# Small Modular Renewable Heating and Cooling Grids

## *A Handbook*

CoolHeating.eu

Authors: Dominik Rutz, Christian Doczekal, Richard Zweiler,
Morten Hofmeister, Linn Laurberg Jensen

Reviewers: Rita Mergner, Rainer Janssen, Per Alex Soerensen, Tomislav Puksec,
Neven Duic, Borna Doracic, Rok Sunko, Blaž Sunko, Vladimir
Gjorgievski, Ljupco Dimov, Natasa Markovska, Nikola Rajkovic, Ilija
Batas Bjelic, Anes Kazagic, Alma Ademovic-Tahirovic, Izet Smajevic,
Slobodan Jerotic, Emir Fejzovic, Amra Babić, Milada Mataradzija,
Mitja Kolbl

ISBN: 978-3-936338-40-9

Translations: The original language of the handbook is English.
This handbook is also available in the following languages:
Bosnian, Croatian, Macedonian, Serbian, Slovenian, German

Published: © 2017 by WIP Renewable Energies, Munich, Germany

Edition: 1st edition

Contact: WIP Renewable Energies, Sylvensteinstr. 2, 81369 Munich, Germany
Dominik.Rutz@wip-munich.de, Tel.: +49 89 720 12 739
www.wip-munich.de

Website: www.coolheating.eu

Disclaimer: The sole responsibility for the content of this handbook lies with the authors. It does not necessarily reflect the opinion of the European Union. Neither the INEA nor the European Commission are responsible for any use that may be made of the information contained therein.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691679.

## Acknowledgements

This handbook was elaborated in the framework of the CoolHeating project. The authors thank the European Commission for supporting the project. For permitting the use of information and graphs, the authors thank the following companies and contributors: Wien Energie GmbH (Burkhard Hölzl), DLR (Michael Nast), Steinbeis Forschungsinstitut Solites (Thomas Pauschinger), Thermaflex Isolierprodukte GmbH (Jana Tanneberg-Kranz), W.A.S. Wasseraufbereitungssysteme GmbH (Ralf Kotlan), Snowpower AB (Kjell Skogsberg), Gram Fjernvarme AmbA, Braedstrup Fjernvarme AmbA, Dürr Thermea GmbH, UNEP, Solair Project, GeoModel Solar s.r.o., PlanEnergi, Danish Geothermal District Heating, GeoDH Project, Heat Roadmap Europe Map and Data Portal, PARAT Halvorsen AS, Danish Energy Agency, Energinet.dk, Hjallerup Fjernvarmeværk A.m.b.a., Güssing Energy Technologies, WIP Renewable Energies, Isoterm AS, and Tour & Andersson Ges.m.b.H.

## The CoolHeating project

The heating and cooling demand in Europe accounts for around half of the EU’s final energy consumption. Renewable energy policies often mainly focus on the electricity market, whereas policies for renewable heating and cooling are usually much weaker and less discussed in the overall energy debate. Therefore, it is important to support and promote renewable heating and cooling concepts, the core aim of the CoolHeating project.

The objective of the CoolHeating project, funded by the EU’s Horizon2020 programme, is to support the implementation of "small modular renewable heating and cooling grids" for communities in South-Eastern Europe. This is achieved through knowledge transfer and mutual activities of partners in countries where renewable district heating and cooling examples exist (Austria, Denmark, Germany) and in countries which have less development (Croatia, Slovenia, Macedonia, Serbia, Bosnia-Herzegovina) (Figure 1).

Core activities, besides techno-economical assessments, include measures to stimulate the interest of communities and citizens to set-up renewable district heating systems as well as the capacity building on financing and business models. The outcome is the initiation of new small renewable district heating and cooling grids in five target communities up to the investment stage. These lighthouse projects will have a long-term impact on the development of "small modular renewable heating and cooling grids" at the national levels in the target countries.

An important instrument of the CoolHeating is the present handbook. Although various information materials on technologies for small modular renewable heating and cooling systems exist, there was a need to create this up-to-date handbook that is accessible for free in national languages. In many of the target countries there is lack of such information in national language. The handbook provides an overview of both, technical and non-technical (planning) aspects. The main characteristics of different heat sources from solar, biomass, geothermal and excess heat are described and the opportunities of their combination in small modular RE district heating and cooling system are presented. Seasonal and diurnal storage systems are included, as well as the use of heat pumps. Specific aspects of heating and cooling in small grids are shown.

**Figure 1: Countries and target villages (red dots) involved in the CoolHeating project**

***Project Consortium and National Contact Points:***

**WIP Renewable Energies**, project coordinator, Germany
Dominik Rutz [Dominik.Rutz@wip-munich.de]
www.wip-munich.de

**PlanEnergi**, Denmark
Morten Hofmeister [mh@planenergi.dk]
www.planenergi.dk

**Güssing Energy Technologies GmbH**, Austria
Richard Zweiler [office@get.ac.at]
www.get.ac.at

**University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture**, Croatia
Neven Duić [neven.duic@fsb.hr]
www.fsb.unizg.hr

**Skupina Fabrika d.o.o.**, Slovenia
Rok Sunko [rok@skupina-fabrika.com]
www.skupina-fabrika.com

**International Center for Sustainable Development of Energy, Water and Environment Systems - Macedonian Section**, Macedonia
Natasa Markovska [sdewes.skopje@sdewes.org]
www.sdewes.org/macedonian_section.php

**University of Belgrade, School of Electrical Engineering**, Serbia
Nikola Rajakovic [rajakovic@etf.rs]
www.etf.bg.ac.rs

**JP Elektroprivreda BiH d.d.-Sarajevo**, Bosnia-Herzegovina
Anes Kazagic [a.kazagic@elektroprivreda.ba]
www.elektroprivreda.ba

**City of Šabac**, Serbia
Slobodan Jerotić [slobodan.jerotic@sabac.org]
www.sabac.org

**Opcina Visoko**, Bosnia-Herzegovina
Emir Fejzović [ler@visoko.gov.ba]
www.visoko.gov.ba

**Občina Ljutomer**, Slovenia
Mitja Kolbl [mitja.kolbl@ljutomer.si]
www.obcinaljutomer.si

# *Content*

# 1 Introduction

Small modular district heating and cooling grids are local concepts to supply households and small and medium industries with renewable heat and/or cooling. In some cases, they may be combined with large-scale district heating (DH) grids, but the general concept is to have an individual piping grid, which connects a smaller number of consumers. Often, these concepts are implemented for villages or towns. They can be fed by different heat sources, including solar collectors, biomass systems and surplus heat sources (e.g. heat from industrial processes or from biogas plants that is not yet used, but wasted). A scheme of these grids is presented in Figure 2.

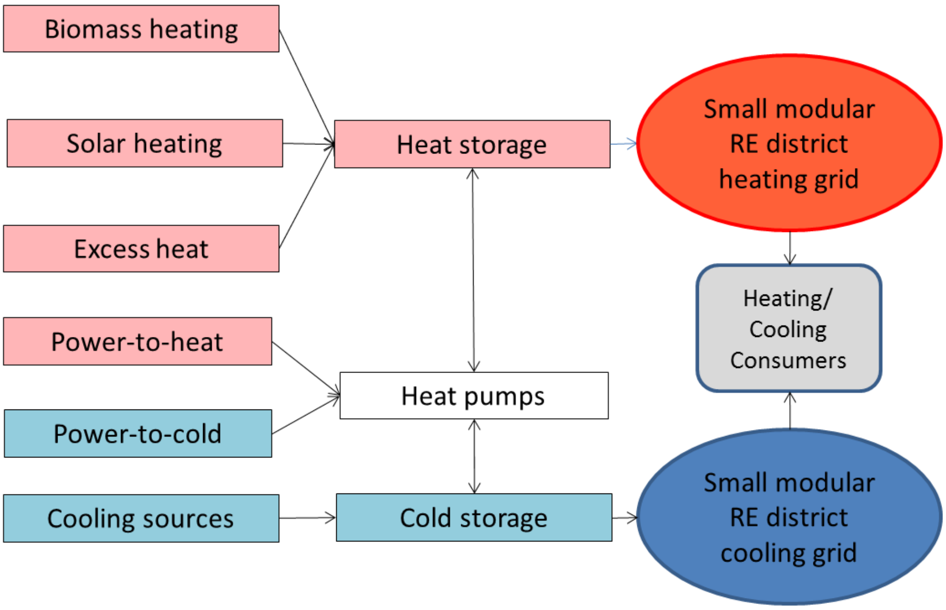


**Figure 2: Concept of small modular renewable heating & cooling grids (Source: Rutz D.)**

Especially the combination of solar heating and biomass heating is a very promising strategy for smaller rural communities due to its contribution to security of supply, price stability, local economic development, local employment, etc. On the one hand, solar heating requires no fuel and on the other hand, biomass heating can store energy and release it during winter when there is less solar heat available. Thereby, heat storage (buffer tanks for short-term storage and seasonal tanks/basins for long-term storage) needs to be integrated. A scheme of a typical seasonal demand and supply of a combined small heating grid is presented in Figure 3. The main advantages of a biomass/solar heating concept are:

- Reduced demand for biomass
- Reduced heat storage capacity
- Lower maintenance needs of biomass boilers

With increasing shares of fluctuating renewable electricity production (PV, wind), the Power-to-Heat conversion through heat pumps can furthermore help to balance the power grid.

If the planning process is done in a sustainable way, small modular district heating/cooling grids have the advantage, that at the beginning only one part of the system can be realised and additional heat sources and consumers can be added later. This modularity requires good planning and appropriate dimensioning of the equipment (e.g. pipes). It reduces the initial demand for investment and can grow steadily.

Besides small district heating, also small district cooling is an important technology with multiple benefits. With increased temperatures due to global warming, the demand for cooling gets higher, especially in southern Europe in which the target countries are located. In contrast to energy demanding conventional air conditioners, district cooling is a good and sustainable alternative, especially for larger building complexes. However, experiences and technologies are much less applied than for district heating. The CoolHeating includes both, heating and cooling in its planning process.

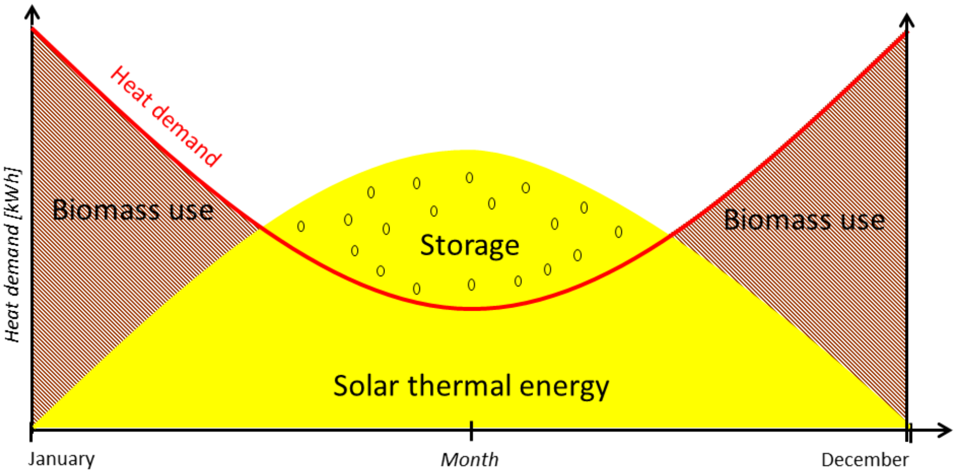


**Figure 3:** **Scheme of the seasonal heat demand and supply from solar and biomass sources in Europe (Source: Rutz D.)**

Especially countries in southern Europe with high solar irradiation need both, heating and cooling. The combination of small district heating and cooling in the same planning step saves cost and efforts, even if some consumers will demand only either heating or cooling. Thereby, also technical synergies are created (piping, the use of heat pumps). CoolHeating will develop business plans for the target communities with the following characteristics:

- Seasonal storage
- Diurnal storage
- Renewable heating (e.g. with a solar thermal plant and a biomass boiler)
- Thermal cooling
- Utilization of the waste heat from thermal cooling for heating (e.g. hot water supply)

Small modular district heating/cooling grids have several benefits. They contribute to increase the local economy due to local value chains of local biomass supply. Local employment is enhanced as well as security of supply. The comfort for the connected household is higher: in the basement of the buildings only the heat exchangers are needed and no fuel storage tank or boiler. Furthermore, no fuel purchase has to be organised.

Due to all these benefits, the objective of the CoolHeating project is to support the implementation of small modular renewable heating and cooling grids for communities (municipalities and smaller cities) in South-Eastern Europe.

# 2 Basics about heat[1]

Heat is defined in **thermodynamics** as energy transferred from one system to another by thermal interaction. It is a function of process in contrast to a function of state such as temperature or volume. It describes the transition of a system from an equilibrium state to another equilibrium state. Thereby the system is characterized by dedicated system boundaries. Heat flows spontaneously always from a high to a low temperature system. The term “heat” is often also expressed as "heat flow" and "heat transfer". Heat transfer can occur by conduction, radiation, convection, mass transfer, and by chemical reactions. **Cooling** is the service of providing low temperature media, whereas at the same time energy (heat) is transferred to other media. Thus, cooling is always associated with heat transfer.

A differentiation between **sensible heat** and **latent heat** has to be made. Sensible heat is directly measurable through the change in temperature. Latent heat is the heat released or absorbed by a body or a thermodynamic system during a process that occurs without a change in temperature. A typical example is a change of state of matter, such as the phase transition from ice (solid phase) to water (liquid phase).

Applied to the district heating grid, heat can be characterized by a certain volume of water with a certain temperature that is transported through pipes to consumers. This heat can be used by the consumers, whereas the temperature of the water is decreased to a lower level.

## 2.1 Figures and conversion units of heat

The mathematical symbol of heat is **Q** and the SI unit is the **joule (J)**. In many applied fields in engineering the British Thermal Unit (BTU), the tonne of oil equivalent (toe), and the calorie are used. The mathematical symbol for the rate of heat transfer (capacity) is $\dot{Q}$ and the standard unit **watt (W)**, defined as joule per second. Watt is also the most frequently used unit in the field of district heating and cooling.

- 1 J = 1 Ws = 1/3,600 Wh
- 1 Wh = 3,600 Ws = 3,600 J
- 1 toe = 11,630 kWh = 41.87 GJ
- 1 BTU = 1,055 J

The capacity of a heating system is usually expressed in **kW** or MW (kilo or mega Watt) for the total capacity. In cogeneration (or combined heat and power units, CHP), **$kW_{el}$** is used for the electrical capacity and **$kW_{th}$** for the thermal capacity. The produced energy is expressed as **kWh** (kilo Watt hour) or MWh. The actual energy output of a heating system is usually expressed as **kWh/a** (kilo Watt hours per year). This is based on the number of hours of a regular year, being **8,760 hours per year** (a). For the size of typical small heating plants usually the SI prefixes kilo ($10^3$), mega ($10^6$) and giga ($10^9$) are used.

Heat can be either measured by a **calorimeter** or **calculated** by using other figures, such as by volume, mass, temperature, and heat capacity. For the use of heat in applied energy systems, such as for residential heating, a **heat meter** is usually used. It is a device which measures the thermal energy from a source (e.g. biogas CHP unit) by measuring the flow rate of the heat transfer fluid (e.g. water) and the change in its temperature (ΔT) between the flow and return pipes.

An important figure for CHP units is the **power-to-heat ratio** which is the relation of electrical energy to useful thermal energy (Directive 2004/8/EC). A high figure characterizes a high electrical output. The figures of typical CHP units are between 0.4 and 0.9, for biomass fired systems it is often lower.

---

[1] This chapter is based on Rutz et al. 2015

## 2.2 Heat quality

Besides the amount of energy (quantity), the characteristics of the type of energy (quality) are important when developing energy concepts. One important parameter that characterizes the quality of energy is the transferability of one energy form to another energy form. Generally, electricity is considered of higher quality than heat, since electricity can easily be transported and used for different purposes such as the production of mechanical energy, heat, electromagnetics, etc.

In thermodynamics, often the term **exergy** is used. It describes the maximum energy part of a system that can be converted into useful work, if the system is in equilibrium with the environment.

Furthermore, heat is characterized by the **temperature level** and by the **quantity** of heat. Generally, it can be said that the higher the temperature and the amount of energy (entropy), the more options for its use exist. Examples for minimum temperatures of different uses are:

| | |
|---|---|
| **Hot water supply**: | 50-80°C |
| **Residential heating**: | 50-80°C |
| **Rankine cycles** (ORC, CRC): | 60-565°C |
| **Dryer** for agricultural products: | 60-150°C |

Modern small **heating grids** should not only be renewable, but should also consider the exergy of the used heating resources. The quality of the heat in the grid should be optimized and adjusted to the needed energy demand. Heat with high temperatures should be used, if possible, for higher value services such as electricity production or industrial processes. Residual heat with lower temperatures from the industry or power generation can be used for space heating and hot water preparation. The return flow of this can be even further used in combination with heat pumps in so called low-temperature grids for settlements with high insulation standard. This cascading in the heat use increases the sustainability in addition to being renewable. The concept of these "**LowEx heating grids**" is well described in Von Hertle et al. (2015)

## 2.3 Heat use

Heat is needed for many purposes. The heat distributed in district heating grids is primarily used for space heating and domestic hot water (DHW) supply of buildings which can be private households or public buildings. An example of the heat demand of private households is presented in Box 1.

Besides heating for buildings, also industries and businesses can be supplied with heat from DH grids. However, they often require higher temperatures than the DH grid provides for space heating. Industries can not only be heat consumers, but also be heat suppliers. The waste heat from industries, which is not used for the industrial processes, can be used to supply the district heating grid. This means that, depending on the type of production, the industry is a consumer, producer, or both (prosumer).

**Box 1: What is the heat demand per person in a household?**

The following example shows the average net energy consumption per person in Germany (based on calculations from Paeger 2012; Rutz et al. 2015):

- Net energy consumption for heating and DHW per person in households:
  20.2 kWh/day or 7,373 kWh/a
- Net energy consumption for heating per person in households:
  17 kWh/day or 6,205 kWh/a
- Net energy consumption for heating per person in households (per m² living area):
  155 kWh/a/m²
- Net energy consumption for DHW per person in households:
  3.2 kWh/day or 1,168 kWh/a

# 3 Heating sources and technologies

For small modular renewable district heating (DH) grids, various technologies are available, which are mature and commercially viable. The most important heat sources are solar thermal, biomass and geothermal energy. The use of excess heat, such as waste heat from biogas plants or industrial processes, is a very interesting option for situations, where heat is already available, but currently not used and therefore wasted. Power-to-heat is an increasingly important and simple technology to convert surplus electricity from fluctuating renewable power generators, such as wind turbines and photovoltaic plants, to heat. Even smarter is the use of heat pumps to use various low temperature heat sources to provide heat at higher temperatures. Often, peak load boilers are integrated in smart district heating systems in order to make the overall project financially feasible, as the investment costs of its technologies (oil or gas boiler) can be rather cheap.

## 3.1 Solar thermal energy[2]

Collecting energy from the sun to heat water is a technology, which has been in use for many years. Today, more than 580 million $m^2$ of solar collectors are installed around the globe, with a total installed capacity of 410 $GW_{th}$.

Outside the atmosphere of the Earth, the solar radiation is 1,367 $W/m^2$. The irradiation on the surface of the Earth is approximately 1,000 $W/m^2$. It is higher at the equator and lower further to the North or South. The effect is higher perpendicular to the solar radiation; this is why solar collectors should be placed with an angle of approximately 30-40 degrees.

Solar thermal technologies can be easily and flexibly combined with other technologies. They are furthermore modular extendable which allows the installation of any size. Thereby, an important part of the technology is the heat storage which can balance the variations in the solar thermal production. In the climate of Denmark, short-term storage tanks facilitate in many projects approximately 20-25% of the annual heat demand to be covered by solar thermal. A seasonal storage can facilitate a higher solar fraction, in principle up to 80-100%. This is also described in chapter 4.2.

The main challenge of a solar heating system is the fact that its main production occurs in summer and during daytime when the heat demand is lowest – both on daily and seasonal basis. The share of solar heating in a district heating system without heat storage is relatively low (5-8% of yearly heat demand). The most common applications include a diurnal heat storage, which will enable approximately 20-25% share of solar district heating in a district heating system. Moreover, combination with seasonal heat storage can increase the share of solar heating to 30-50%, or even higher, in theory up to 100%. Hence, there is an important synergy with seasonal storage technologies.

---

[2] This chapter is based on the following sources: www.Task45.iea-shc.org, Data on specific plants: www.solvarmedata.dk and www.solarheatdata.eu, supplier of solar panels: www.arcon.dk

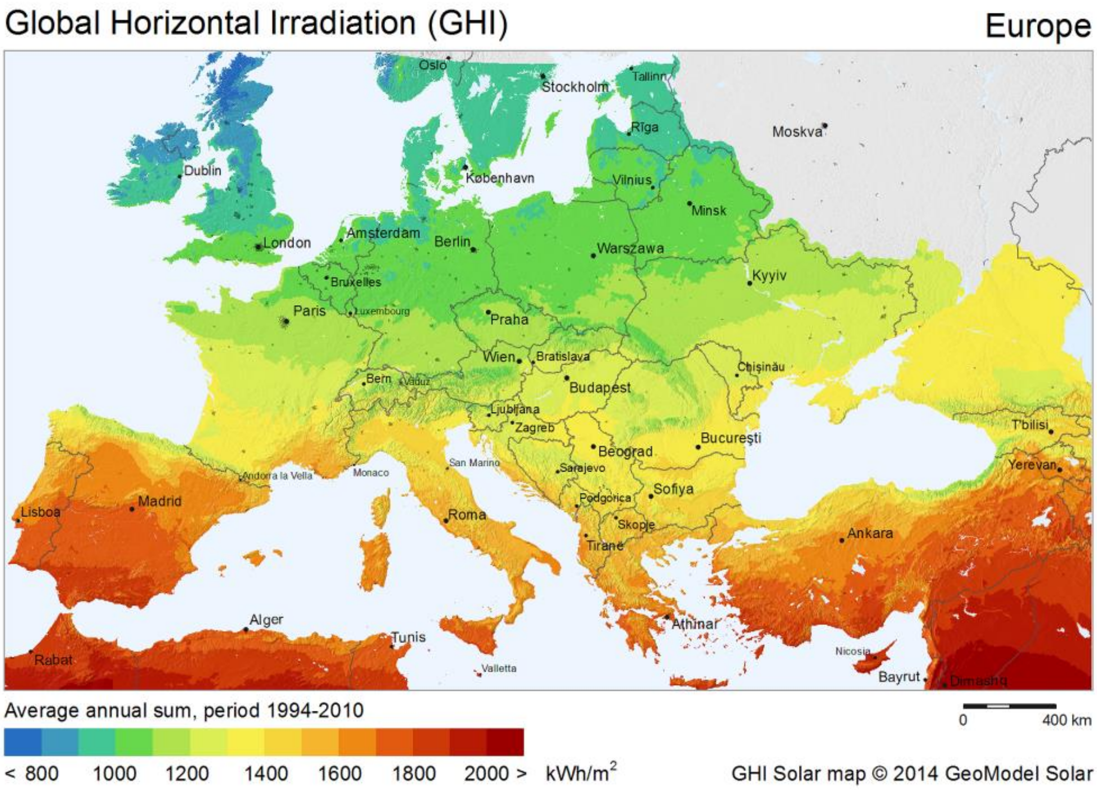


**Figure 4:** **Solar Radiation Map of Europe: Global Horizontal Irradiance Map of Europe (Source: SolarGIS © 2011 GeoModel Solar s.r.o.[3])**

### *3.1.1 Solar thermal technologies*

Solar heating is used for space heating and domestic hot water (DHW). Typically, water is heated by arrays of solar thermal collectors. For district heating systems, the collectors are often installed on the ground in long rows connected in series (Figure 7, Figure 8). In smaller systems, the collectors are also installed on roof tops (Figure 9, right).

