absorption (geothermal)					
	2010	2020	2030	2050	Note	Ref
Energy/technical data						
Generation capacity for one unit (MJ/s heat)	**5-10**					
Coefficient of performance	1.7	1.75	1.8	1.8		1
Technical lifetime (years)	20	20	20	20		
Construction time (years)	0.5-1	0.5-1	0.5-1	0.5-1		
Environment						
Refrigerants	Ammonia / LiBr					1
Financial data						
Specific investment (M€ per MJ/s heat out)	0.4-0.5	0.4-0.5	0.4-0.5	0.4-0.5		1
Total O&M (€ per MJ/s heat out per year)	15000	15000	15000	15000	B+C	

References:

1 DONG Energy, October 2009.

Notes:

A Heat pumps used in connection with geothermal energy. Geothermal water (70 C) is used as heat input to lift the district heating temperature from about 40C to about 80 C

B 5% of initial investment per year. Costs for steam to drive the heat pump and electricity for pumps etc. are not included.

C The electricity consumption for internal pumps is about 1% of the heat extracted from the heat source by the evaporator (ref: 1).

51 ELECTRIC BOILERS

Brief technology description
An electric boiler is used for producing hot water directly from electricity. Two types of installations are available:

- The heating elements using electrical resistance (same principal as a hot water heater in a normal household). Typically, electrical resistance is used for smaller applications up to 1-2 MW's. These electric boilers are connected at 400 V.
- Heating elements using electrode boilers. Electrode systems are used for larger applications (larger than a few MW's). In Denmark, larger electrode boilers (larger than a few MW's) are connected at 10 kV.

The water in the electrode boiler is heated by means of an electrode system consisting of three-phase electrodes, a neutral electrode and control screens. Power is fed to the electrodes which transfer it to the water, thus heating the water.

The current from the phase electrodes flows directly through the water, which is heated in the process. The current is a function of the active surface area of the electrodes and the water conductivity. The active area of the electrodes can be infinitely varied by operating the control screens, thus enabling output to be controlled between a minimum load of 10-20 % (depending on boiler size and voltage) and 100 %.

Input
Electricity.

Output
Heat (hot water).

Typical capacities
1 - 25 MW.

Regulation ability
The electrode boiler output can be adjusted by means of the control screens which are mounted on a motor-driven gear shaft so that they can be moved up and down along the electrodes. In this way it is possible to adjust the output from approx. 10-20% up to 100%.

Environment
The boiler has no local environmental impact. However, it uses electricity and the environmental impact is highly dependent of the origin of the electricity.

Advantages/disadvantages
Due to its very simple design, the electric boiler is extremely dependable and easy to maintain. The boiler has no built-in complex components which may impede operation and maintenance. The boiler has quick start up and is easy to regulate. It requires no fuel feeding systems or stack. However, as it uses electricity as fuel, the operating costs can be high compared to other boilers.

The investment costs are very dependent on the size of the boiler.

Research and development
The technology is well developed and tested and commercially available. Future development will focus on dynamic use of electric boilers in connection with the power system.

Examples of best available technology
Swedish boiler manufacturer, Zander & Ingeström AB, distributed by Averhoff Energi Anlæg in Denmark.
Swedish boiler manufacturer, Värmebaronen (smaller electric boilers up to 1.5 MW).

Additional remarks
The operating costs of an electric boiler are highly dependent on the electricity price. Thus, heat production from of electric boilers can only compete with other heat production units at low electricity prices (i.e. at periods with high wind power production). Furthermore, electric boilers can be used for upward or downward regulation in the power systems with short notice. For upward regulation the electric boiler needs to be in operation to deliver this service.

The investment cost stated in the data sheet is without grid connection, which may more than double the cost.

References
Averhoff Energi Anlæg, web page and personal communication 2009.
Zander & Ingeström AB, 2009.

Data sheet

The costs presented below do not include the installation of a hot water storage tank.

Technology	**Electric boilers**					
	2010	**2020**	**2030**	**2050**	**Note**	**Ref**
Energy/technical data						
Generation capacity for one unit (MW)	**1-25**					
Efficiency (%)	99	99	99	99		1
Technical lifetime (years)	20	20	20	20		
Construction time (years)	0.5-1	0.5-1	0.5-1	0.5-1		
Environment						
Local emissions	-				A	
Financial data						
Specific investment (M€/MW); 400 V; 1-3 MW	0.12-0.15	0.12-0.15	0.12-0.15	0.12-0.15	B;C	2,3
Specific investment (M€/MW); 10 kV; 10 MW	0.06-0.09	0.06-0.09	0.06-0.09	0.06-0.09	C	2,3,4
Specific investment (M€/MW); 10 kV; 20 MW	0.05-0.07	0.05-0.07	0.05-0.07	0.05-0.07	C	2,3
Fixed O&M (€/MW per year)	1000	1000	1000	1000		2
Variable O&M (€/MWh)	0.5	0.5	0.5	0.5		2

References:

1 Zander & Ingeström AB, web page, October 2009
2 Averhoff Energi Anlæg, personal communication, May 2009
3 Security of supply for Bornholm, Integration of fluctuating generation using coordinated control of demand and wind turbines, Demand side options for system reserves, Ea Energy Analyses 2007
4 "Erfaringer med centrale elpatroner og varmepumper", Jan Diget, Skagen Varmeværk at "Vind til varme og transport", conference held by the Danish Wind Industry Association, October 22, 2009
5 JPH Energi A/S; 2008.
6 Energinet.dk, 2009.

Notes

A Environmental impacts depends on how the electricity for the boiler is produced.
B If this small boiler needs to take the electricity from a 10 kV grid, a transformer is required. This costs around 0.14 M€/MW (ref. 5).
C Costs do not include extra costs for connecting to the grid. Costs of strengthening the local grid and transformer-station, if required, may be around 0.13 M€/MW (ref. 6).