Different types of solar panels exist, as shown in Figure 5. For small solar district heating systems, mainly flat plate collectors and vacuum tubes (evacuated tube collectors) are used.

The most common solar panel type is **flat plate collectors** (Figure 8), which are available in different variations. They consist of a dark flat-plate absorber which can be thermally stable polymers, aluminium, steel or copper, to which a matte black or selective coating is applied. The absorber is backed by a grid or coil of fluid tubing placed in an insulated casing with a glass or polymer cover. In the tubing the heat-transport fluid (air, antifreeze or water) removes heat from the absorber to the heating cycle. The absorber is usually placed in an insulated casing with a transparent glass or polymer cover that reduces heat losses. There are also non-glazed collectors, but they are usually not installed in solar district heating plants. A heat insulating backing reduces the heat losses in the back of the panel.

**Vacuum tube collectors** (Figure 7) are composed of evacuated glass tubes assembled to a collector. The glass tube is evacuated to below $10^{-2}$ to $10^{-6}$ bar in order to minimize heat losses. Most vacuum tubes are evacuated at $10^{-5}$ bar (Metz et al. 2012). There are various different technologies of vacuum tubes available. Two basic principles are:

- **Direct flow tubes**: tubes through which the liquid passes directly without evaporation
- **"Heat pipe" tubes**: tubes in which a liquid is evaporated in the absorber

---

[3] http://solargis.com/products/maps-and-gis-data/free/download/europe

Direct flow tubes can be classified into two categories. They may consist of a single glass tube which is evacuated. In this tube, an absorber plate is fused to a pipe through which the heat-transport fluid flows. The other category is the so called „Sydney" tube, which is a double glass tube (like a vacuum flask). The inner tube is coated in order to act as an absorber. A U-shape copper pipe collects the heat from this absorber.

Vacuum tubes may be also equipped with a Compound Parabolic Concentrator (CPC) underneath the tubes in order to also benefit from the irradiation between the tubes.

There are many suppliers of solar collectors on the market in Europe. Solar thermal collectors are a mature technology, which now enter a phase of large-scale applications, further decreasing the investment costs and thus increasing the feasibility.

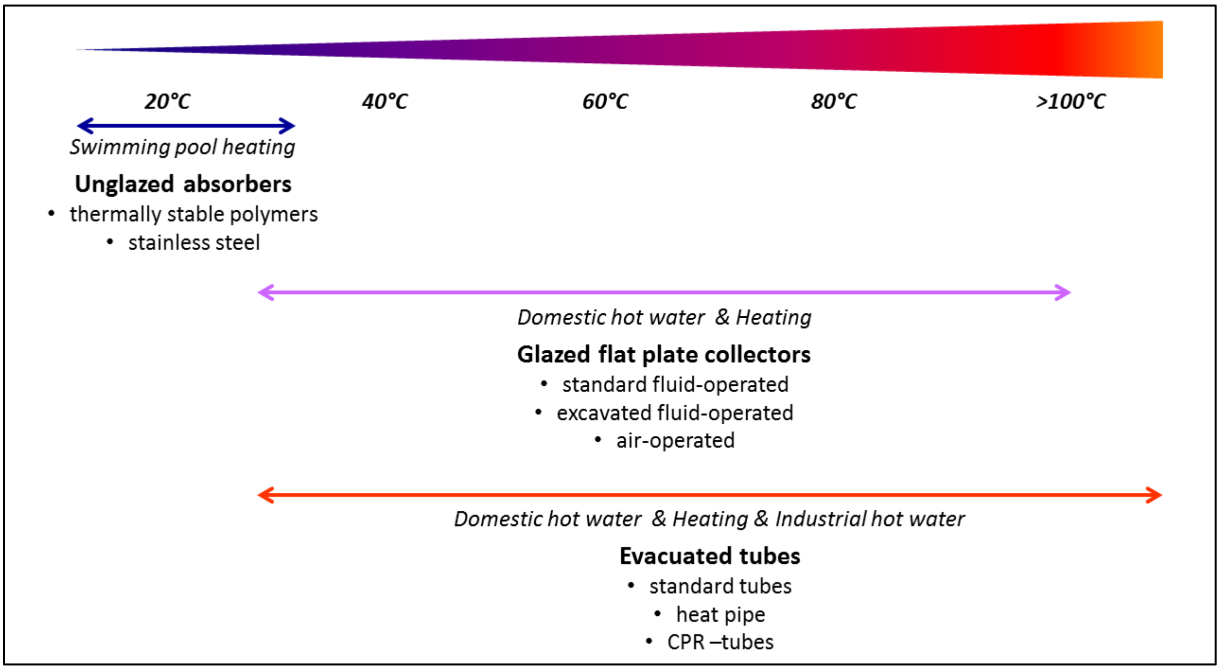


**Figure 5: Types of absorbers and solar collectors related to the temperature range (Source: Rutz D.)**

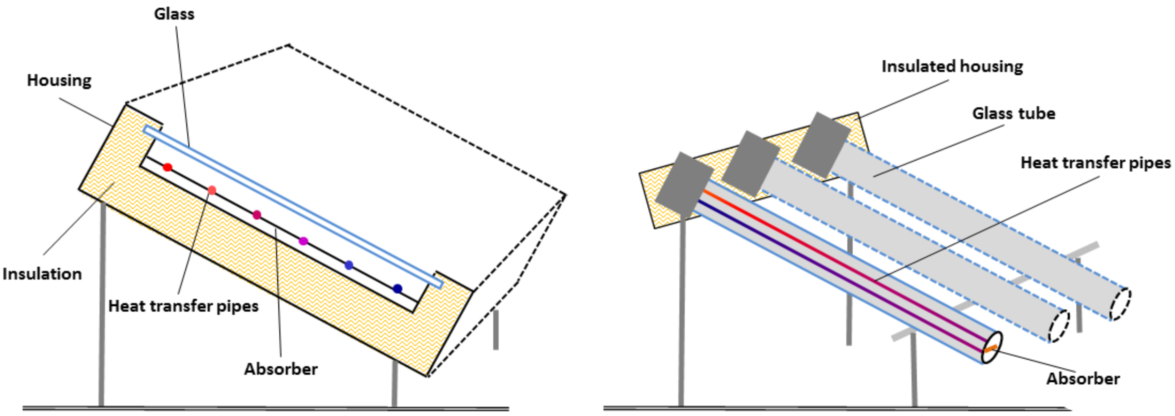


**Figure 6: Principles of a flat plate collector (left) and an evacuated tube collector (right) (Source: Rutz D.)**

**Figure 7:** Ground-mounted vacuum tube collectors (left) of the solar district heating plant in Büsingen, Germany and sample of these collectors (right) showing the U-type fluid pipe in the right tube as well as the Compound Parabolic Concentrator (CPC) technology (Source: Rutz D.)

**Figure 8:** Ground-mounted flat plate collectors of the solar district heating plant in Gram, Denmark (Source: Rutz D.)

**Figure 9:** Parabolic trough solar thermal research plant (left) as well as a roof-top solar collectors connected to a small district heating system in Bad Aibling, Germany (Source: Rutz D.)

**Box 2: What are the main advantages/disadvantages of vacuum tube collectors in comparison to flat plate collectors? (based on Metz et al., 2012)**

*Advantages*

- The efficiency is higher at cold ambient temperatures and low irradiation (in winter)
- The efficiency is higher under conditions with high temperature differential between the absorber and the ambient temperature (in summer)
- With the same area, vacuum tube collectors yield about 30% more heat
- Higher temperatures can be achieved which increases the exergy
- If the collector needs to be mounted in other directions than south, the reduced irradiation can be compensated by either axially turning the tubes or by using CPS
- They are compatible with systems where only water is used as heat transport medium

*Disadvantages*

- They are more expensive
- The cost-performance ratio is lower, i.e. not so good
- The system needs to be able to tolerate higher stagnation temperatures

Besides flat plate collectors and vacuum tubes, also **parabolic troughs** (Figure 9, left) could be used as solar thermal collector for small district heating grids. However, they are mainly used for so called concentrated solar power (CSP) plants, which generate electricity by high temperatures. The feasibility of parabolic troughs depends on the demand for high temperature levels, e.g. for electricity production or for industrial applications.

The principle of the solar panel, in a district heating system, is to absorb the solar energy in a **heat-transport fluid** (e.g. glycol, water). The heat of the fluid is then transferred by a heat exchanger to the district heating water or storage tank (Figure 10). The fluid is usually water with glycol added for frost protection.

Water should be used as heat-transport fluid whenever possible, as it presents better characteristics from both the thermo-physical and economic points of view. However, depending on the climate and on the risk of freezing, propylene glycol (PG)/water mixtures may be necessary. As higher concentrations of glycol entail poorer fluid properties in terms of specific heat and heat transfer, a lower concentration assuring anti-freezing protection only at a certain extent may be preferred. If the fluid temperature approaches its freezing point, the pump of the solar collector loop can be started and the fluid circulated and warmed up. This approach makes the control strategy a bit more complex and requires more temperature sensors, but can enhance the solar collector performance on a yearly basis. (Bava et al., 2015)

In some plants water may be used as heat-transport fluid even if the plant is installed in locations where frost occurs, due to e.g. ground water protection or water sensitive areas. In the case of low temperatures, the water in the collectors must be slightly heated with the return flow of the DH system in order not to be damaged by freezing. An example where this is applied is the solar district heating plant of Büsingen in Germany.

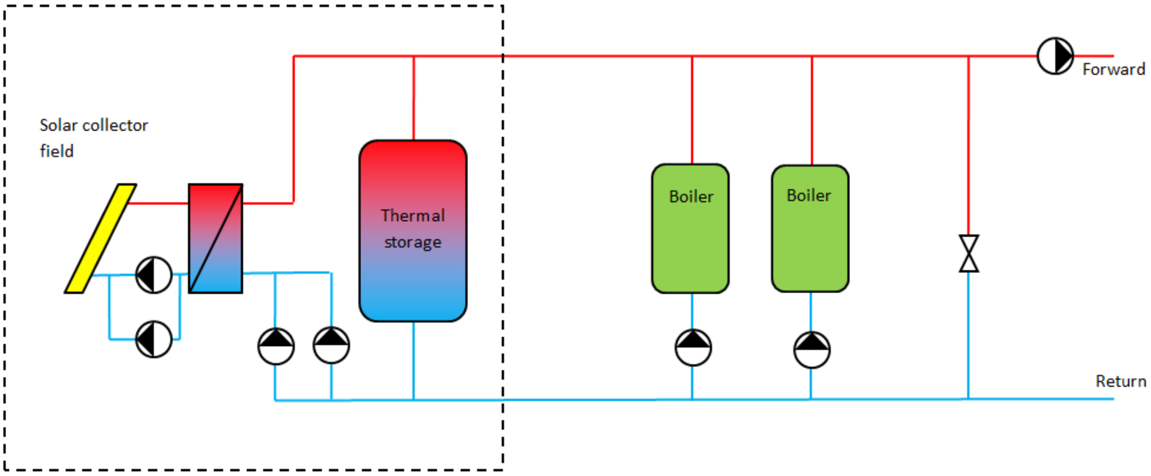


**Figure 10: Principle drawing of solar district heating (Source: PlanEnergi)**

Solar thermal collectors can be installed on buildings such as single or multi-family houses, i.e. as individual applications. However, it can be also installed as a ground-mounted system at larger scale. Most large-scale solar thermal plants have the solar collectors mounted on the ground. Ground mount foundations can be concrete blocks, concrete foundations or steel foundations, rammed into the ground.

Good installed solar collectors can even work when the outside temperature is very low. They are protected also from overheating on hot, sunny days. District heating systems equipped with solar heating usually need also other heat generators in order to ensure continuous heat supply, if there is insufficient sunshine available.

### *3.1.2 Markets and experiences from existing solar thermal plants*

An overview of the world’s largest solar thermal plants can be found at www.solarthermalworld.org. Due to the larger market share and importance of Denmark in the sector, the following sections present an overview and some results from Denmark.

The development of solar plants and collector area in Denmark is illustrated in Figure 12. The trend is that the new plants are larger and include seasonal heat storages. There are (end of 2016) in total more than 1 million m$^2$ of solar thermal above 1,000 m$^2$ in Denmark. This is a significant increase from less than 100,000 m$^2$ in 2009.

An online map with solar heating plants in Denmark is shown at www.solvarmedata.dk. The map is interactive and includes detailed information on solar heating plants. It shows more than 125 plants with more than 1 million m$^2$ collector area in total.

The investment costs for solar plants in Denmark are presented in Figure 11. The plant in the upper right corner of the graph is “Dronninglund” with 37,573 m$^2$ which includes a seasonal heat storage. The investment for that is 2.4 M€ (see the section below on the seasonal heat storage), corresponding to the difference down to the red line.

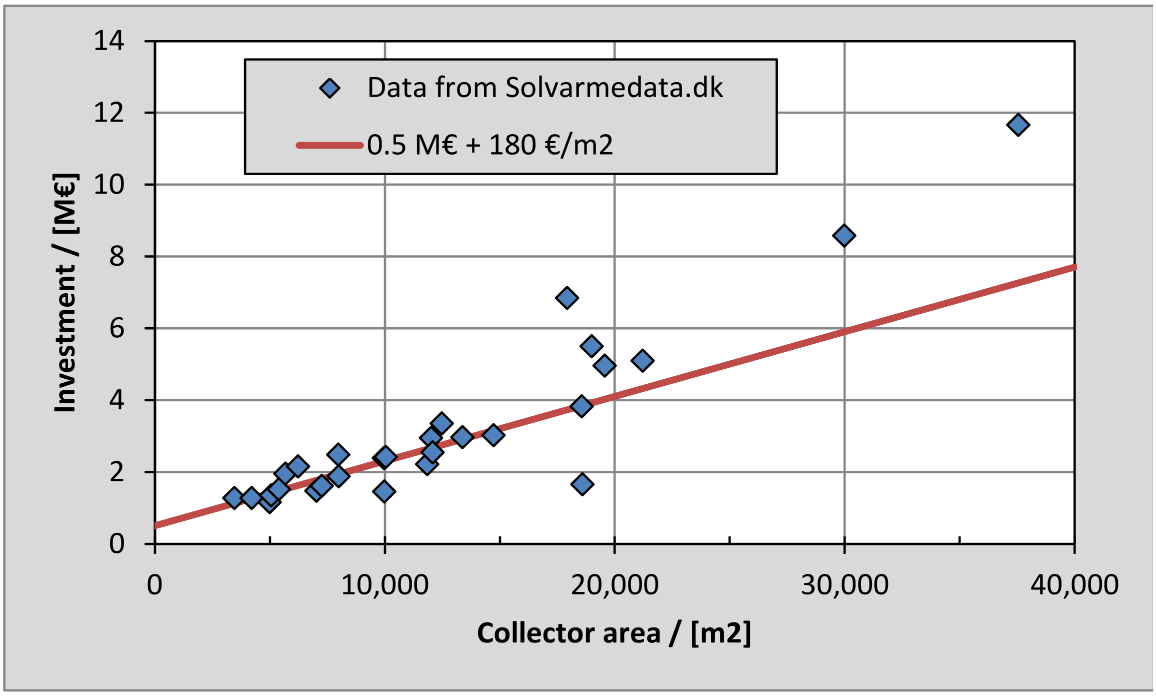


**Figure 11: Solar plant investment for Danish SDH projects (Source: PlanEnergi)**

This growth for solar thermal plants in Denmark has led to the following developments:

- **More suppliers and manufacturers**: They are involved, further develop technologies and become competitors: e.g. Arcon-Sunmark, Viessmann, KBB, Clipsol, Savo Solar, Greenonetech.
- **Hybrid systems**: Small district heating grids often involve several technologies. Especially the combination of solar and biomass energy (wood chips and straw) is implemented. Energy saving measures are considered as well.
- **Heat storage systems**: In systems that are operated with large-scale solar thermal plants, the use of seasonal storage systems is often implemented. They can store up to 80% of the annual heat demand.
- **Solar thermal plants for large cities**: Some new solar thermal plants are planned or currently being built for larger cities, e.g. Graz, Austria (265,000 inhabitants, 450,000 $m^2$ solar panels, 1.8 million $m^3$ storage), or Belgrade, Serbia (under investigation).
- **Solar thermal plants with higher temperatures**: Several plants are operated with higher temperatures to supply industries or to existing district heating grids. Some examples provide heat for power generation (e.g. CSP - concentrated solar power, ORC - Organic Rankine Cycles).

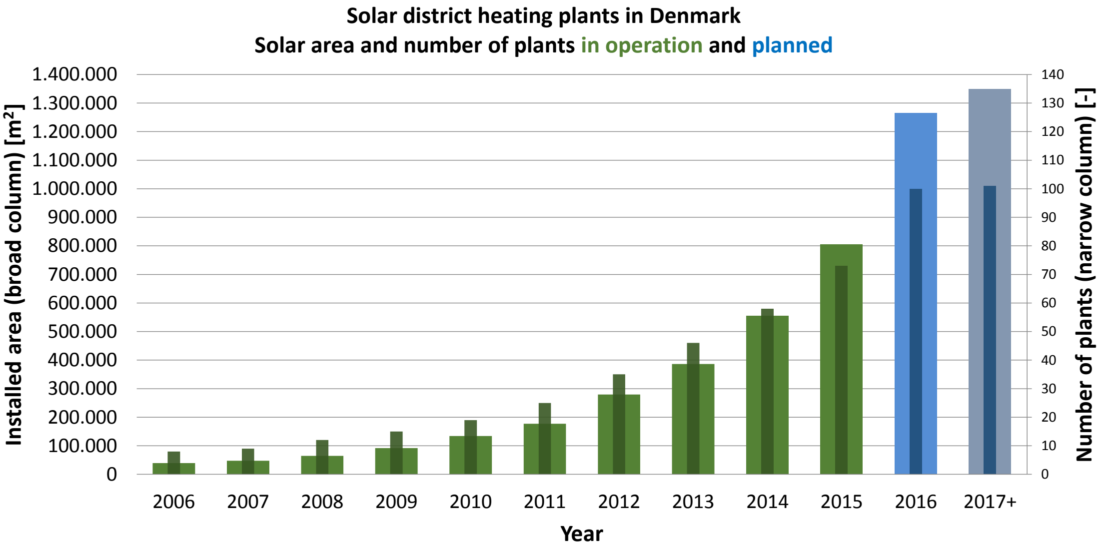


**Figure 12: Solar district heating plants in Denmark in operation (until 2015) and planned (Source: PlanEnergi)**

The development in the solar thermal plant sector illustrates that solar thermal is a well-proven and robust technology with a long technical lifetime and is now reaching a stage of development where it is competitive also in large scale applications in combination with other technologies, including seasonal heat storage technologies. The main **advantages** of solar heating are:

- Simple, robust and proven technology; more than 100 Danish district heating plants have solar thermal plants.
- Long life-time which is proven for at least 25-30 years. New plants will even have longer life-times.
- Low maintenance costs. Based on current plants they are approximately 0.7 € per produced MWh heat.
- It has low electricity consumption (3-4 kWh per produced MWh solar heating).
- No continuous presence of operation personnel is required.
- The heat production price is not sensitive to variable costs of fuel. The planning of the heat price is easier, when a share of the heat price is known.
- It is a $CO_2$-free energy source.
- High energy yield/area compared to biomass and PV.
- Easy re-establishment of the area of ground-mounted systems with no or low impact on the soil.
- 98% of a plant can be recycled.

The main **disadvantages** of solar heating are:

- The heat production depends on the solar radiation and weather conditions.
- Summer load defines the size of the capacity in case of diurnal storage only.
- It produces 80% of the heat energy during the period April – September, when the heat demand is lowest. This problem can be mitigated by including a seasonal heat storage facility.

- Compared to other district heating technologies like boilers or heat pumps, ground mounted solar plants require a large land area, approximately 2.5 $m^2$ ground area for each $m^2$ solar panel collector. The location should be nearby the district heating grid – although this can be mitigated with a transmission pipeline of some km length. However, this will imply additional costs.
- High initial investment costs per MW. However, with a depreciation period of 15-20 years, the heat production cost is competitive with e.g. biomass based heat production.

Extensive guidelines for solar district heating have been elaborated in the project IEA SHC Task 45[4]. Info-sheets as well as Tech-sheets are available, describing requirements and guidelines for collector fields and information about seasonal storages.

## *3.2 Biomass systems*

Biomass is the organic matter created by living (plant material, humans and animals and their excreta), or recently living organisms. It also includes secondary products when biomass is used, such as bio-waste, paper, wood products, etc. Primary organic matter is produced by photosynthesis of plants that take $CO_2$ from the atmosphere, water and the energy from the sunlight and build carbon based compounds (see Box 3). These carbon compounds contain the stored energy from the sun, which can be released again by combustion.

**Box 3: Why is biomass renewable? (Dimitriou & Rutz 2015)**

The main greenhouse gas of the combustion processes is **carbon dioxide** ($CO_2$), which is mainly responsible for the increase in global temperature. Carbon dioxide is emitted during combustion of fossil fuels (e.g. lignite, hard coal, oil, natural gas), but also of biomass. The difference, however, is that biomass extracts **$CO_2$** from the atmosphere during its growth (photosynthesis). Also for short rotation plantation, the trees remove $CO_2$ from the atmosphere for a period of e.g. 4-6 years of growth, after they are e.g. combusted in a woodchip boiler. Due to this short and closed cycle, biomass from SRC is renewable and helps to protect our climate. Yet, biomass energy sources are not entirely '**$CO_2$-neutral**', as fossil energy sources are still used for the preparation and utilisation of biomass (e.g. for harvest and transport).

Thus, biomass can be used as a source of renewable and storable energy. Biomass can be directly combusted, or first converted into secondary products (biogas, ethanol, biodiesel, charcoal, etc.), and then combusted. The conversion of biomass into further products can be classified into the following categories:

- **Mechanical treatment**: chipping, pressing, milling, pelletization, briquetting
- **Thermo-chemical treatment**: gasification, pyrolysis, torrefaction
- **Biochemical treatment**: anaerobic digestion, fermentation

Biomass is a very suitable and widely used energy source for small district heating grids. The main advantage is its storability and its utilisation on-demand. For example, wood can be stored for a long period until its heat is needed in winter. The main disadvantage is that the biomass systems need to be fed with feedstock, which needs to be harvested or collected, brought to the biomass plant and then processed. This is a main difference to fluctuating renewable energies such as solar and wind, which have lower maintenance requirements. On the other hand, these fluctuating renewables are more difficult to store. Thus, the

---

[4] http://task45.iea-shc.org/fact-sheets

combination of a biomass system with a solar system has the potential to maximize synergies.

### *3.2.1 Combustion process*

Solid biomass is defined as lignocellulosic biomass that can be directly used for combustion. It is predominantly wood, woodchips and pellets from forestry, landscape maintenance, sawmill industry, or short rotation coppice (SRC). However, in some cases, also agricultural residues, such as corn cobs or straw, can be used directly for combustion.

Plant based biomass is essentially composed of carbon (C), hydrogen (H) and oxygen (O). The proportion of carbon determines the energy released during combustion (oxidation). Also the hydrogen contained in solid biomass delivers energy when combusted. Together with the carbon it determines the heating value of the dry fuel. The oxygen only supports the combustion process, but has no influence on the energetic content of the fuel. (Dimitriou & Rutz 2015)

The heat of combustion (Δ $H^0$) (Equation 1) is the energy released as heat when a compound (biogas, wood, fossil fuels) undergoes complete combustion with oxygen under standard conditions. The chemical equation is biomass reacting with oxygen to form carbon dioxide, water and heat.

$$C_x\, H_y O_z + O_2 \quad \rightarrow \quad CO_2 + H_2O \ + \Delta H^0 \quad [kJ/mol]$$ **Equation 1**

In applied combustion systems, fuels are often characterised by lower and higher heating values (Box 4). They depend on the chemical composition of the fuel.

**Box 4: What is the difference between the lower and the higher heating value? (Dimitriou & Rutz 2015)**

Important information on fuel properties are provided by the heating values.

The **lower heating value** (LHV) (net calorific value (NCV), lower calorific value (LCV)) indicates the quantity of heat that is released with the complete combustion (oxidation) of biomass. This value does not consider the condensation heat (heat of evaporation) of water vapour contained in the exhaust gas. Thus, the lower heating value decreases with increasing water content of the biomass.

The quantity known as **higher heating value** (HHV) (calorific value, gross energy heating value, upper heating value ($H_o$), gross calorific value (GCV), higher calorific value (HCV)) is determined by bringing all the products of combustion back to the original pre-combustion temperature, and in particular condensing any vapour produced. For biomass the HHV lies at an average of about 6% (bark), 7% (wood) or 7.5% (agricultural produce) above the LHV (Table 1). However, this is only valid for solid fuels in an absolutely dry and water free condition (wf). For moist biomass this discrepancy increases. Table 2 shows the heating values of different wood samples.

Wood fuels have a high carbon content of 47 to 50%. The oxygen content of wood fuels lies between 40 and 45% and the hydrogen content between 5 and 7%. Alongside these three elements, they consist of other elements as well. These can, despite their small proportions, have strong effects on the exhaust emissions. Sulphur, chlorine, and nitrogen are among the elements that have the greatest effect on the polluting exhaust emissions. Fuels can be partly differentiated, depending on the considerable emission-relevant components. The energy content per mass is expressed in the lower and higher heating values (see Box 4) as it is shown in Table 1. For woodchips, often the energy content per volume (per cubic meter) is used. An example therefore is shown in Table 2. Depending on the type of wood, size of the woodchips, and moisture, a cubic metre of woodchips is about 200 – 300 kg. (Dimitriou & Rutz 2015)

### *3.2.2 Solid biomass quality*

An important factor that influences the combustion process is the quality of the fuel. Good quality fuels can be used in any system, but very low quality fuels may be used only in selected systems, that are usually larger systems and have special equipment. The fuel quality of solid biomass (pellets, briquettes, wood chips, firewood, etc.) is classified by the International Organization for Standardization under the different norms with the number ISO 17225 (e.g. "ISO 17225-1:2014 - Solid biofuels -- Fuel specifications and classes -- Part 1: General requirements").

**Table 1: Combustion characteristics of solid fuels (Hiegl et al. 2011) (average/typical values; based on absolute dry matter (0% water content); real values depend on several factors!)**

| Fuel type | LHV [MJ/kg] | HHV [MJ/kg] | Ash content [%] | Ash melting point [°C] |
|---|---|---|---|---|
| **Poplar wood** | 18.5 | 19.8 | 1.8 | 1,335 |
| **Willow wood** | 18.4 | 19.7 | 2.0 | 1,283 |
| **Beech/oak wood** | 18.4 | 19.7 | 0.5 | No entry |
| **Spruce wood** | 18.8 | 20.2 | 0.6 | 1,426 |
| **Bark (coniferous)** | 19.2 | 20.4 | 3.8 | 1,440 |
| **Wheat straw** | 17.2 | 18.5 | 5.7 | 998 |
| **Wheat grain** | 17.0 | 18.4 | 2.7 | 687 |
| **Hard coal** | 29.7 | No entry | 8.3 | 1,250 |
| **Lignite** | 20.6 | No entry | 5.1 | 1,050 |

**Table 2:** **Overview on the energy content of woodchips in relation to the water content (average/typical values; real values depend on several factors!)**

| Water content [%] | | 0 | 15 | 20 | 30 | 50 |
|---|---|---|---|---|---|---|
| | Reference unit | Lower heating value [kWh] | | | | |
| **Beech (density 558 kg dry matter/solid m³)** | kg | 5.00 | 4.15 | 3.86 | 3.30 | 2.16 |
| | Solid m³ | 2,790 | 2,720 | 2,700 | 2,630 | 2,410 |
| | Bulk m³ | 1,116 | 1,090 | 1,077 | 1,052 | 964 |
| **Spruce (density 379 kg dry matter/solid m³)** | kg | 5.20 | 4.32 | 4.02 | 3.44 | 2.26 |
| | Solid m³ | 1,970 | 1,930 | 1,900 | 1,860 | 1,710 |
| | Bulk m³ | 788 | 770 | 762 | 745 | 685 |
| **Poplar (density 353 kg dry matter/solid m³)** | kg | 5.00 | 4.15 | 3.86 | 3.30 | 2.16 |
| | Solid m³ | 1,765 | 1,723 | 1,705 | 1,662 | 1,525 |
| | Bulk m³ | 706 | 689 | 681 | 666 | 610 |
| **Willow (density 420 kg dry matter/solid m³)** | kg | 4.54* | 3.76** | n.a. | 2.97** | n.a. |
| | Solid m³ | n.a. | n.a. | n.a. | n.a. | n.a. |
| | Bulk m³ | n.a. | 680-810** | n.a. | 620-740** | n.a. |

*Source: CARMEN 2014, *Verscheure 1998, ** ETA Heiztechnik GmbH n.d. (first value of bulk m³ is related to G50, second to G30, other sources)*

**Figure 13:** **Pellet press (left) and high-quality pellets (right) (Source: Rutz D.)**

**Figure 14: High quality (left) and low quality (middle, right) woodchips in Germany (Source: Rutz D.)**

### *3.2.3 Combustion systems for solid biomass*

Solid biomass can be used in the following systems:

- **Small woodstoves** (logwood or pellets) for heating single rooms
- **Centralized wood boilers** (logwood or pellets) for heating a single household
- **Small-scale wood boilers** (logwood, pellets or woodchips) for heating larger buildings or few households
- **Medium-scale boilers** (woodchips, logwood, or pellets) for micro district heating grids for several connected households
- **Small-scale combined heat and power plants** (CHP) (pellets or woodchips) using gasifiers
- **Medium-scale CHP plants** (logwood, pellets or woodchips) using Organic Rankine Cycle (ORC) technologies
- **Large-scale scale CHP** plants (logwood, pellets or woodchips) using steam turbines
- **Co-firing** of woodchips or industrial pellets in large (fossil fuel based) power plants

Pellet boilers are used for smaller heating systems (single or multiple household level), but can be also used for medium-scale systems. Woodchip boilers (Figure 15, Figure 16) are used for heating systems starting from about 20 kW. Heating with woodchips is usually only economical for larger households, farms, or several households, or even smaller villages (small heating grids). (Dimitiou & Rutz 2015)

The technology for woodchip and pellet heating is mature and provided by many manufacturers. It consists of a storage bunker, feeding system, biomass boiler, exhaust system, and a heat distribution system (often including a buffer tank). The investment for a woodchip or pellet boiler is often higher than for a fossil fuel boiler, but, usually the fuel costs are much cheaper. Hence, in the long-term, woodchip or pellet boilers are more economical than fossil fuel boilers. (Dimitiou & Rutz 2015)

Figure 15: Small woodchip heating system (24-50 kW heat capacity) with the boiler (left), the feeding system (middle) and the woodchip storage (right) of Fröling (Source: Rutz D.)

Figure 16: Medium sized woodchip heating system (3,000 kW heat capacity) with the boiler (right) and the buffer tank (left) of the Biomassehof Achental in Germany (Source: Rutz D.)

For the combustion of agricultural residues such as, e.g. straw, special equipment is needed (Figure 17 and Figure 18) due to the specific characteristics of the herbaceous non-woody feedstock. A challenge related to the combustion of straw is mainly the high concentration of chlorine in the feedstock which may lead to corrosion problems of non adapted equipment. Furthermore, the low ash melting temperature is a challenge, as the removal of molten ash (slag) (Figure 18) is more sophisticated than for ash from wood combustion.

**Figure 17: Feeding-unit for straw bales (left) and 1.6 MW straw bale boiler in Ballen-Brundby, Denmark (Source: Rutz D.)**

**Figure 18: Molten bottom ash after straw combustion (Source: Rutz D.)**

### *3.2.4 Combined heat and power systems for solid biomass*

Systems that, besides heat, also generate power (**combined heat and power** units, CHP) are increasingly implemented. As they provide two energy types, heat and electricity, they are more complex than the systems for only heating as presented above. Its optimal integration into small district heating systems is influenced by various border conditions. The design of the system can be either more heat-demand driven or more power-demand driven.

A **heat-demand driven** CHP unit generates only the amount of heat that is actually needed. If less heat is needed, also less electricity is generated. Ideally, this concept is used, when there is a constant heat demand and 7,500 up to 8,760 full load hours per year. If the heat demand is varying, or if it is decreasing during certain periods, the CHP unit is operated at partial load, according to this definition. This leads to less full load hours (2,000 to 3,000 hours) for district heating systems, in which just domestic consumers for space heating are connected.

A **power-demand driven** CHP unit generates only generates the amount of power that is actually needed or that can be fed into the power grid. Most installed biomass CHP units are designed to generate green electricity according to a guaranteed feed-in tariff. Thus, nearly all power-demand driven systems are either operated at maximum full load hours or at grid-related demand. In some countries, such as in Germany, dedicated incentives were introduced to double the capacity at peak power load (e.g. during the day) and to stop operation at low power load (e.g. during night). Thus power-demand driven CHP units will play an increasingly important role in balancing the power grid.

If this power-demand driven concept is applied, the heat supply may not match a potential heat demand, or may be too much. In this case, the surplus heat is often wasted, as described in Box 5 for biogas plants. This led to the situation, that units have been installed, which wasted up to 70% of primary energy. After a few years nearly all countries reacted via their legislation and since then the heat utilisation of 40% to 50% is mandatory for plants that apply for a feed-in tariff. This increases the overall efficiency of the biomass CHP unit to approximately 70%. Hence, the installation of a CHP just makes sense if most of the heat is utilised and if minimum revenue is gained.

Historically, **biomass technologies** for combined heat and power generation were selected according to the thermal and electric capacity of the system. At this time, ORC systems were selected for small to medium-scale systems and for large-scale systems steam turbines. Both are thermodynamic processes base on the principle of the Rankine Cycle.

The development of highly efficient **steam turbines** has been driven by large scale coal or nuclear power plants with an electrical power of a few hundred MW. These steam cycles have been scaled down for the utilization in biomass power plants to 5 – 100 $MW_{el}$ (Figure 19.

For smaller scale **Organic Rankine Cycle (ORC)** processes have been developed, which provide some advantages. The main difference between a steam process and an ORC-process is the working media. Water, respectively steam, is replaced by an organic fluid, which has different condensation and evaporation temperatures. With these properties the process can be designed according to the needs of the heat consumer and the heat source. Thus, ORC processes have been optimized for a lower temperature level for the produced thermal energy of 85-95°C and a temperature level for the heat source (biomass boiler) of 250-350°C. With these parameters, the ORC process is slightly more efficient than a steam cycle as a whole. Another practical reason for choosing this technology is the low effort for operation and maintenance. Some ORC manufacturers produced standardised ORC-modules with complete long-term maintenance contracts. This increased the reliability in such a way, that operation with minimum human resources was achieved easily. Another border condition for decision making was the need for trained operation personnel. In most EU countries a special education was required for the operation of a steam boiler. Due to lower pressures, temperatures and different fluid conditions of the organic working media of an ORC process, no such special education was necessary to operate these plants. Finally, the entire ORC plant performed slightly better within the overall economic lifecycle assessment compared to different types of steam. Due to this faster market readiness ORC plants are widespread, today.

Figure 20 shows a typical ORC installation with 1.5 $MW_{el}$. When the market developed rapidly in Europe between 2002 and 2010 due to the provided feed-in tariff for green electricity some steam turbine manufacturers started to develop small scale steam turbines and nowadays these two technologies, ORC and steam cycle, are performing similar from an economic point of view (Zweiler, 2008).

**Figure 19: Wood chip fired CHP plant and its steam turbine of the Stadtwerke Augsburg Energie GmbH in Germany (capacity: 80,000 t/a wood chips; 7.8 MWel; 15 MWth) (Source: Rutz D.)**

**Figure 20: ORC system (1,520 kWel) of the Grünfuttertrocknungsgenossenschaft Kirchdorf a.H. eG in Germany (Source: Rutz D.)**

**Biomass gasification** systems are known for more than 100 years, but became mature after 2002 for mid- to large-scale systems and after 2012 for small-scale systems. Based on some demonstration and commercial plants gasification is nowadays applied to many applications, especially at small-scale. Gasification systems for woodchips or pellets often have a capacity of 10-100 $kW_{el}$ (Figure 21).

Gasification is a process that converts the solid biomass into a usable gas consisting mainly of hydrogen, methane, carbon monoxide and carbon dioxide. The biomass reacts at high temperatures (>600°C) with a controlled amount of oxygen ($0<\lambda>1$) to producer gas. This step is similar to the first step of a combustion process, where gas is converted to gaseous products. On the contrary to a combustion process this gas is not incinerated in situ. Therefore up to 80% of the chemical energy of the biomass is contained in the producer gas. This gas is used in a gas engine to generate power and heat in the case of a CHP. If another gasification agent than air is used, syngas is produced, but for utilization in a gas engine it is sufficient to use air as gasification agent.

Figure 21 shows typical small scale commercial gasification CHP units. The mass production led to this price decrease, thus gasification is nowadays also a good option at small scale.

**Figure 21: Small-scale gasifiers in a container (left) and during manufacturing (right) of the company „SpannerRE²“ (Source: Rutz D.)**

All aforementioned technologies have been assessed within different studies. One report combining the summary of some previous studies updated with latest development shows, that the discussed processes follow a common economy of scale, whereas just small differences between the discussed CHP processes occur (Zweiler, 2013). Figure 22 displays the marginal costs for electricity production of different technologies. After 2012 mass production of small scale gasification CHP's led to a decrease of electricity production costs at a power size up to a few hundred $kW_{el}$.

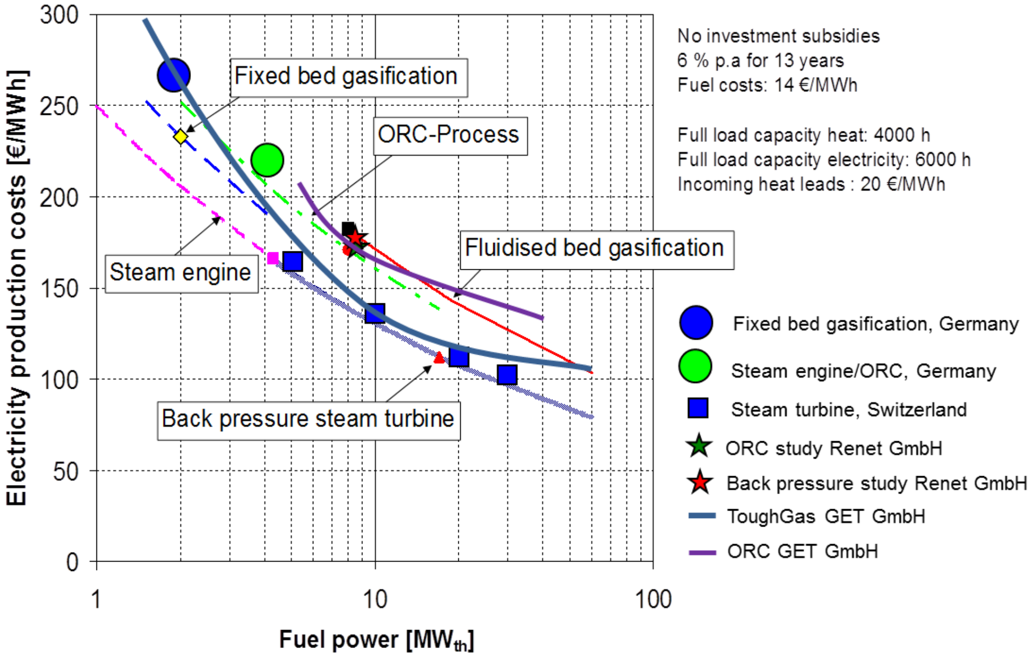


**Figure 22: Comparison of CHP processes for different power sizes based on the results from different studies (Zweiler, 2013)**

The proper selection and implementation of a CHP requires good know-how, but it is a mature technology with high efficiency. Important aspects for the selection of the CHP technology are:

**Fuel quality**: The lower the quality, the less it is suitable for fixed bed gasification. Currently fixed bed gasifiers require high quality wood chips larger than G50 or a standardised fuel, like pellets. Fluidised bed gasification and combustion based CHP’s are less sensitive to the fuel quality. They can process any kind of fuel, even residues or waste, but there is still some research and demonstration efforts required to demonstrate waste utilisation in fluidised bed gasification (Zweiler, 2013). Even less sensitive to fuel quality are boilers with appropriate feeding systems that provide the heat for Rankine Cycle CHP’s. They are in the position to handle nearly any kind of fuel. However the lower the fuel quality is, the more challenging are the cleaning methods for the exhaust gas emissions.

**Water content:** Due to low prices of fuels with high water content it may seem profitable to run a CHP with wet fuels (water content up to 60%), which is not preferable from an overall and technical point of view. Standard boilers are typically in the position to incinerate fuel with a water content between 5-40% (designed for dry fuel), or between 20% and 60% (designed for wet fuels). More flexibility can be achieved with flue gas recirculation. Again, fluidised bed gasification, or combustion CHP’s are more flexible in terms of high water content of the fuel. Due to the heat- and material balance of a fixed bed gasification plant, the maximum water content must not exceed 15%, otherwise waste water will be produced which is a problem for the process. For this reason, fixed bed gasifiers usually include a drying unit.

**Temperature Level**: Technologies based on the Rankine Cycle are very sensitive to the applied lower temperature level which should not be too high. This level defines the flow temperature of the DH grid. Larger heating grids with attached industrial consumers often require temperature levels above 120°C, which is not favourable for steam or ORC cycles. In this case, efficiencies decrease significantly compared to flow temperatures of 85°C. Depending on the power size, the electrical efficiency may be decreased from 18-20% to 15-17%. Fluidised bed gasification systems provide a stable electrical efficiency between 23% and 28% up to a produced flow temperature for the DH grid of 180°C.

### 3.2.5 Biogas systems[5]

Biogas is produced by **anaerobic digestion (AD)**. AD is a biochemical process in which various types of anaerobic microorganisms (bacteria) decompose complex organic matter (biomass) into smaller compounds, in the absence of oxygen. The process of AD is common to many natural environments such as in marine water sediments, stomach of ruminants or in peat bogs. Also in biogas plants organic input material, which is called feedstock, is anaerobically digested in order to decompose it into the two main products biogas and digestate. In most biogas plants, several feedstock mixtures are simultaneously used in order to stabilize the process to optimise biogas production. This is called co-digestion. Suitable feedstock for AD includes a large range of biomass materials, preferably consisting of easily decomposable material. This includes fats, oils, sugars, and starch. Also cellulose is easily decomposable, whereas lignin, a major compound of wood, is difficult to decompose by AD. Typical feedstock for biogas plants can be of plant and animal origin:

- Animal excrements (manure, slurry, dung)
- Agricultural residues and by-products
- Organic wastes from food and agro industries
- Organic wastes from biomaterial industries (e.g. pulp and paper, pharmaceuticals)
- Organic fraction of municipal solid waste
- Food waste from catering services
- Sewage sludge from wastewater treatment plants
- Dedicated energy crops (e.g. maize, sugar beet, grass)

The type of the feedstock influences the AD process and the final composition of the produced biogas. Biogas consists mainly of methane ($CH_4$, 40-80%) and carbon dioxide ($CO_2$, 15-45%) as well as smaller amounts hydrogen sulphide ($H_2S$), ammonia ($NH_3$), nitrogen gas ($N_2$), and other compounds. Furthermore, biogas is normally saturated with water vapour ($H_2O$). The methane yield is one of the most important characteristics of the used feedstock in the AD process. Besides the feedstock type, also other factors such as the design of the digestion systems, digester temperature, retention time, and organic load influence the composition of the biogas.

The European biogas sector accounts for thousands of biogas installations. Countries like Germany, Austria, Denmark, Sweden, Czech Republic, Italy and The Netherlands are among the technical forerunners, with the highest numbers of modern biogas plants. Today, electrical capacities of biogas plants range from 50 $kW_{el}$ up to 30 $MW_{el}$. Capacities of typical agricultural biogas plants in Europe using CHP units are in the range of about 500 $kW_{el}$, whereas about 550-600 $kW_{th}$ heat is produced. Thereof, about 500 $kW_{th}$ would be available for commercial heat use. About 25% of the produced heat is required to heat the digesters under central European climatic conditions. Assuming about 8,000 full load hours per year, the total energy of a 500 $kW_{th}$ biogas plant would be 4,000 $MWh_{th}$.

Biogas is an energy carrier with multiple use options (Figure 24). In the period of the biogas boom in Germany and Europe, some years ago, the maximization of the electricity output was the main focus of biogas plants. The focus on power generation was mainly due to most public support schemes for biogas plants that only considered electricity production (electricity feed-in tariff). Thereby, the efficient use of heat was often neglected. In the meantime, this has changed, as several countries have introduced appropriate tools to increase the use of waste heat, such as CHP bonuses, or mandates that request to use a

---

[5] For the elaboration of this chapter the BiogasHeat Handbook (Rutz et al. 2015) was used. Several parts of the text are taken from this source.

certain share of waste heat. An overview on options for heat use of biogas plants is given by Rutz et al. (2015).

The following figures are useful for the energy calculation and measurement of biogas plants:

- Energy content of 1 kg biomethane: 50 MJ
- Energy content of 1 Nm³ biomethane: 35.5 MJ or about 9.97 kWh
- Biomethane content of 1 Nm³ biogas: 0.45-0.75 Nm³
- Energy content of 1 Nm³ biogas: 5-7.5 kWh
- Electrical output of 1 Nm³ biogas: 1.5-3 $kWh_{el}$
- Density of 1 Nm³ biomethane: 0.72 kg/Nm³

Another figure which is useful for illustrating the energy content of biogas is the energy equivalent of 1 m³ biogas to about 0.6 l of domestic heating oil.

Considering the net energy consumption for heating and hot water per person of 7,373 kWh/a, the energy production of 4,000 $MWh_{th}$ in a 500 $kW_{th}$ biogas plant would be sufficient for the annual energy needs of 543 persons. This of course is only a rough estimation based on average numbers. Other factors, such as variable seasonal heat demand due to different climatic conditions in winter and summer need to be considered, too. This seasonality in heat demand is a major challenge for waste heat concepts for residential heating.

**Figure 23: Digesters of an agricultural biogas plant (left) and CHP unit (right) of a biogas plant (Source: Rutz D.)**

The integration of heat from biogas plants in small renewable heating grids is getting increasingly important. Various concepts are implemented. As biogas plants were planned in the past often in remote areas, on the “green” field a key challenge is often the distance to potential heat consumers. As an alternative to the direct heat pipeline from the biogas plant to heat consumers often a biogas pipeline is installed to a so called **satellite CHP** unit which is close to the heat consumers (Figure 25).

A further alternative for the use of biogas is its upgrading to **biomethane**, which has natural gas quality, and its injection into the natural gas grid. Several technologies exist for this upgrading: amine scrubbing, water scrubbing, pressure swing adsorption, membrane separation and cryogenic separation. Due to its relatively high costs, upgrading plants are usually only applied to larger biogas plants of >1 $MW_{el}$ capacity. Once the biomethane is in the natural gas grid, it can be used at any place with connection to the gas grid. As the gas is physically mixed with natural gas, a certification system allows the consumer to only use biomethane.

For planning how to use the heat from a biogas plant, it has to be considered that the digesters need to be heated in order to guarantee a stable and efficient process. Common digester temperatures range from 38°C to 44°C for typical mesophilic biogas plants, depending on the feedstock and on the overall process. The digesters can be heated by different technologies, e.g. by heating pipes along the digester walls, or by pumping the digestate through a heat exchanger.

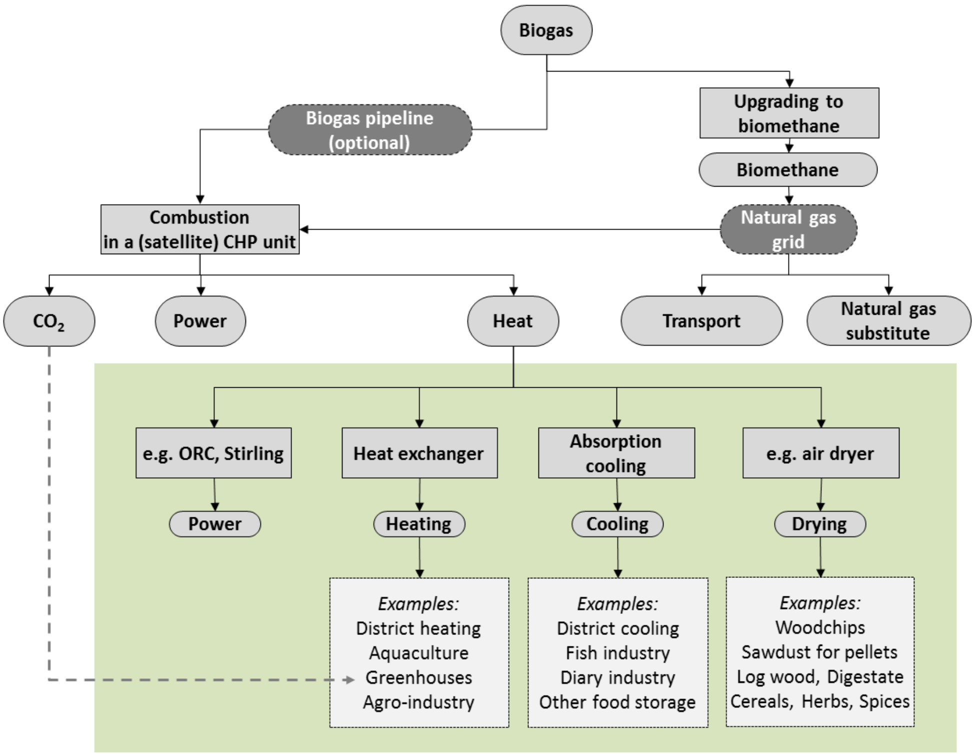


**Figure 24: Simplified flowchart for the use of biogas (Source: Rutz et al. 2015)**

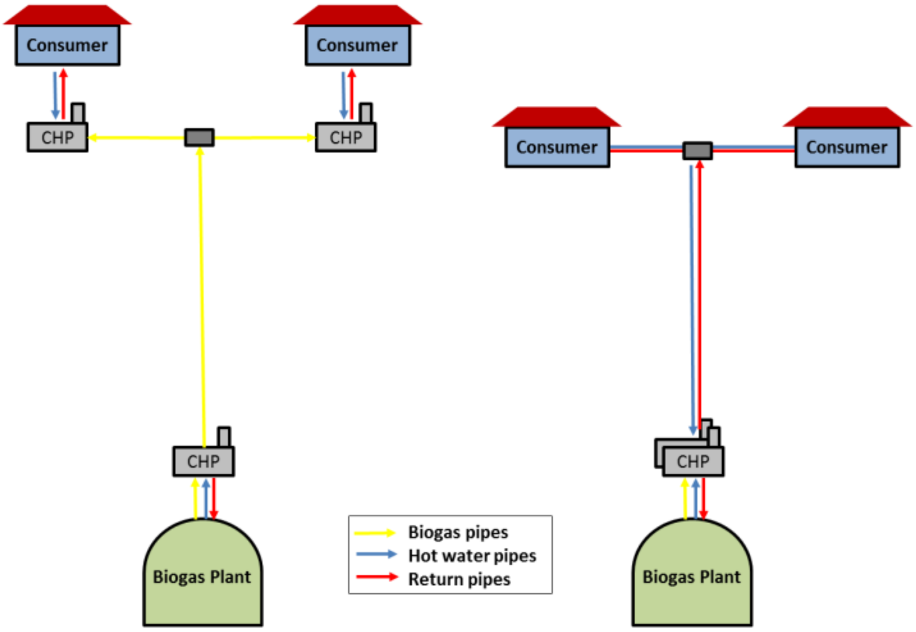


**Figure 25: Biogas pipeline to satellite CHPs (left) and micro-district heating system (right) (Source: Rutz et al. 2015)**

For heat concepts, the heat demand of the digesters is important, since this influences the heat quantity available for further purposes. The heat demand of the digester is influenced by the ambient temperature and thus by climatic conditions. Furthermore, in waste treatment plants, heat may be also needed for hygienisation of the feedstock. Examples for the heat demand of digesters are shown in Figure 26 and Figure 27.

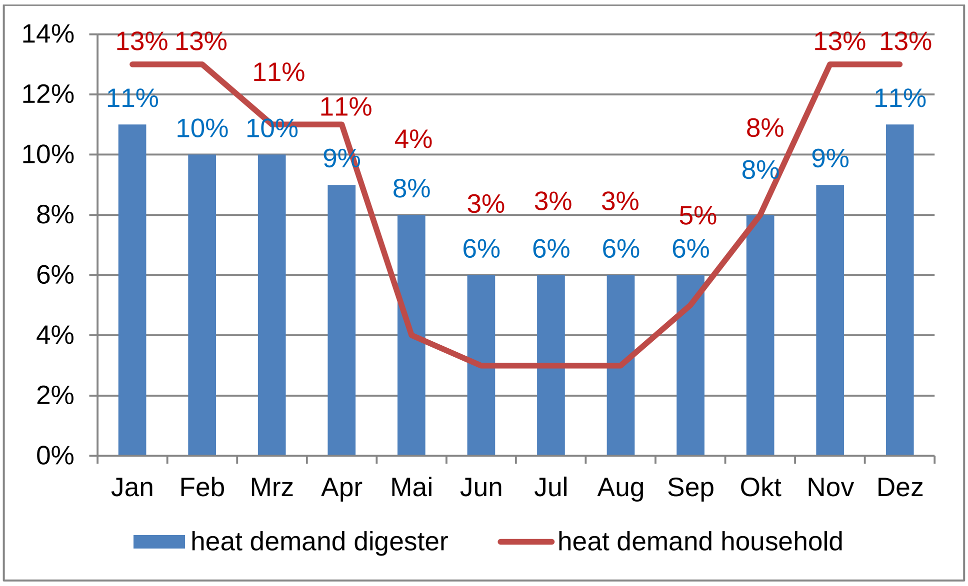


**Figure 26:** **Monthly distribution of the heat demand of a digester (assumption) and of a household (space heating and hot water supply; measured data) from a BiogasHeat case study in Germany (Source: Rutz et al. 2015)**

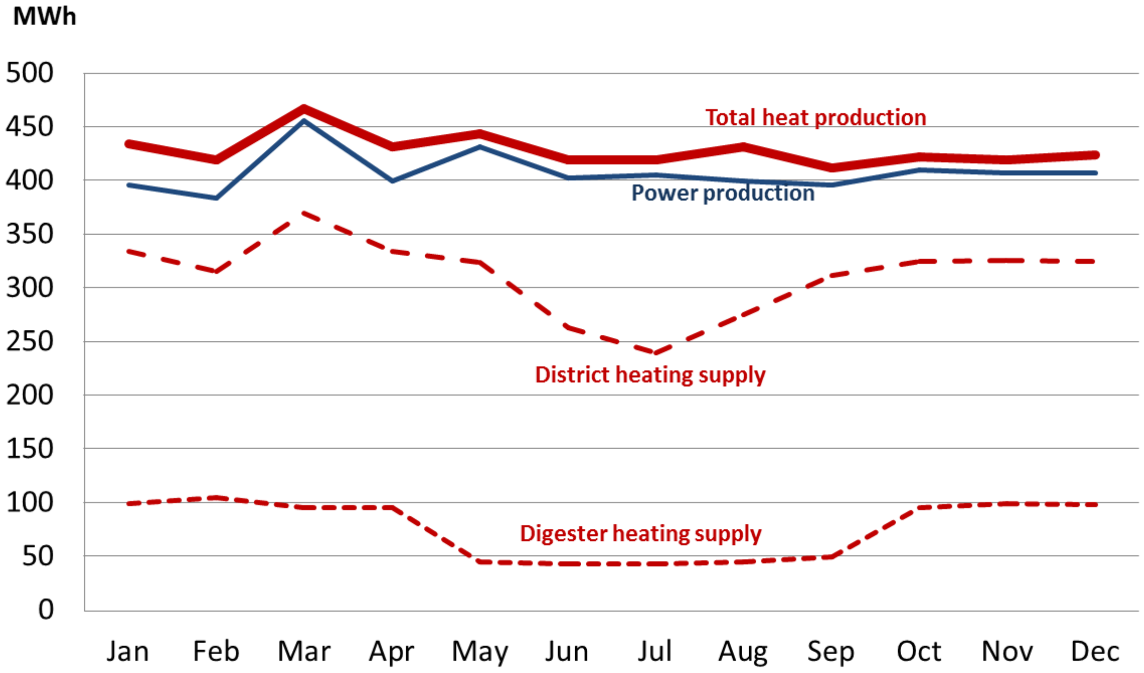


**Figure 27:** **Example of heat supply curves during one year for a 600 $kW_{th}$ biogas plant in central Europe (Source: Rutz et al. 2015)**

### 3.2.6 Plant oil systems

Plant oils are derived from pressing the seeds of dedicated oil crops. Important oil crops in Europe are rapeseed and sunflower. An overview on oil crops is given by Rutz & Janssen (2008) In the Biofuels Technology Handbook. Plant oils can be either directly used as transport fuel or converted by transesterification into biodiesel and then used to substitute fossil oil. If used in the transport sector, these fuels are called "biofuels".

Plant oils can be also used in stationary oil boilers or stationary CHP units. In this case, they are called "bioliquids" (EC, RED Directive). Some years ago, there were very good incentives in Germany to operate stationary plant oil CHP units as it was supported by high feed-in tariffs. Due to sustainability issues, these incentives were cancelled, so that today the use of plant oil in stationary boilers or CHP units is neither widely applied in Germany nor in other countries.

However, its use has some niche applications. In some small renewable district heating grids, peak-load boilers are needed in order to supply heat at maximum heat demand (see chapter 3.7). As peak load boilers, sometimes fossil oil boilers are used which could be easily substituted with plant oil boilers.

**Figure 28 Rapeseed oil CHP unit (Source: Rutz D.)**

## 3.3 Geothermal energy

Geothermal energy is the heat generated and stored in the Earth. It originates from the formation of the earth and from radioactive decay of materials. There is a difference in temperature between the core of the planet and its surface, called geothermal gradient. The core of the earth has extremely high temperatures and the rock is molten (magma). The temperature level changes at different depths in the crust. In some areas, high temperatures are very deep below, in some other areas, high temperatures are very shallow.

Geothermal energy can be used as an energy source in many ways, from large and complex power stations to small and relatively simple pumping systems. The use of geothermal energy depends on the geothermal temperature gradient, being the temperature at a certain depth. Power generation from geothermal energy is feasible only at high temperatures which are close to the Earth's surface. If the temperature is lower, e.g. 100°C, it is difficult to use it for electricity production, but it can be used as source for heating.

Depending on the temperature gradient, different concepts exist for the extraction of geothermal heat. Usually, geothermal brine is pumped up by one well (the production well) and the heat is extracted through heat exchanges or heat pumps. Then, the brine is pumped back to the underground through a second well (the injection well). Figure 29 shows this concept.

Geothermal wells are quite similar to oil and gas wells. The same technology and equipment is used, but typically geothermal wells have a larger diameter, as the volumes that have to be pumped up and reinjected are relatively large. (Dansk Fjernvarme, 2016)

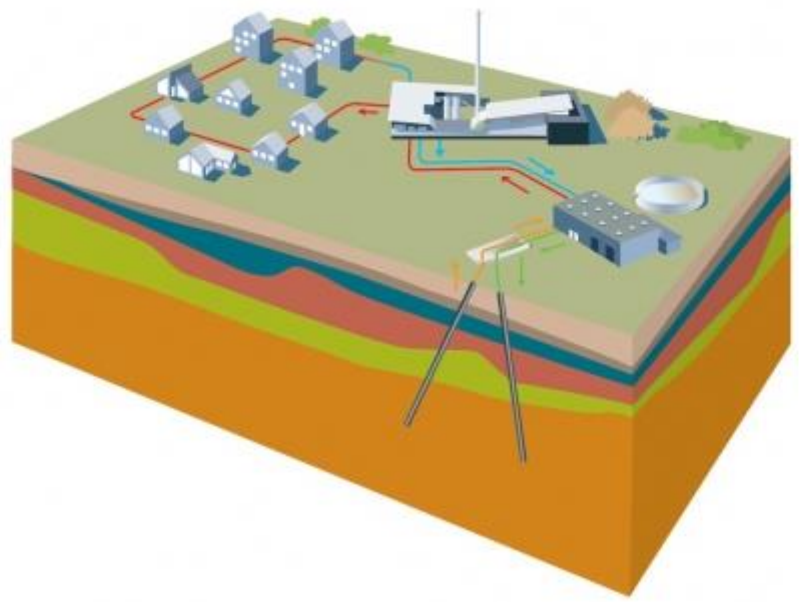


**Figure 29: The geothermal concept (Source: Danish Geothermal District Heating, 2016)**

The main benefits of geothermal heating and cooling are the provision of local and flexible renewable energy for baseload, diversification of the energy mix, and protection against volatile and rising fossil fuels prices.

25% of the EU population lives in areas directly suitable for geothermal district heating (GeoDH, n.d.). Currently, there are around 250 geothermal DH systems (including cogeneration systems) in operation in Europe, with a total installed capacity of about 4,400 $MW_{th}$ and an estimated annual production amounting to some 13,000 GWh/y (2013). There has been an increase in development of geothermal district heating systems in the past few years, in particular in France, Germany and Hungary. There are 200 planned projects (including upgrading of existing plants), which will imply that the capacity will grow from 4,500 $MW_{th}$ installed in 2014 to at least 6,500 $MW_{th}$ in 2018. Hence, geothermal heat is exploited in many parts of Europe, and there is a potential for further utilization of this renewable energy source. Geothermal heat is available in many parts of Europe (Figure 30) and DH is a method by which geothermal heat can be economically distributed on to buildings at large scale.

Figure 30 illustrates existing and potential district heating in south-eastern Europe and Europe. The maps are interactive online-maps and have different layers, which can be turned on and off, illustrating different features of heat demand, heat flow density, reservoirs and temperatures.

**Figure 30: Maps showing existing district heating systems (red dots) with geothermal energy (left) and potential for geothermal energy (right); Legend: temperature > 50°C at 1,000 m depth (blue) and temperature distribution > 90°C at 2,000 m depth (red); purple colour = overlap of the two layers. (Sources: http://map.mfgi.hu/geo_DH/)**

A key characteristic for geothermal energy is its relatively high investment costs, in particular in areas, where the reservoir is deep underground. Thus, geothermal energy is best feasible in areas with relatively high temperature levels at relatively shallow depths and if it can be supplied as base load capacity to a relatively large district heating system. Another key characteristic, in particular regarding the deep reservoirs, is the risk associated with drilling of boreholes of 2-3 km depth.

Depending on the accessible temperature level, it may be reasonable to combine geothermal energy with heat pumps in order to increase the temperature levels. These can be either electrical heat pumps or absorption heat pumps, which can be driven by other renewable energies such as by biomass boilers. Hence, the utilization of geothermal energy sometimes implies considerable additional inputs such as biomass or electricity. This also affects the operation costs, which are relatively low for the geothermal energy itself (pumping costs), but also includes costs for electricity and/or biomass in case of application of heat pumps.

The pumping costs increase with the depth. From experiences in Denmark, it is thus economically more attractive to use heat pumps and extract heat from shallower reservoirs, typically at 1,000-3,000 m depth, where temperatures are 30-90°C. This geothermal gradient of 30°C for each 1,000 m depth is a general rule of thumb. (Frederiksen & Werner, 2013)

When planning geothermal plants, the annual energy production should therefore be relatively large since it must be able to pay back and write off the cost of wells and surface facilities. Based on data from the Danish Energy Agency, a district heating system should have an annual sale of at least 400-500 TJ before the geothermal heating prices are competitive with current price ratio (experiences from Denmark). This may vary from country to country, depending on the geothermal potential.

The potential of deep geothermal is significant. However, geothermal DH is at present poorly developed. Four key areas have been identified as important to improve this situation (GeoDH, n.d.):

- Consistent energy strategies aiming to decarbonise the heat sector
- The removal of regulatory and market barriers, and simplified procedures for operators and policy makers
- The development of innovative financial models for GeoDH projects, which are capital intensive
- The training of technicians, civil servants, and decision-makers from regional and local authorities in order to provide the technical background necessary to approve and support projects.

There are several support projects concerning the use of geothermal for district heating and cooling, such as the following ones:

- In the period 2012-2014 the EU-financed project GeoDH[6] was carried out. This project had the main focus of the non-technical barriers for deployment of geothermal energy in district heating systems in 14 countries in Europe. The project produced a number of guidelines and a video, explaining the basic concept of geothermal energy.
- A general outline of the geothermal technology is the technology roadmap for geothermal heat and power from 2011[7]

### 3.4 *Excess heat*

Excess heat (also called waste heat or surplus heat) from industry or from other renewable energies (e.g. biogas) is an interesting heat source, since the price can be very low. Before applying this option, an analysis of the energy flow in the industry is required, including identification of temperature levels as well as energy efficiency potential.

The feasibility of using excess heat always depends on the location of the industry, the amount of available heat and the temperature level of the heat. Exploitation of excess heat is characterised by the available heat amount, which the industry cannot utilize itself. The utilisation of excess heat shall not influence the process in the industry. It has to be considered, that if the production in the industry is interrupted, the supply of excess heat is also interrupted. Hence, the dynamics of the specific industry should be taken in to account.

Another key point is the risk of engaging with an industry, which may stop one day its production. Hence, the agreement should clearly define how the risk related to the investment is split between the parties. Typically, the industry wants to depreciate the investment within a short period (e.g. three to five years), which is a relatively short period for the district heating utility.

This becomes particularly important in case the excess heat constitutes a high share of the district heating supply. One example from Denmark (Skjern Papirfabrik delivering heat to Skjern district heating utility)[8] shows a share of more than 50% of excess heat in a district heating system, but in other district heating grids typically, the share is relatively small.

The Heat Roadmap Europe 2050 provides options for maps showing heat demand as well as potential for different energy sources, including excess heat from industry. This can be a first step based for identification of possible heat sources.

---

[6] www.geodh.eu

[7] http://www.iea.org/publications/freepublications/publication/Geothermal_roadmap.pdf

[8] http://www.skjernpaper.com/sustainability/production-of-district-heating

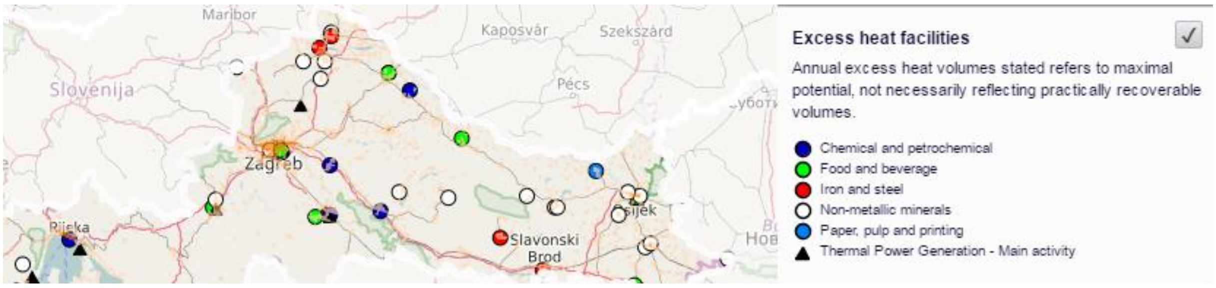


**Figure 31: Examples of excess heat potential in Croatia**[9]

Another approach is to contact the nearby energy consuming industry and to get in dialogue on the options of utilizing the excess heat. Usually, the industry would be interested in getting an income from a waste product, but often they do not want to put too much effort in it, since it is not their core business. This implies that the initiative should be taken by the district heating company.

When using excess heat, often a heat pump is applied in order to increase the temperature level to the required supply temperature in the district heating system.

Besides the use of industrial waste heat, also the heat from other renewables, such as from existing biogas plants can be used. Reasons why biogas plants often still do not efficiently use their heat are described in Box 5. An advantage of using the heat of existing biogas plants is its continuous availability throughout the year and its relatively low costs, depending on the specific framework conditions, of course. A challenge is that many biogas plants are in rural areas “on the green field” and not in vicinity to potential heat consumers. For new biogas plants, the heat use, and hence the location of the biogas plant, shall be considered already in the planning process. More details on biogas are described in chapter 3.2.5.

**Box 5: Why do some biogas plants produce excess heat?**

In Europe, as well as worldwide, the production and use of biogas is considerably increasing, due to the growing demand for renewable energy as substitute for fossil energy carriers. Most agricultural and industrial biogas plants in Europe use the biogas for electricity production in CHP units. However, in many cases the heat from the CHP unit is not used, but wasted. This is a result of the focus of many support schemes on electricity production neglecting the efficient use of heat. The inefficiency in energy use is a bottleneck in current biogas production, causing macroeconomic and microeconomic losses and challenges in the context of increasing land use competition. More information on the use of waste heat from biogas plants is available in the Handbook “Sustainable Heat Use of Biogas Plants - A Handbook” (Rutz et al. 2015).

## *3.5 Electric boilers: Power-to-Heat*

The conversion from electrical energy to thermal energy takes place at almost 100% efficiency. However, the generation of electricity is usually related to energy losses. Hence, the overall efficiency of the whole chain depends largely on the power source. Furthermore, the exergy (= flexibility to use the energy) of power is higher than of heat, that it the reason why usually the use of electricity for heating is not recommended.

---

[9] http://maps.heatroadmap.eu/maps/30662?preview=true#

The application of electric boilers in district heating systems is primarily driven by the demand for ancillary services on the electricity market rather than the demand for heat. Hence, the use of electric boilers is usually a supplementary technology, generating income on the electricity market, thus reducing the heat price. Electric water heaters can be a part of the energy system facilitating the utilization of peak-load wind energy and enabling efficient utilization of various heat energy sources.

Electric boilers are devices in the MW size range using electricity for the production of hot water for industrial or district heating purposes. They are usually installed as peak load units in the same way as oil or gas boilers. Generally, two types of electric boilers are available:

- Heating elements with **electrical resistances**: this is based on the same principle as a hot water heater in a normal household. It is used for smaller applications up to 1-2 MW. These electric boilers are connected at low voltage.
- Heating elements with **electrodes** (Figure 32): They are used for larger applications (larger than a few MW) and are directly connected to the medium to high voltage grid.

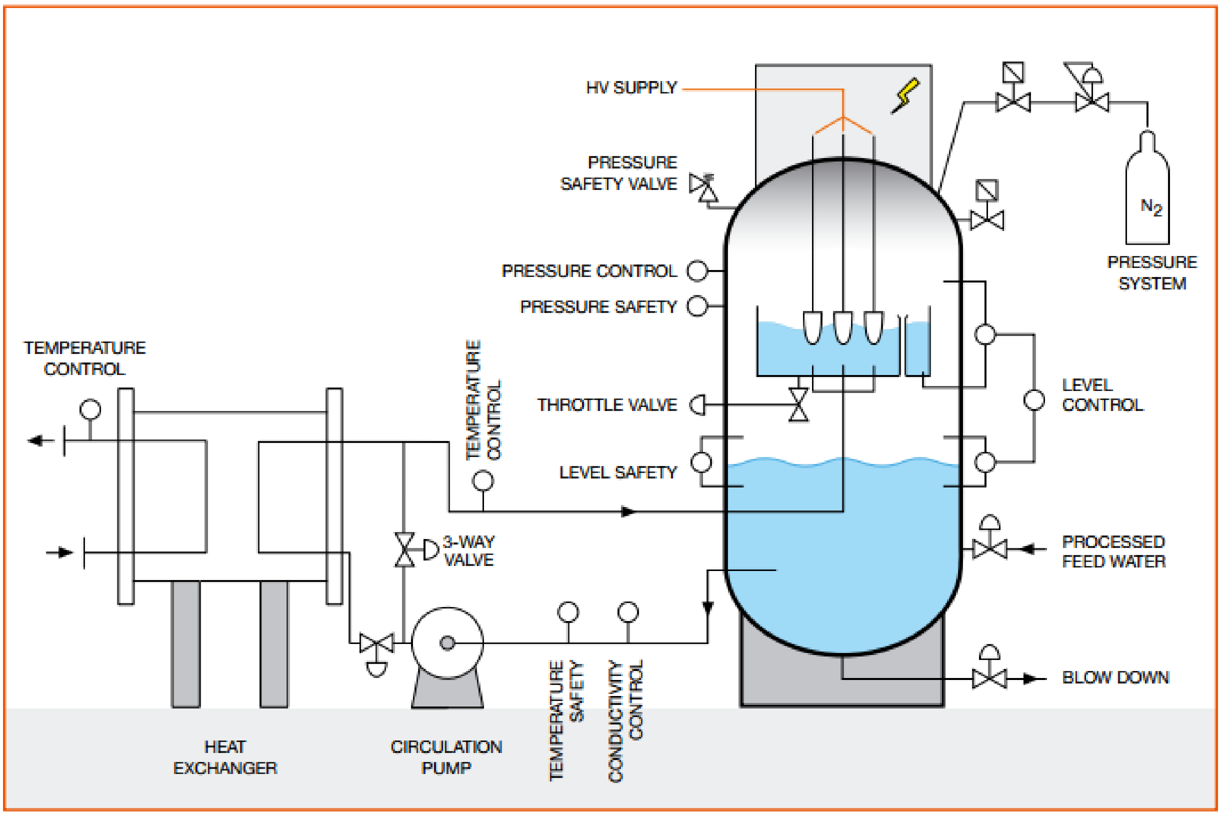


**Figure 32: Schematic illustration of an electrode boiler. The heat is generated in the upper chamber through ohmic resistance between the electrodes. The boiler is pressurized with an inert gas system, e.g. nitrogen (Source: PARAT Halvorsen AS[10])**

---

[10] http://parat.no/en/products/industry/parat-ieh-high-voltage-electrode-boiler/

**Figure 33: Electric boiler of 10 MW and 14.4 m³ capacity of the solar district heating plant in Gram, Denmark (Source: Rutz D.)**

Due to its very simple design, the electric boiler is extremely reliable and easy to maintain. The boiler has no complex built-in components, which may impede operation and maintenance. The boiler can start up quickly and is easy to regulate. It requires no fuel feeding systems and no stack.

The use of electric boilers is frequently implemented in DH systems in Denmark. There, 45 applications are installed with a total capacity of 490 MW. The largest applications are 80 and 93 MW (2015 and 2002 respectively). An interactive map, showing the different projects in Denmark, is accessible under www.smartvarme.dk (In Danish).

### *3.6 Heat pumps*

Heat pumps are not predominantly used as the primary source for heating grids, but as to optimise and improve systems based on other renewable energies such as solar thermal. They are able to use energy sources with too low temperatures to be used directly for district heating. The heat pumps use this energy by increasing the temperature level.

Heat pumps can be used in small modular renewable heating and cooling systems as **central** device in the heat generation unit. In this case, only one or a few heat pumps are used. They can be also used **decentralized** at the heat transfer stations at the consumers. In this case, each connection point has a small heat pump installed in addition to the heat exchanger and the transfer station. This can be applied if the flow temperature is kept low due to increased efficiency, but if hot domestic water is needed at the consumers. Examples of heat pumps in small modular renewable heating and cooling systems, both as centralized or decentralized equipment, are presented in the Best Practice report of Laurberg Jensen et al. (2016).

Heat pumps employ the same technology as refrigerators (see chapter 7.2), moving heat from a low-temperature location to a warmer location by a fluid, the so called refrigerant. Heat pumps extract heat from the ambience (input heat, heat source) and convert the heat to a higher temperature level (output heat) through a closed process. The process operation requires additional heat or electricity input. A general scheme of the heat pump process is shown in Figure 35.

A general advantage of heat pumps is that the heat pump is able to recycle waste heat or utilize energy from the ambient which enables a utilization of heat sources otherwise left unused by conventional heat production technologies. The heat source must be available and suitable according to the required heat demand. Changes in flow or temperature of the heat source will affect the performance of the heat pump, which can increase the complexity of a heat pump system.

Heat sources can be ambient air, surface water or groundwater, ground (soil) or surplus heat from industries. Typical average ambient air temperatures in northern Europe may be about 8°C, whereas in Southern Europe they may be above 10°C. These temperatures are similar to the temperature levels of the soil and the groundwater. Waste heat from industrial processes has much higher temperatures – sometimes enabling direct heat recovery. In some cases, the input heat is delivered through a secondary water or glycol circuit, but for optimum performance of the heat pump, the heat source should be connected directly to the evaporator of the heat pump.

Heat pumps are categorized according to their design or operational principle as follows:

- **Compressor-driven heat pumps**: Driven by electricity or by gas
- **Sorption heat pumps**: They are driven by gas or heat (“thermally driven” heat pumps): Absorption heat pumps and Adsorption heat pumps

Both types of heat pump technologies require a heat source (in the residential sector typically low temperature heat sources like ambient air or ground source) and process energy. The process energy for compression heat pumps is electricity (or engines consuming fuel), whereas absorption heat pumps are driven by heat; e.g. steam, hot water or flue gas, but also consume a small amount of electricity.

Heat pumps are also differentiated by the ways used to collect heat from the free source and ways used to distribute the heat in the house.

- **Air-to-Air heat pumps** draw heat from ambient air and supply heat locally through air heat exchangers.
- **Air-to-Water heat pumps** draw heat from ambient air and supply heat through a hydraulic heat distribution system (radiator, convectors, floor heating).
- **Brine-to-Water heat pumps** are generally taking heat from the ground using water pipes and are distributing heat in the house via a hydraulic system (radiator, floor heating etc.).

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 drive energy (fuel in thermal driven heat pumps or electricity). A COP of 3 means that the heat pump delivers three times more heat than the required drive energy, which is electricity in an electrical compression heat pump. Two thirds of the delivered heat is collected through the heat source.

Depending on the heat pump size, heat source, heat demand, temperature levels, and on practical issues, different types of heat pump technologies can be applied. An important technical characteristic of the heat pump is the **refrigerant** which is the fluid in the system. The physical properties of the refrigerant is mainly determined by its boiling temperature, as the phase transitions from liquid to gas and back are the key properties. Various refrigerants exist, among others hydrofluorocarbon (HFC) and hydro chlorofluorocarbon (HCFC). Further refrigerants are described below.

**Figure 34: 440 kW ground water heat pump in the small solar heating grid of Dollnstein, Germany (Source: Rutz D.)**

**$CO_2$** heat pumps operate in the so-called trans-critical pressure range, meaning that the refrigerant has a temperature glide on the warm side while the cold side evaporate at a constant temperature. This means that $CO_2$ is particularly suited in applications where heat is drawn from a low temperature source by cooling it only a few degrees, while the delivered heat is provided at a temperature glide of maybe 40°C. The maximum outlet temperature of $CO_2$ systems is approximately 90°C. In order to obtain good COP values in $CO_2$ systems the inlet temperature of the heated media should not be higher than approximately 40°C. An example of an installed heat pump using $CO_2$ as refrigerant is the Marstal Fjernvarme, Denmark - 1.5 MW – maximum temperature of 75°C, as shown in the in the Best Practice report of Laurberg Jensen et al. (2016).

**Ammonia** is a widely used refrigerant for industrial refrigeration meaning that large-scale equipment with high efficiencies can be utilized for the heat pumps. Ammonia is typically used for the largest plants reaching up to around 95°C utilizing special components for high pressure levels. Ammonia is also suitable for lower temperature levels where standard components are utilized meaning less investment cost and high COP values. Examples of installed plants using ammonia as refrigerant are the Drammen District Heating, Norway (15 MW – max. temperature of 90°C), Skjern Paper Mill, Denmark (4 MW – max. temperature of 90°C), and the Bjerringbro District Heating, Denmark (3.7 MW – max. temperature of 70°C).

**Lithium bromide (LiBr)/Water** is used in absorption heat pumps, whereas ammonia/water is typically used in absorption cooling systems. Water is the refrigerant meaning that the gauge working pressure is negative. The lowest possible temperature on the source side is around 6°C while the sink temperature can be up to around 85°C. The different temperatures influence each other meaning that a low source temperature can limit the delivery temperature for the heat sink. For higher temperature lifts, it is possible to buy absorption plants where two systems are built into one and connected in series to increase the temperature lift. Examples of installed LiBr/Water plants are the Bjerringbro District Heating, Denmark (0.9 MW (cooling) – max. temperature of 70°C) and Vestforbraending, Denmark (13 MW (cooling) – max. temperature of 80°C).

The efficiency of heat pumps can be increased if they can be operated in multi-stages that both cool and heat in steps to minimize thermal losses. Oil coolers, desuperheaters and subcoolers are utilized to minimize pressure differences and thus, the required mechanical work. High efficiency motors can be applied preferably cooled by water or by the refrigerant.

### *3.6.1 Electric heat pumps*

The basic principle of compressor-driven heat pumps is shown in Figure 35. Heat pumps consist of a low- and a high-pressure zone, which corresponds with the pressure level of the refrigerant being circulated in the heat pump. The intake of the heat source is the low-pressure zone, where the condensed refrigerant evaporates due to the thermal effect of the heat source (step 1 in Figure 35). This implies that the heat source is being cooled down. In compression heat pumps, the pressure of the refrigerant is then raised in a compressor (step 2), resulting in an increase of temperature. The water in the heating installation (step 3) is used to regenerate the refrigerant, by cooling the refrigerant and thus heating water (in ventilation systems and other air based heat distribution systems: air). The pressure in the high-pressure zone is regulated through an expansion valve (step 4), creating a flow of the refrigerant and resulting in a continuous process.

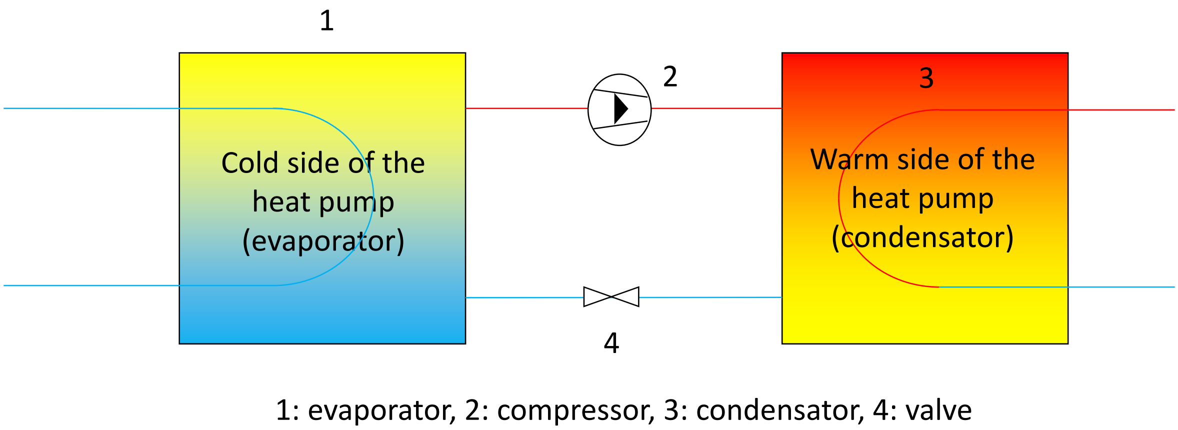


**Figure 35: Illustration of a compression-heat pump. The function of an engine driven heat pump is similar, as the compressor can be engine- or electrical driven. The main differences to sorption driven heat pumps is the way how the refrigerant is regenerated (Source: Danish Energy Agency & Energinet.dk, 2015)**

For compression heat pumps, the usable heat output is 3 to 5 times (COP) higher as the needed electricity. This factor depends on the efficiency of the specific heat pump, the temperature of the heat source and the heat sink and the temperature difference between heat source and heat sink. The energy flow is illustrated in the Sankey diagram in Figure 36.

The COP of electrical heat pumps is a function of the temperature of the heat source (in this case the ambient temperature) and the temperature of the heat sink (in this case the supply temperature in the central heating system). Therefore, the energetic performance of electrical heat pumps should be evaluated according to local conditions and thus be evaluated as a Seasonal Coefficient of Performance (SCOP) when comparing with other alternatives. In the following figures, the COP of an electrical driven heat pump is illustrated as a function of the temperature of the heat source.

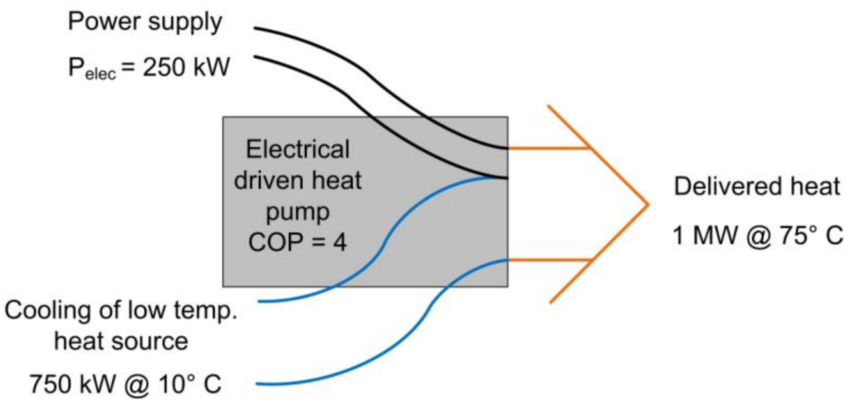


**Figure 36:** Sankey diagram of a 1 MW heat pump; The electrical power consumption of 250 kW enables the heat pump to utilize 750 kW from a low temperature heat source at 10°C, thus delivering 1 MW at 75 °C(COP is 4) (Source: Danish Energy Agency & Energinet.dk, 2015)

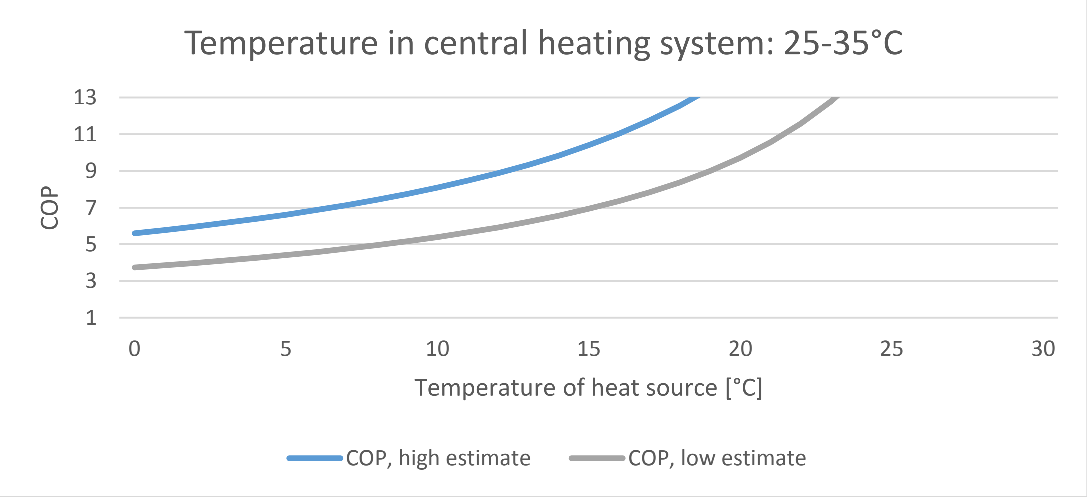


**Figure 37:** COP of a heat pump as function of the temperature of the heat source. Temperature levels of the central heating system: 25-35°C (return-supply), the cooling of the heat source is 5°C at all operating points. Lorentz-efficiency$_{\text{low}}$: 40%, Lorentz-efficiency$_{\text{high}}$: 60% (Source: Danish Energy Agency & Energinet.dk, 2016)

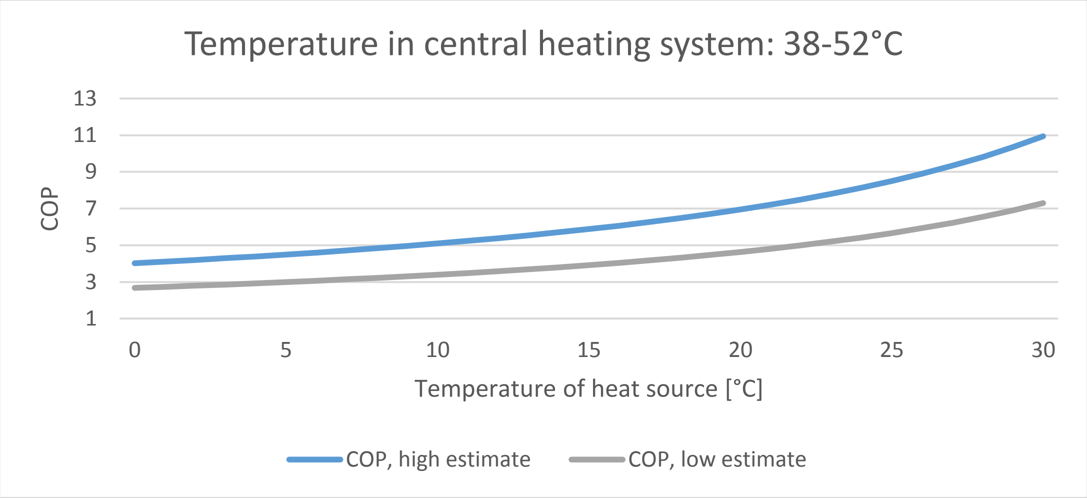


**Figure 38:** COP of a heat pump as a function of the temperature of the heat source. Temperature levels of the central heating system: 38-52°C (return-supply), the cooling of the heat source is 5°C at all operating points. Lorentz-efficiency$_{\text{low}}$: 40%, Lorentz-efficiency$_{\text{high}}$: 60% (Source: Danish Energy Agency & Energinet.dk, 2016)

As illustrated in Figure 37 and Figure 38, the temperatures of the central heating system (and the difference between supply and return) of the building have a crucial influence on the COP of the heat pump. The temperature range of the heat source is chosen according to the estimated reasonable operating points. Please note that the supply and return temperatures in buildings are subject to regional specific factors like building traditions, regulations and comfort preferences by the consumers which vary across Europe. The above chosen temperature sets are chosen in order to illustrate the difference between typical temperature sets in a building with floor heating (25-35°C) and a modern radiator heating system (38-52°C).

For the application of large scale heat pumps in district heating systems, the same points on temperature levels apply. The lower the supply temperature, the higher is the COP and thus the lower is the heat price. A varying supply temperature becomes relevant, optimising the supply of heating and the related costs.

Compression heat pumps that are electrically driven have no emissions from burning fuel, meaning that these systems can be installed in locations with restrictions on exhaust emissions. However, the real primary energy factor depends on the production of electricity (e.g. fossil, nuclear, renewable etc.), which varies considerably by country and will also fluctuate and evolve with time.

In energy systems, where electricity plays a vital role, compression heat pumps can incorporate electricity in heating systems in an effective manner. For processes that are electrically heated, heat pumps reduce power consumption and load on the electrical grid.

### *3.6.2 Sorption heat pumps*

**Absorption heat pumps** are driven not by electricity, but by a heat source which acts as process heat. This heat regenerates the refrigerant that can evaporate at a low temperature level and hereby utilize low grade energy. Energy from both drive heat and the low temperature heat source is delivered at a temperature in between. In theory 1 kJ of heat can regenerate around 1 kJ of refrigerant meaning that an absorption heat pump has a theoretical maximum COP of around 2. Due to losses in the system, the practical COP is around 1.4 to 1.7. The energy flow of an absorption heat pump is illustrated in the Sankey diagram in Figure 39.

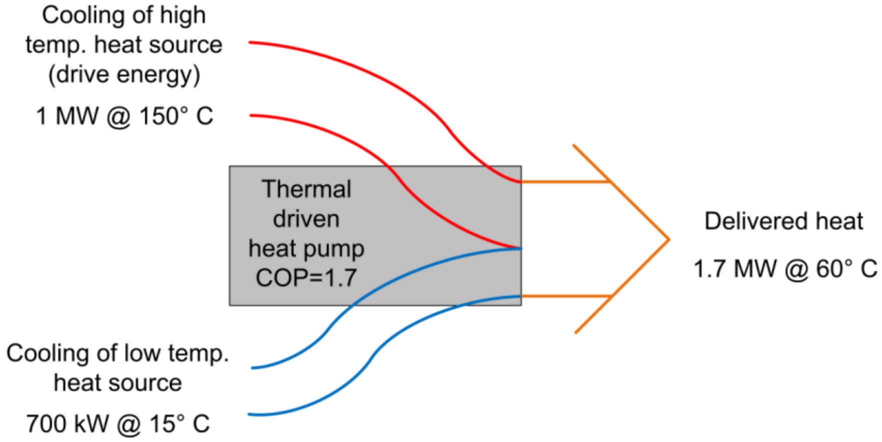


**Figure 39: Sankey diagram of a 1.7 MW absorption heat pump. The high temperature drive energy of 1 MW enables the heat pump to utilize 700 kW from a low temperature heat source at 15°C. Thus delivering 1.7 MW at 60°C (COP is 1.7) (Source: Danish Energy Agency & Energinet.dk, 2015)**

The principle of operation of **adsorption heat pumps** is similar to that of the absorption heat pump. However, the main difference is that an adsorption heat pump uses solid-sorption instead of the liquid-sorption that is used in absorption systems. Regularly applied material pairs in adsorption heat pump systems are:

- Zeolite – water
- Silica gel – water
- Active carbon – methanol
- Active carbon/salt - ammonia

### *3.6.3 Comparison of heat pumps*

The economic characteristics of gas driven and electric heat pumps must always be compared in a total economic perspective comprising investment and operation costs of the alternatives, including all necessary component costs for the given alternative installations. This is mainly due to potential differences in the dimensioning of the heat source, as exemplified in the table below. The heat amount of the source for a gas driven heat pump can be smaller than the heat source for an electric heat pump, as the drive energy in a gas driven heat pump supplies a larger share of the total energy input.

**Table 3: Advantages and disadvantages of different heat pump technologies (Source: PlanEnergi)**

| Heat pump | Advantages | Disadvantages |
|---|---|---|
| **Electrical, air-to-air** | Can be a relevant option in buildings without a waterborne central heating system<br>Simple installation, no earthwork operations required<br>Typically low investment costs<br>Reversible air-to-air HPs can cover both heating and cooling demands | Generally low convergence between optimal operation conditions and high heat demands<br>One unit per room or other technologies for other rooms needed<br>In humid frost periods, ice may build on the outdoor-units, decreasing the efficiency<br>Cheaper products may cause noise pollution |
| **Electrical, air-to-water** | Higher COP in the heating season than e.g. air-to-air HPs<br>Simpler installation than e.g. ground source HPs | Cheaper products may cause noise pollution<br>Efficiency dependent on outdoor temperature and supply temperature to heating system. Thus least efficient in cold periods, when demand is highest.<br>Most models have a max. output temp. of 55-60°C, thus requiring a continuous flow water heater for higher temperatures or peak demands.<br>A high SCOP may require an adjustment of the central heating system (i.e. additional investments) |
| **Electrical, brine-to-water** | Higher COP in heating season than e.g. air-to-air and air-to-water HPs<br>Less variation in COP throughout the year<br>The same unit can cover space heating and tap water demands<br>No potential noise pollution from outdoor unit | Most expensive EHP-technology<br>Additional investment for ground-source heat collector.<br>A high SCOP may require an adjustment of the central heating system (i.e. additional investments)<br>Installation of brine-system may require earth work to be carried out (additional investment) |

| | | |
|---|---|---|
| **Electrical, groundwater** | High temperature-stability of energy source, thus low variation in COP due to heat source<br>Other advantages same as for ground source | High investment costs<br>Use of ground water for energy purposes may be restricted<br>Nearest aquifer may be too deep to reach with a simple well<br>Safety measures to prevent decontamination of groundwater need to be taken |
| **Electrical, ventilation air** | Possibility to increase fuel efficiency by recirculating (parts of) the waste heat that would otherwise be emitted from the building | Requires a ventilation system, which may be expensive or impossible to implement in existing buildings<br>Thermal capacity is limited by the exhaust heat from the building and not all energy losses can be utilized |
| **Gas, absorption** | Mature technology, e.g. to replace existing gas boilers<br>Higher fuel efficiency of natural gas than e.g. boilers | Very limited product variety on the market |
| **Gas, adsorption** | Easy to replace gas boilers<br>Zeolithe (refrigerant) has GWP=0, opposed to HFC-refrigerants in most heat pumps | Lower limit for input heat of approx. 2°C, i.e. solar thermal or ground source heat are necessary to secure lower limit is reached<br>Slightly lower fuel efficiency than e.g. absorption heat pumps<br>Very limited product variety on the market and limited operation experience |
| **Gas, engine driven compressor** | Mature technology for commercial purposes<br>High SEER, compared to other gas heat pumps and thus a good technology when cooling is also needed | Currently, the technological development is focusing on commercial appliances<br>Noise from the engine may be an issue |

### *3.7 Peak load and back-up boilers*

This handbook only focuses on renewable components for small district heating systems. However, in order to make projects feasible, sometimes fossil heat boilers (heating oil/natural gas) are needed as a minor component, for instance as peak load and back-up boiler.

**Peak load boilers** are boilers that are only switched on if all other components are not sufficient to supply the peak heat demand. Usually, this situation occurs only during a few days per year. However, the costs for having this capacity are rather high. Therefore, it may make sense to install a cheap peak load boiler, which makes the overall project feasible. This boiler could be also operated with biomethane as natural gas substitute (see chapter 3.2.5) or with plant oil as heating oil substitute (see chapter 3.2.6).

In the case that other system components of the small district heating grid fail, **emergency boilers (back-up boilers)** may be used to provide heat. They can be based on oil or gas. Depending on the overall system design and on the business concept, emergency boilers may be installed as back-up system or could be integrates from external service providers in the case of emergency.

In some special cases of small district heating grids, especially if heat is supplied by the waste heat of a biogas plant, the heat grid operator only provides base load heat and does not guarantee full heat supply. In this business model, the heat price for the consumers is lower as their heat supply is not guaranteed. Therefore, they have to maintain their individual heating system in their house, which then act as emergency or peak load boilers. This special case is described in detail by Rutz et al. (2015).

**Figure 40: Peak load boiler for fossil heating oil at a biogas plant in Germany (left) and natural gas boilers (right) at a biomass plant in Czech Republic (Source: Rutz D.)**

# 4 Heat storage technologies

Storage technologies can help to detach the production from the demand and to balance (buffer) fluctuations of energy production. Storages increase the flexibility to utilize sources of energy that are not available at the same time as the demand. They can also store cheap energy, e.g. low prized electricity that can be converted to heat. Furthermore, storages help to increase the efficiency of production units. They enable e.g. biomass boilers and CHP plants to operate continuous at higher capacity.

The purpose of storage is to produce heat or cooling while the production conditions are as effective and favourable as possible, e.g. production of solar thermal during the day or production of electricity while electricity prices are high in relation to CHP. The size of the storage depends on the time and amount of stored energy.

Depending on the time when the heat is needed from the storage, a typical classification is made between short term storages and seasonal storages. Short-term storages balance the heat supply and demand of a few hours to some days. They are also called buffer tanks. Seasonal storages are much larger, as they balance the heat supply and demand from one season to another. This is mainly applied for storing solar thermal heat from summer to wintertime.

The following types of storage technologies exist:

- **Sensible storage**: use the heat capacity of the storage material. The storage material is mainly water due to its high specific heat content per volume, low cost and non-toxic media.
- **Latent storages**: make use of the storage material’s latent heat during a solid/liquid phase change at a constant temperature. They use Phase Change Materials (PCM).
- **Thermochemical storages**: utilize the heat stored in a reversible chemical reaction.
- **Sorption storages**: use the heat of ad- or absorption of a pair of materials such as zeolite-water (adsorption) or water-lithium bromide (absorption).

In **sensible heat storages**, the temperature of a material is increased by addition of heat. In this way, heat is stored in the material and the storage properties depend on the material´s heat capacity as well as thermal insulation of the system. Mainly water is used as storage material. The technology is well known from e.g. hot water tanks in residences. This is the most frequently used storage system and further explained in chapter 4.1 and 4.2.

The most frequently used technologies of sensible heat storages are (Figure 41):

- **Tank thermal energy storage**, TTES (mainly daily storage)
- **Pit thermal energy storage**, PTES (daily to seasonal)
- **Borehole thermal energy storage**, BTES (daily to seasonal)
- **Aquifer thermal energy storage**, ATES (daily to seasonal)

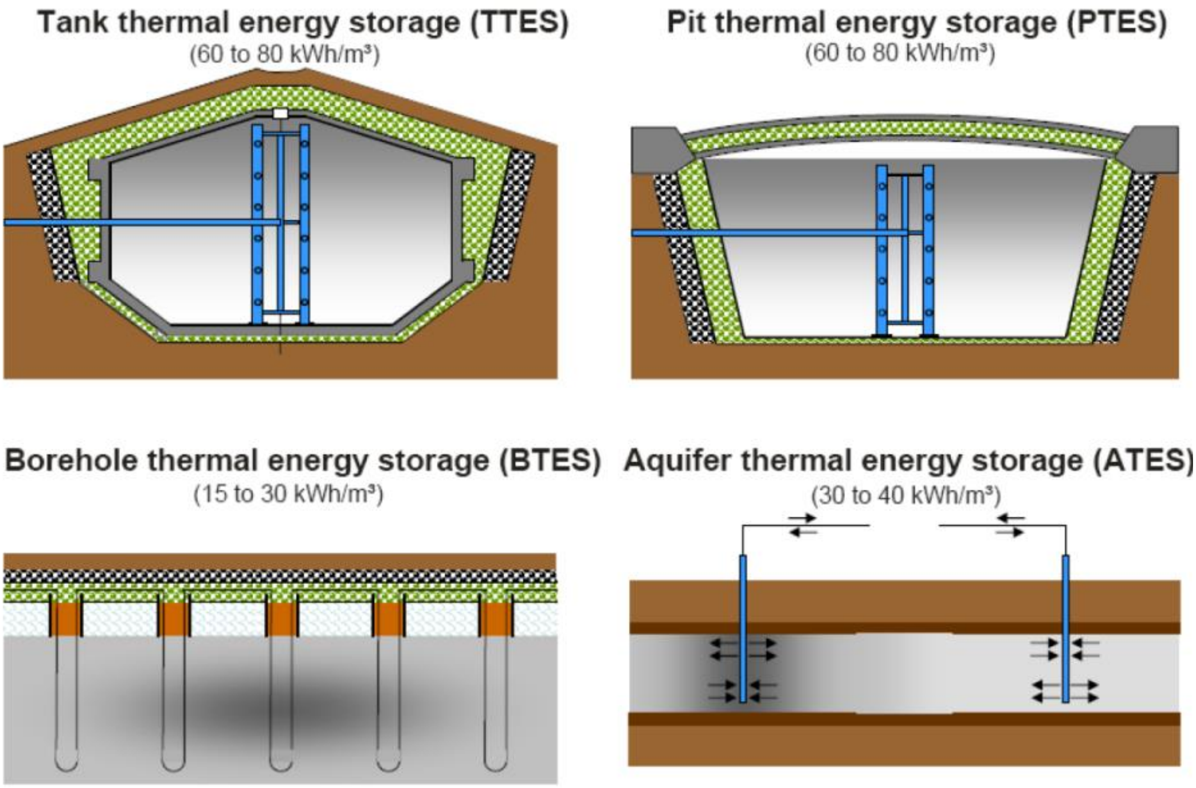


**Figure 41: Concepts of thermal energy storages (Source: Steinbeis Forschungsinstitut Solites)**

**Latent storages** use **Phase Change Materials** (PCM), which are subjected to a phase change induced by addition of heat. If the phase change is associated with heat of transformation (which is the case for most phase changes) heat is stored in the transformed material and can be released by the reversed transformation. Storage properties depend on the heat of transformation and thermal insulation.

A special application for heat storage using PCM is the storage in **mobile containers** (Figure 42). They can be applied where it may not be possible to install district heating systems either as the distances are too far or as it is not possible due to legal or other framework conditions. However it must be noted that this technology is not yet widely applied. Only few manufacturers are currently offering heat storage systems in containers.

High temperature latent heat storage (HT-LHS) above 300°C and low temperature latent heat storage (LT-LHS) below 0°C are examples of these technologies together with traditional phase change materials within the temperature span between 0°C and 300°C.

By storing heat using **thermochemical** heat storage, a reversible chemical process, involving change of system enthalpy is utilized. An example of a practically usable reaction is metal hydride splitting/formation and is illustrated by Equation 2.

The storage capacity of thermochemical storages depends on the involved enthalpy change, but losses over time are reduced to zero, if the reversed process is prevented simply by isolating the evolved gas by a valve. The heat can then be regenerated by opening the valve and thereby allowing the reversed reaction.

$$MH_2 + \dot{Q} \leftrightarrow M + H_2$$ **Equation 2**

$\dot{Q}$ *heat required to dissociate the hydride (the hydride splitting is an endothermic process) [W]*

$M$ *Metal*

$H_2$ *Hydrogen*

**Figure 42: Heat storage container on a trailer at a waste incineration plant (Augsburg, Germany) (Source: Rutz D.)**

Finally, **sorption storages** use the heat of ad- or absorption of a pair of materials such as zeolite-water (adsorption) or water-lithium bromide (absorption). They have gained a lot of interest, due to their high energy densities and long-term preservation ability for thermal energy.

## 4.1 Short-term storage

There are a range of different short term storage technologies, which can help optimize the production of heat and cooling. However, the most commonly used is the **tank thermal energy storage**, mainly as steel tank.

Short-term thermal energy storage tanks are typically made of stainless steel, concrete or glass-fibre reinforced plastic. They usually contain water as storage material. Their size depends on the overall system size and range from household systems of some hundred litres water capacity, to storage tanks for district heating systems of several hundreds of cubic meters capacity. The insulation requirement of the storages is determined according to the climatic conditions, the temperature level, and its use. Some steel tanks of district heating systems in Denmark use 30 – 45 cm of mineral wool to keep heat losses low as shown in Figure 43.

**Figure 43: Establishment of steel tanks at Hjallerup District Heating. Left: Establishment of two new steel tanks in connection to the CHP plant in Hjallerup. Right: Establishment of a new steel tank in connection to the solar field and straw boiler. See more about Hjallerup DH in the Best Practice report of Laurberg Jensen et al. (2016) (Source: www.hjallerupfjernvarme.dk)**

The temperature level in storages can range from cold storages used for cooling purposes to hot storages, where the temperature in the top of the storage corresponds to the supply temperature of the district heating grid.

The **storage capacity** depends on the temperature levels in the storage, since the storage capacity for sensible heat storage is expressed as shown in Equation 3. The larger the temperature difference, the higher is the heat storage capacity for a fixed mass of the storage medium.

$$Q = m \cdot c_p \cdot \Delta T$$ **Equation 3**

| | |
|---|---|
| $Q$ | *stored heat* |
| $m$ | *mass of the storage medium* |
| $c_p$ | *specific heat capacity of the storage medium* |
| $\Delta T$ | *difference between the maximum and minimum operating temperature of the storage* |

Water is the most widely used storage medium for storing heat at temperatures below 100°C. If pressurized, water can also be used for storing heat at temperatures above 100°C. Water is normally chosen due to its advantages. It is not toxic, cheap and the physical characteristics are very good to store heat. The specific heat capacity of water is about 4.18 kJ/(kg·K), which is higher than that of most other low-cost, abundant materials such as sand, iron, or concrete.

The temperature supplied to the storage is typically the temperature produced from the heating units at the DH plant. In most installations the storage is capable of supplying the supply temperature in the DH grid. The temperature distribution in the storage is managed by a pipe system. This system serves to keep the efficiency of the storage as high as possible.

A vertical temperature distribution (temperature layers) in the tank is beneficial as the hottest water can be extracted from the top. This is referred to as **thermal stratification**. Some tanks have several outlets and connection points to the different heat sources so that heat can be extracted from the different layers. Using such tanks water can be extracted at the desired demand temperature level (e.g. from the middle part of the tank), while maintaining high temperature water in the top of the tank if the temperature in the top of the tank is higher than what is needed as supply temperature to the grid. This is especially useful when operating with very large storages, where a good thermal stratification needs to be maintained. A good thermal stratification is seen as a high temperature difference in the tank from top to bottom, in order to avoid having a large volume of too low temperature to be utilized in the grid.

Steel tanks are the most commonly used storage technology; nearly 300 Danish district heating plants have accumulation tanks. Steel tanks can be seen both as cylindrical steel tanks above ground, which is the most common case in Denmark or the storage can be located below ground level. This is for instance seen in Germany, where steel tanks are sometimes used even as seasonal storages in connection to solar thermal plants, supplying smaller residential areas. If the storage is placed as steel tank above ground, it can be dominant in the landscape. If the storage is below ground level, it is possible to use the area for other purposes.

The cylindrical steel tanks were originally used in Denmark in connection to CHP in order to maximize the revenues from combined heat and power production, when the electricity prices were high. The average size of these applications is approx. 3,000 $m^3$ and the sum of all these in Denmark is approximately 50 GWh. Due to the increased electricity production from wind turbines in Denmark, the yearly operation hours of the CHP’s are decreasing. Now, these tanks can also be utilised for solar heating plants, and they are sometimes supplemented by additional tank capacity. The storage(s) can also help to optimise the operation of other production units (e.g. biomass boilers).

### *4.2 Seasonal storage*

Seasonal storages balance the heat supply and demand from one season to another. This is mainly applied for storing solar thermal heat from summer to wintertime. A seasonal storage enables a high solar fraction, but also implies a higher investment. The seasonal storage should be designed for the expected capacity, as it is not suitable for modular expansion like the solar thermal plant.

Besides the use of a seasonal storage in combination with solar thermal heat, it can be combined with a heat pump or facilitate the integration of excess heat, e.g. from industry. An example of such system is the district heating plant of Gram, Denmark (see the CoolHeating Best Practice Report of Laurberg Jensen et al. 2016).

The different storage technologies for seasonal storage and some examples are (Figure 41):

- Pit thermal energy storage (PTES): Dronninglund, Marstal, Gram (Denmark)
- Borehole thermal energy storage (BTES): Brædstrup (Denmark)
- Aquifer thermal energy storage (ATES)

Figure 44: Pit thermal energy storage in Marstal, Denmark (Source: PlanEnergi)

Figure 45: Border of a pit thermal energy storage of the solar district heating plant in Gram, Denmark (Source: Rutz D.)

**Figure 46: Borehole thermal energy storage of the solar district heating plant in Brædstrup, Denmark (Source: PlanEnergi)**

**Pit thermal energy storages** are a relatively cheap storage technology, which has been developed in combination with solar thermal plants. The number of PTES is yet limited and the technology has some development potential. One limitation today is the temperature level, which implies that high temperatures (90°C) shorten the lifetime of the liner. The development of high temperature PTES (90°C) as well as low temperature storage implies that PTES can be used not only in combination with solar thermal, but at the same time in combination with e.g. surplus industrial heat. This is the case in Gram, Denmark, where the nearby industry provides surplus heat and gets some of it back later. The physical footprint of PTES is significant; therefore applicability of PTES is dependent on the local conditions.

**Borehole thermal energy storage** is a relatively new technology which has been applied at one plant in Denmark (Brædstrup). BTES can supplement PTES as seasonal heat storage in areas, where location of a PTES is not possible. The BTES-technology is still in the development phase.

**Aquifer thermal energy storages** can be applied for storage of up to 20°C. This low temperature level limits its applications. In Denmark there are a few applications in combination with district heating. Most applications are stand-alone plants for large buildings. There could be a potential for the storage of heat in deep reservoirs (below 250 m), but this depends on the local sub-surface conditions.

# 5 Small modular district heating systems

## 5.1 Size of the system

A district heating (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 few houses. The capacities of a DH grid can be of all sizes, depending on the size of the area. In large DH systems, the DH grid may consist of both, a transmission grid (transporting heat at high temperature/pressure over long distances) and a distribution grid (distributing heat locally at a lower temperature/pressure) (Danish Energy Agency & Energinet.dk, 2015).

**Small district heating grids** are local concepts to supply households as well as small and medium industries with renewable heat. In some cases, they may be combined with large-scale district heating (DH) grids, but the general concept is to have an individual piping grid which connects a relatively small number of consumers. Often, these concepts are implemented for villages or towns. They can be fed by different heat sources, including solar collectors, biomass systems and surplus heat sources (e.g. heat from industrial processes or a biogas plant that is not yet used). Fossil fuel boilers could be installed for peak loads and as a backup in order to increase the economic feasibility of the overall system. Small grids do normally have commercial operators and are larger than micro grids.

**Micro heating grids** are usually installed for fewer customers, e.g. 2 to 10. An advantage of micro grids is that these systems could be build easier and faster, because of the small amount of customers, without long public procedures. The customers agree on a suitable accounting for the used heat and on who is the operator of the system.

Independent of the grid size, it is important not to oversize the grid during planning. Large dimensions cause higher heat losses and higher investment costs.

There is a characteristic factor called “heat density” of the grid (see chapter 6.2.2), which is calculated by the annual sold heat (MWh/a), divided by the length of the grid (in meter, length of pipeline). A common rule of thumb says that this factor should be at least 900 kWh/m per year. The goal should be to sell a high amount of heat at a grid with a short length. In case that the heat density of a potential grid is too low, individual household heating systems may be preferred.

## 5.2 Temperature level of the system

### 5.2.1 Selection of suitable temperature levels

The bigger the difference between flow and return temperature (**differential temperature**) is, the better is it for the heat supplier. A high differential temperature reduces the mass flow and the heat losses of the heating grid. In addition, the power consumption of the pumps is reduced.

There are some rules to consider for selecting the right temperature level for heating grids:

- The temperature level in a small district heating system depends on the temperature which the customers need. If this required temperature is too high or only for a few customers, an individual heating system shall be considered for them, or not to connect them to the grid.
- Another important characteristic of heating grids is the heat losses for distribution. The higher the temperature is the bigger are the heat losses.
- Fluctuating temperatures of the flow pipe, within one day, should be minimized to lower friction (stress) of the pipes. Frequently changing temperatures of the flow pipe or switching off the grid causes stress and lowers the lifetime of the heating grid.

- The difference between flow and return temperature of the small DH grid should be at least 30°K in order to lower the mass flow, dimensions of the pipes and electrical costs for pumps.

The flow temperature of the grid can be higher or lower, depending on the ambient temperature (Figure 47). In winter, at minimum outside temperatures, the flow temperature has the highest level. In summer, the temperature needs to cover at least the temperature level for domestic hot water production.

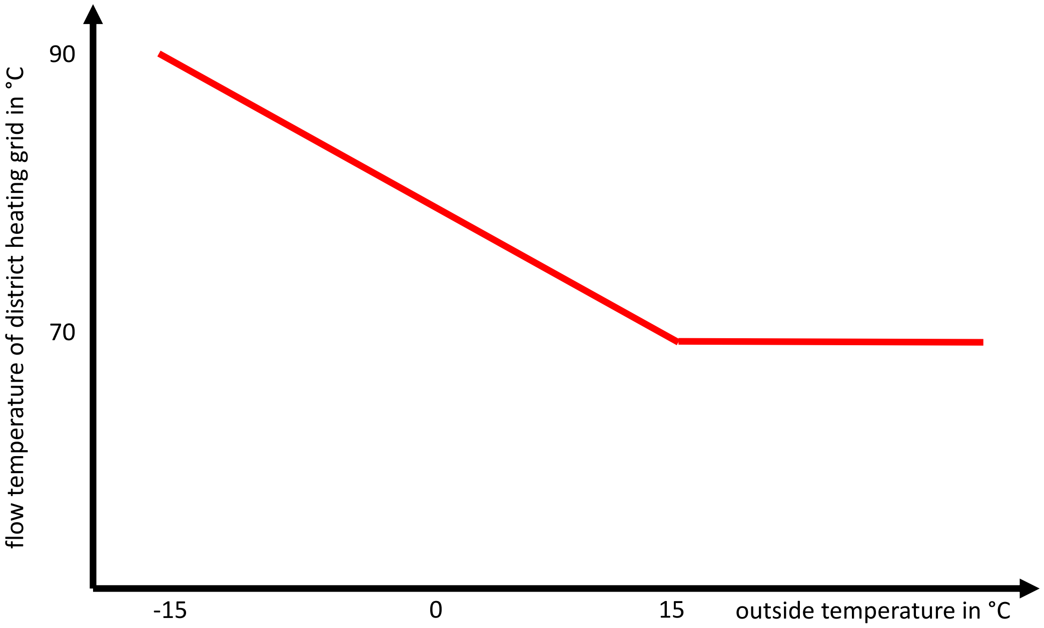


**Figure 47: Example for the flow temperatures of a grid depending on the ambient temperature (Source: Güssing Energy Technologies)**

### *5.2.2 High temperature systems*

High temperature systems are used if high temperature levels are needed, e.g. for industrial users. A high temperature system is operated with hot water above 90°C. High temperatures cause higher heat losses and lower lifetime of the DH grid.

The heating plant should be located close to the industrial users that need the high temperature. The rest of the DH grid (e.g. for heating buildings, households) should be operated with a lower temperature level.

Industrial users often cause higher return temperatures of the grid, by using wrong hydraulic facilities or incorrect controlling devices. The goal should be to lower the return temperature in order to decrease the mass flow and heat losses. It is important to consider that some heat producers (e.g. gas engines) need low return temperatures for proper operation.

### *5.2.3 Medium temperature systems*

Medium temperature systems are the most common systems. The flow temperature ranges from 65°C to 90°C. These temperature levels are often used for heating buildings (e.g. houses, office or public buildings) and to provide domestic hot water. Existing old houses often need flow temperatures of 80°C and more. Newer buildings could use flow temperatures between 50 and 70°C, depending on the status of insulation and on which heating system they have installed (e.g. radiators or floor heating).

To produce domestic hot water (hot water tank), the flow temperature of the DH grid needs to be at least 65 or 70°C for the whole year in order to prevent the growth of Legionella which can cause health diseases.

### *5.2.4 Low temperature systems*

Low temperature systems (low-temperature district heating, LTDH) with flow temperatures below 65°C are getting more popular for customers with low energy needs. The advantage is that heat losses in the pipes are lowered and that polymer pipes can be used. Additionally, also other low temperature heat sources, like heat pumps or waste heat from industry can be integrated in the system. At this temperature level, Legionella could be a problem. Thus, additional devices such as heat exchangers may be needed for hot water supply.

Low temperature systems can also be used as subsystems in high or medium temperature grids (Figure 48). The return pipe can be used as the flow pipe for the low temperature system. After using the heat, it can be returned to the return pipe.

The advantages of LTDH are that the grid heat loss is lowered, which gives energy savings and lower fuel costs. Furthermore, the lower grid temperatures allow using a larger range of heat sources including more renewable energy sources and surplus heat from industrial processes. LTDH is not considered to be more expensive to build than conventional DH.

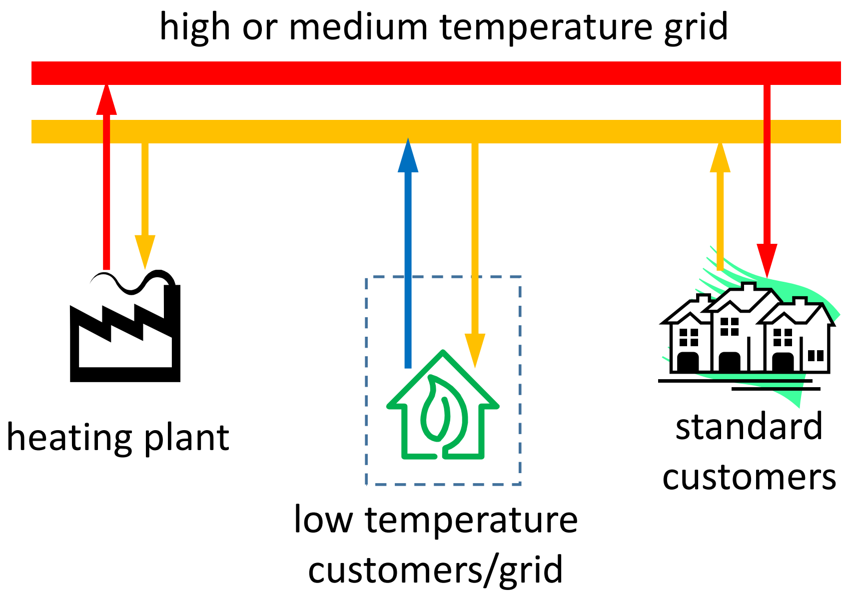


**Figure 48: Usage of return temperature for low temperature customers/grids (Source: Güssing Energy Technologies)**

For example, in Austria there are low temperature grids established with constant flow temperatures of 55°C during the whole year. The domestic hot water is prepared instantly with a heat exchanger at every customer. The customers are connected directly to the grid. In winter, the grid is heated with a pellets boiler and in summer with an air/water heat pump. There are only buildings with low energy needs (floor heating or low temperature radiators) connected, in a dense area where no long distances of pipes are needed.

In another example in Germany (Dollnstein) (see the CoolHeating Best Practice Report of Laurberg Jensen et al. 2016), temperatures of 20-30°C are used as flow temperatures in summer. There is no appropriate demand for high temperatures in summer in a small town like Dollnstein. High temperatures would cause high heat losses. For reducing these losses, the grid temperature is lowered to 20-30°C from May till end of September. This allows covering the heat demand in summer operation completely by renewable energy (solar).

More information about low temperature systems with some case studies are presented by Köfinger et al (2015).

### 5.2.5 Importance of low return temperature of the DH grid

The amount of heat utilised from the district heating system depends mainly on the design and adjustment of the buildings’ internal heating systems, but also on the performance and the condition of the district heating substation. Good cooling of the district heating return flow (i.e. more heat subtracted) and good performance of the district heating substations are in the interests of both the customer and the heat supplier. Control and monitoring of the flow and return flow of the DH system is important (Euroheat & Power, 2008).

The goal should be to reduce the return temperature of the customer side and thereby the return temperature of the DH system. This results in lower mass flow, pumping costs and higher heat load capacity of the grid. That is the reasons why DH operators should review the hydraulic scheme of the customers and encourage consumers to adapt their heating installation to reduce the return temperature.

### 5.2.6 Monitoring temperature levels

The monitoring helps to reduce the flow and return temperatures and at the same time to maintain a large temperature differential. In order to minimize heat loss in the grid, to optimize the heat production, to save fuels, and to reduce $CO_2$ emissions, many plants use temperature optimizing software. Optimization software programs can be linked to grid calculation programs and to SCADA systems (Supervisory Control and Data Acquisition) of district heating plants.

The optimization program obtains relevant data from external conditions and measurement data from the grid, for example, the flow temperature. The meter will typically be located at the "weak" points in the grid. The collected data may include data on weather forecasts, heating demand, and measured temperatures in the grid. The data are processed in short time intervals. In this way, a number of operational parameters can be identified on an hourly basis (or even with shorter time steps) and help to ensure that the operation is conducted as efficiently as possible.

Generally, software programs use the following parameters to calculate the flow temperature:

- Weather
- Flow rate
- Return temperature
- Consumption patterns in domestic hot water consumption
- Weekday / weekend / holidays

The effect of the temperature optimization will be:

- Lower average temperatures in flow and return
- Lower grid losses
- More optimal flow rate of distribution pumps

## 5.3 Pipes

A district heating network or grid consists of connected district heating pipes (**flow pipes**), through which hot water is transported from the heat producer to the consumers. The cooled water from the consumers is transported through pipes (**return pipes**, return flow pipes) back to the heat producer. The pipes must be carefully selected in order to increase the overall efficiency of the system and to minimize losses. The diameter of the pipes and the used material of the pipes are the main characteristics which need to be considered.

### *5.3.1 Type and diameter of the pipes*

The type and the diameter of the pipes depend on the distance, pressure, and amount of heat which shall be transported to the consumers. The diameter and thus, the capacity of district heating pipes, can range from as low as 16 mm to capacities of more than 600 mm.

For main grid pipes, service pipes and most transmission pipes, pre-insulated district heating pipes are used. These pipes have a sandwich construction in which three layers are included (Figure 49). The media pipe or carrier pipe transports the heating medium, usually water. The layer of insulation reduces heat losses. The casing pipe or jacket pipe protects the insulation layer.

In small dimensions, flexible pipes are preferable, whereas in larger dimensions, steel pipes will be necessary.

Especially for smaller diameter pipes, **twin pipes** can preferable be used instead of single pipes. In twin pipes, the flow and return pipes are combined in one single district heating pipe. It consists of two pipes in the same casing, a supply and a return pipe. This reduces heat losses compared to the installation of two single pipes as well as lower construction costs. In very large dimensions (> Ø219 mm) like for transmission lines or large distribution lines, twin pipes are not available.

The media pipe in service pipes is normally made of polymers, alu-PEX, copper or steel. For bigger pipes with high pressures often steel is preferred as media pipe, since steel is the most durable material for high volumes and pressures. For smaller pipes often polymer pipes are used as they are more flexible and easier to install.

The casing for service pipes is made of smooth or corrugated polymers such as low density polyethylene (PEL) or high-density polyethylene (PEH). The insulation is made of polyurethane foam (PUR) or mineral wool.

Both, flexible pipes and steel pipes should include a diffusion barrier between the insulation and the outer polyethylene (PE) casing in order to keep thermal conductivity low and unchanged over time.

In modern pipes, often a **leakage warning system** is applied as leakage of the pipe would lead to reduced insulation, high heat losses, and water losses. Core of this system are cables (two integrated wires; Figure 51) installed in the insulation of the pipe which send data to a control unit of the leakage warning system.

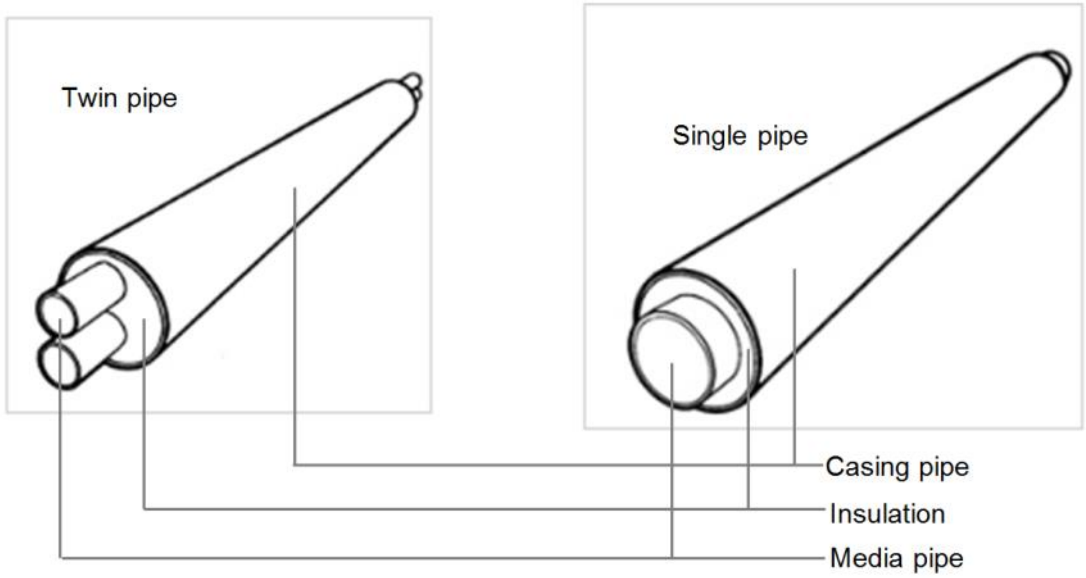


**Figure 49:** Cross section of district heating pipes (Source: Figure reproduced from Isoterm)

**Figure 50:** Samples of old single and double steel pipes (left) and double polymer heat pipe (right) (Source: Rutz D.)

Figure 51: Single steel pipe with two wires for the leakage warning system (Source: Rutz D.)

### *5.3.2 Selection of heat pipes*

When designing district heating systems, many factors must be taken into account and such systems should therefore ideally be dimensioned by using dedicated design software. Often, the pipe manufacturers provide such tools. Furthermore, manufacturers provide tables of different pipe types with the specific characteristics of the pipes, such as material, insulation, heat losses, diameter, etc. A core characteristic is the diameter of the pipe as it influences the capacity of transported heat. Typically, pipe dimensions are given based on the pressure drop and pipe capacity values that are based on the Colebrook and White's formula at a water temperature of 80°C.

It is advisable to consult the pipe manufacturer or a consulting engineer before and during construction.

### *5.3.3 Pipe installation*

In general, pipes can be installed in the ground and aboveground. Pipes **above ground** are normally only seen in relation to large transmission lines and where the pipes need to cross bridges.

For all other main grid pipes (distribution), service pipes and transmission lines, the pipes are usually installed **under ground**. This requires some precaution measures during the installation in order to avoid damages to the pipes. As it was described in chapter 5.3.1, typically fully pre-insulated "sandwich" pipes are installed. This entire pipe behaves as a single integrated unit when temperatures in the pipe fluctuate and thus, impact the temperature related movements of the different materials. Temperature fluctuations generally put stress on the pipe which needs to withstand this stress.

**Figure 52: Installation of a heat pipe to the buildings of a farm (Source: Thermaflex Isolierprodukte GmbH)**

**Figure 53: Directional drilling machine (Source: Rutz)**

The stresses accumulating in the carrier pipes are thus determined by the ability of the pipeline to expand freely in response to temperature fluctuations, the pressure within the pipe, and the weight of the pipe and backfill material. (Isoplus, 2016)

“**Yield strength**” or “yield point” is the material property defined as the stress at which a material begins to deform plastically. Prior to the yield point, the material will deform elastically and will return to its original shape when the applied stress is removed. Once the yield point is passed, some fraction of the deformation will be permanent and non-reversible. In the past, plastic yield was the limiting factor in the design of district heating systems using polymer based pipes (Isoplus, 2016). However, today, pipe technologies have developed further, so that even surpassing the yield point is tolerable for modern pipes.

Different installation methods apply to different pipes in order to guarantee long-term operation of the system. Examples of installation methods of pipes include expansion bends (requiring additional equipment such as L, Z and U bends), heat pre-stressing (preheating the pipes before covering them with backfill material), pre-stressing elements, and cold laying of the pipes (Isoplus, 2016) (Table 4).

**Table 4:** **Laying methods (Source: Isoplus, http://en.isoplus.dk/laying-rules-163)**

| Laying method | Advantages | Disadvantages |
|---|---|---|
| **Method 1**<br>**Expansion bends** | - Reduced stresses in system<br>- Less restrictive requirements with parallel excavation<br>- Relatively high installation speed as the trench can be backfilled continuously, immediately after the piping has been laid | - Need for expansion bends<br>- Increased pressure drop<br>- Additional components<br>- Additional displacement zones |
| **Method 2**<br>**Heat pre-stressing** | - Reduced stresses in system<br>- Less requirements with parallel excavation<br>- Simple system with no need for expansion components | - Trench must be kept open and not backfilled until the system has been preheated<br>- Need for heat source during preheating |
| **Method 3**<br>**Pre-stressing elements** | - Reduced stresses in system<br>- Less restrictive requirements with parallel excavation<br>- Relatively high installation speed as the trench can be partially backfilled continuously, immediately after the piping has been laid | - Need for pre-stressing elements/single-use compensators |
| **Method 4**<br>**Cold laying** | - Simple, uncomplicated laying without incurring costs for expansion components and/or preheating equipment<br>- High installation speed as the trench can be backfilled continuously, immediately after piping has been laid | - Excavation parallel to the system is not possible without special precautions as a result of high axial stresses<br>- Considerable initial displacement. Unsuitable for large dimensions at high temperatures<br>- Requires reinforced components under certain circumstances |

Different national standards for the installations of the pipes may apply. Some European Standards, that should be followed, are:

| | |
|---|---|
| EN 253: 2009 + A1: 2013 | Pre-insulated pipe systems fixed |
| EN 448: 2009 | Connectors, district heating |
| EN 488: 2011 | Steel Valves for district heating |
| EN 489: 2009 | Joining media pipe, steel |
| EN 13941: 2009 + A1: 2010 | Design and installation |
| EN 14419: 2009 | Monitoring and surveillance systems |
| EN 15698: 2009 | Pre-insulated fixed two pipe system |

Pipes can be either buried into the ground by an excavator (Figure 52) or by horizontal directional drilling (also called HDD, directional boring, wash boring) (Figure 53). HDD is a steerable trenchless method of installing underground pipes, conduits and cables in a shallow arc along a prescribed bore path by using a surface-launched drilling rig, with minimal impact on the surrounding area. Directional boring is used when trenching or excavating is not practical. It is suitable for a variety of soil conditions and situations including road, landscape and river crossings. Installation lengths up to 2,000 m have been completed. Pipes can be made of materials such as PVC, polyethylene, polypropylene, ductile iron, and steel if the pipes can be pulled through the drilled hole. Directional boring is not practical if there are voids in the rock or incomplete layers of rock. The best material is solid rock or sedimentary material. Soils with cobble stone are not recommended. There are different types of heads used in the pilot-hole process, and they depend on the geological material. (Wikipedia, 2014, Rutz et al. 2015)

Especially in case of paved roads HDD is suitable, as nuisances for the neighbouring households can be reduced and thus, consumer acceptance increased (Rutz et al. 2015).

### *5.3.4 Heat losses*

The **grid loss** (see chapter 6.2.3) depends particularly on the distance of the grid and varies a lot from one system to another. The **heat loss of the pipes** is given by the pipe manufacturer for standard conditions in W/m. “$\Phi = 11$ W/m” is an example. The heat loss depends on the hydraulic conditions, the temperature of the fluid, the temperature of the soil, and on the insulation of the pipe (pipe material and thickness).

Sometimes, heat pipe manufacturers include percentages of heat loss for their products. However, for planning district heating grids, it is recommended to use absolute numbers, since this can also reflect the heat losses at different heat loads.

### *5.3.5 Costs*

It is difficult to provide details on investment costs for the piping grid since the investment depends on the length of grid, insulation, dimension, and if the grid passes existing infrastructure such as e.g. roads. The investment in the pipe itself counts for around one third of the total price of the district heating grid. The largest part of the investment is the costs for the ground work (digging the pipes in the ground). That is the experiences from Denmark, but in other places, labour might be cheaper, which will lower the investment costs.

## *5.4 Heat transport medium*

The heat transport medium is the liquid that carries the heat from the heating plant through the pipes to the customers. In district heating systems usually water is used as transport medium. The water quality has a high impact on the performance of the system and on potential complications. Thus, the water quality should be an important aspect to protect the system against corrosion. In the following chapters, water quality aspects are presented.

### *5.4.1 Gases in the water*[11]

The most important gases that have an impact on the water quality of district heating systems are oxygen ($O_2$) and nitrogen ($N_2$).

Oxygen in the water causes corrosion in unalloyed and low-alloyed iron pipes, especially if the water is salty. In order to avoid high amounts of oxygen in the water, the system should be sealed and closed to the penetration of oxygen.

Nitrogen is an inactive gas in the water, but causes material problems when its concentration is so high that free nitrogen gas bubbles are formed. This happens if the gas solubility decreases which is the case when temperatures increase and the pressure decreases at the same time.

---

[11] This chapter is based on Euroheat & Power, 2008

Circulation disturbances, noise and erosion corrosion will be the consequences. In district heating substations air and gases can permeate the circulation water through the expansion tanks which can be open to the atmosphere. Oxygen (and small amounts of nitrogen) can enter through diffusion from permeable membranes or plastic pipe systems. Furthermore, low pressure conditions in closed systems enable the entry of air through gaskets and automatic vacuum breakers. (Euroheat & Power, 2008)

### *5.4.2 Other components in the water*[12]

In warm water, soluble **alkali** reacts with hydrogen carbonate forming calcium carbonate and resulting in the formation of scale (calcium carbonate). Scale increase impedes the functioning of the heat exchanger and decreases its thermal capacity. In some cases overheating occurs and as a consequence the heat generator can be damaged. To protect the system against scale formation, the filling water and top-up water should be softened.

**Anions** from water-soluble substances, particularly chloride and sulphates, in the presence of oxygen lead to local corrosion (e.g. crack corrosion) with unalloyed ironwork materials. A chloride concentration up to 50 mg/l will usually cause no corrosion damage. However, under certain critical conditions (e.g. in case of increasing concentrations under covers, pores or in columns), chloride ions in stainless steels can lead to pitting- and deposit corrosion. Due to the fact that specific corrosion danger depends on several factors (e.g. material, medium, operating conditions), a limit value valid for all operating conditions cannot be defined. In any case, a very low chloride concentration is recommended. Also, chloride causes corrosion with aluminium materials making this combination unadvisable.

Insoluble and soluble **organic substances** can impair water treatment technology, as well as micro-biological reactions in the circulation water. They should be avoided in district heating systems.

To temporarily prevent the corrosion of old armatures, piping or heating surfaces, substances based on **oils or fats** are used. As a film or cover on materials, oils affect the heat exchanger. They also disturb the function of control- and safety equipment. Oils and fats are nutrients for micro-organisms and can even cause micro-biological corrosion. Therefore, it is strongly recommended to avoid the use of oils and fats in DH systems.

### *5.4.3 Operational parameters of the water*[13]

The district heating system should be closed from air and cold water uptake to prevent corrosion. Therefore, pressure maintenance is necessary. Another aspect is that magnetite - as a corrosion product - builds a homogeneous oxygen surface layer with high corrosion resistance on metallic surfaces. This protection layer is only built at temperatures higher than 100°C. So, this effect cannot be used in domestic warm water systems.

Compliance with the standard values for chemical water treatment (see Table 5) unalloyed ironwork materials, rustproof steels and coppers, separately or in combination, can be applied. Aluminium or aluminium alloys should not be used in direct contact with the circulation water, otherwise alkali-induced corrosion is possible.

Iron and copper can lead to deposits and failures in zones with low flows. Experience shows that concentrations of iron ≤ 0.10 mg /l and copper ≤ 0.01 mg/l are in the normal range.

Euroheat & Power recommends not using aluminium at all in any DH systems, including the secondary side.

For DH systems two different operational possibilities exist, namely low-salt and high-salt operation. For a safe and economic operation of the circulation water the following standard

---

[12] This chapter is based on Euroheat & Power, 2008

[13] This chapter is based on Euroheat & Power, 2008

values should be complied with. In extraordinary operations/situations (e.g. start-up, damage) it is possible to diverge from the values for a short time.

**Table 5:** **Standard values for district heating water quality (Source: Euroheat & Power, 2008)**

| Parameter | Unit | Value |
|---|---|---|
| **Electrical conductivity** | µS/cm | 100-1,500 |
| **pH value** | n.a. | 9.5-10 |
| **Oxygen** | mg/L | <0.02 |
| **Alkaline** | mmol/L | <0.02 |

### *5.4.4 Practical experience*[14]

The normal equipment to ensure a needed water quality of the DH grid is a water softening facility, a filter and the addition of chemicals. A reverse osmosis is normally not needed, is quite expensive and could cause more problems in operation.

Plastic pipes (e.g. from floor heating) could cause oxygenation and sludge formation. This could damage the DH grid. That is the reason why a heat exchanger (indirect system) is required to separate the systems. DH grids without high leakage rates do normally have no problems with oxygenation (rust).

At the DH plant there should be installed a filter with 5 micro meters in the bypass, plus a pump, as shown in Figure 54.

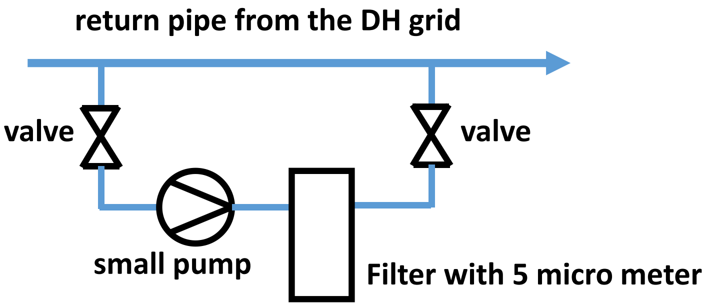


**Figure 54:** **Pump with filter in the bypass of the return pipe from the DH grid (Source: Güssing Energy Technologies)**

In addition, a horseshoe magnet could be included in the filter to remove the magnetite from the water. This magnetite could destroy pumps.

A chemical addition (e.g. IWO VAP 25 FW) could be used to bind carbonic acid and oxygen in the water. A protection layer is built to cover the pipes. Bonded sludge is mobilized by the chemical addition and removed at the filter.

Maintenance is usually done once a year by an external company to check the water quality, the water softening facility, the chemical dosing unit for the chemical addition and the filter.

---

[14] This section is based on Kotlan (2016)

## 5.5 Connection of heat consumers

The district heating grid transports the warm heating medium to the consumers and transports the cooled medium back to the heating generators. In order to transfer the heat, the consumers need to be connected directly or indirectly (through heat exchangers) to the system. The connection point can be defined from the technical viewpoint, as well as from the legal viewpoint. Usually, the central heating system of the building belongs legally to the building owner, whereas the DH grid belongs to the grid operator. The heat transfer station can be owned either by the building owner or by the grid owner, depending on the business models and on the contracts.

### 5.5.1 Heat transfer stations

The heat transfer station is the equipment that transfers the heat from the DH grid to the consumers. Usually, houses are connected (Austria, Germany) to the district heating grid by using a heat exchanger (indirect system) to separate water from DH and installation of the house. This equipment is located in a heat transfer station at the houses, shown in Figure 55. In Denmark, often a direct system without a heat exchanger is applied.

**Figure 55: Heat transfer station with a heat exchanger, control unit, valves and a heat meter (left) (Source: Güssing Energy Technologies) and heat transfer station (including a heat exchanger) of an end consumer in Achental, Germany (Source: Rutz)**

Heat transfer stations usually consist of a heat exchanger (indirect system), a control unit to regulate the flow temperature for the house, a motor valve and a heat meter. It is standard to use differential pressure balanced motor valves, in order to lower fluctuations and to set a maximum flow rate when the valve is completely open. With this adjustment, it is possible to limit the flow rate (heat power) of the heat transfer station to a contractually guaranteed value.

Depending on the legislation, it may be necessary to install an official calibrated heat meter. The heat meter needs to be calibrated periodical. Usually heating costs consist of costs for the used heat (€/kWh), needed heat peak load (€/kW per month) and metering costs (€/a).

A monitoring system (temperatures, opening of valve and quantity of heat consumption) that is connected to the heating plat is standard nowadays. This is achieved with a bus-system for all heating stations. This monitoring system can also be used to control the differential pressure of the main DH pump (valve management). Additionally, monitoring helps to identify customers with higher return temperature and to apply sanctions.

Advantage of an indirect system is that DH water and heating water of the customers are separated and no oxygenation from customers' plastic pipes could damage the DH grid.

### *5.5.2 The heating system of the building*

The heating system of the building needs to be adjusted in order to increase the overall efficiency of the system. A guideline on district heating substations (= heat transfer station) is provided by Euroheat & Power (2008).

The hydraulic installation in the building of the consumer should enable low return temperatures to the DH grid. If the return temperatures are too high, the consumer may be instructed to change some parts of the hydraulic installation. This should also be included in the contract.

Consumers usually use radiators, floor heating, wall heating, or radiant ceiling heating to distribute the heat to the rooms. Radiators need a higher temperature than the other panel heating systems (big surface). Hence, floor, wall and ceiling heating results in lower return temperatures for the DH grid and lower the pumping costs of the grid.

If plastic pipes are used for heating, there should be an indirect connection of the consumer (heat exchanger) to prevent oxygenation and sludge accumulation at the DH grid.

### *5.5.3 Domestic hot water production*

Besides space heating, the heat from the DH grid may be also used for domestic hot water (DHW) supply. In most heating grids in Germany or Denmark, the heat supply for preparing hot water is an integral part of the service. In some other countries, especially in southern Europe existing DH grids are only operated during winter and no service is provided for hot water supply. In this case, other equipment for the preparation of hot water is needed.

The preparation and provision of DHW needs to ensure health safety. Pathogens, such as bacteria and Legionella (Box 6), may cause health problems and need to be avoided. The occurrence of them is not a specific problem related to district heating, as they may occur in all warm water systems. The contamination with Legionella takes place in the domestic hot water production and distribution facilities, i.e. in the drinking water pipe system, the circulation and the storage tank. The owner of the domestic hot water facility is responsible for ensuring health safety.

**Box 6: What are Legionella?**

The genus *Legionella* is a pathogenic group of Gram-negative bacteria that includes the species *L. pneumophila*, causing legionellosis which includes all illnesses caused by Legionella. It also includes a pneumonia-type illness called Legionnaires' disease and a mild flu-like illness called Pontiac fever. The bacterium is not transmissible from person to person and many people exposed to the bacteria do not become ill. Legionella may occur in domestic water systems in a small concentration. If the concentration increases, they pose a health risk. They infect persons through inhaling atomized water contaminated with Legionella – hence not from drinking water, but from e.g. showers.

The World Health Organization (WHO, 2007) states the temperature affects for the survival of Legionella as follows:

| | |
|---|---|
| Above 70°C | Legionella dies almost instantly |
| At 60° | 90% die in 2 minutes (Decimal reduction time (D) = 2 minutes) |
| At 50°C | 90% die in 80–124 minutes, depending on strain<br>(Decimal reduction time (D) = 80–124 minutes) |
| 48 to 50°C | can survive but do not multiply |
| 32 to 42°C | ideal growth range |
| 25 to 45°C | growth range |
| Below 20°C | can survive, even below freezing, but are dormant |

In the domestic hot water system, the temperature level should be kept warm enough to avoid multiplication. There are various technical applications to prevent legionella growth.

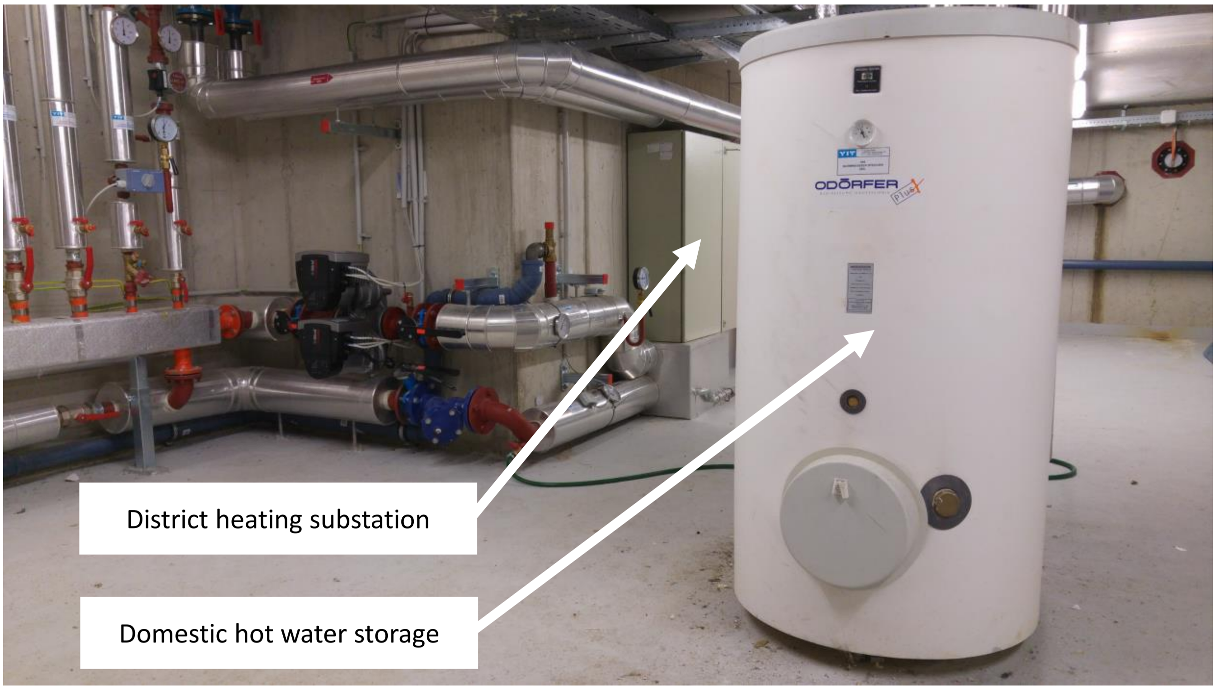


**Figure 56: Example for a domestic hot water storage tank (Source: Güssing Energy Technologies)**

### *5.5.4 Connection between district heating and consumer systems*

The heating system of the consumers (households) needs to be connected to the district heating system in an efficient way. Thus, the hydraulic system at the consumer side needs to be well adapted. It is important to avoid **shortcuts** in circuit. The system of the consumer should not raise the return temperature of the district heating system; this means that the flow of the consumer heating should not be directly mixed with the return flow.

Figure 57 presents suitable and non suitable hydraulic distribution systems used at the consumer’s side. Practical experience shows that the third system is the most common system which is easy to plan and which operates without hydraulic problems. When connecting the hydraulic system of the consumer to the DH system, they should ensure the good practice schemes of Figure 57. If the system is not suitable, it should be changed. Furthermore, it should be considered that the systems, including the heat exchanger, pipes, valves and motor valves are not oversized.

Figure 58 shows an example for heat distribution at the consumer side for a business building that is supplied with district heating.

Often, consumers will have already installed **solar heating systems** on their buildings when the DH grid is planned. The integration of these solar collectors depends on various aspects, such as the type, size and age of the solar system. If there are solar collectors existing at the consumer’s building, they should be used mainly used for the production of domestic hot water. If it is also planned to include them into the heating system, a buffer storage tank should be used. The solar system could feed the buffer storage tank with heat and if the temperature is too low, heat of the DH grid could be used to maintain the desired temperature. Thereby, the heat could be transferred to the top of the buffer storage tank or the system could be heated externally with a heat exchanger.

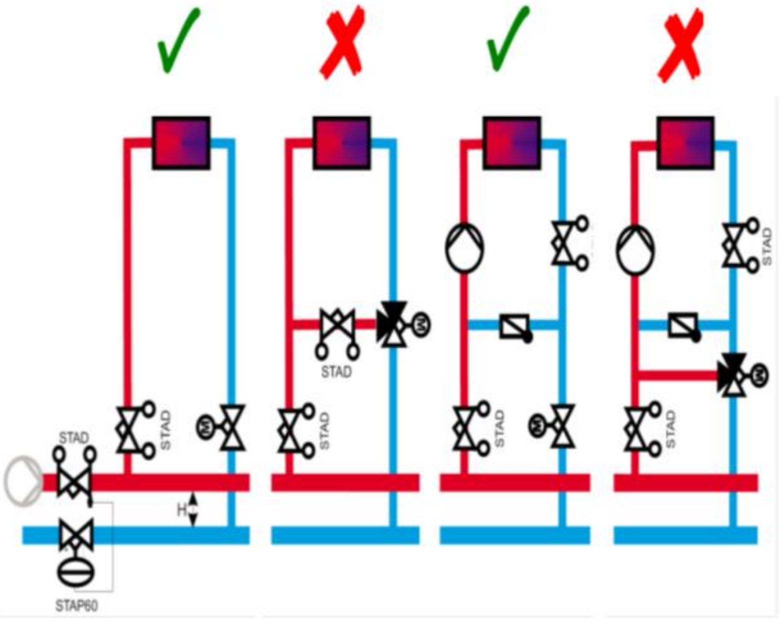


**Figure 57: Hydraulic distribution that can be used for DH systems at consumer side (Source: Güssing Energy Technologies, based on Tour & Andersson Ges.m.b.H., 2005)**

Figure 58: Heat distribution at a business building with DH supply (Source: Güssing Energy Technologies)

# 6 Planning of small heating grids

The planning of a small district heating system is crucial as this determines the overall performance, efficiency and economy of the grid. The system should consider the current heat demand, but also future extensions or, in case of large refurbishments of buildings, decreasing demand. It should be modular so that consumers, who do not want to be connected at the moment, can be still connected in the future.

For very small systems, the planning can be done by the initiators of the project, even if they are no technicians. This can be done in cooperation with the piping manufacturer who often provide basic planning tools for their systems. Several projects show that these self-planned systems can operate very well, e.g. in Germany. However, the involvement of a professional planning company is highly recommended especially if the involved initiators have no technical skills. This applies especially for more complex systems which include several heating sources.

## 6.1 Assessment of the heating demand

An important prerequisite for the planning of district heating grids is a good data collection of the heating demand of the consumers that should be connected to the system. Besides the current heat demand, also an assessment of the future heat demand should be made. The correctness of the data can considerably affect the economic calculation of the project. For assessing the heating demand, several **data sources** can be used.

- Meteorological data of the region
- Maps with the building standard (insulation) of the houses
- Energy plans of the authorities
- Survey with the potential consumers
- On-site investigations

If the wider area, where the customers should be connected, is defined, the more detailed planning and assessment can start. Ideally, potential locations for the heating plant can be already defined. **Maps** are needed to make the first planning. If potential customers are located in the map, a first draft of drawing the DH grid can be made. The length of pipes can be estimated already. This could be connected to the information on the building types, heat demand for specific building types, or the age of the buildings. Hence, databases on buildings can be very useful.

After the preparatory work, the heating demand of each potential private, public, or commercial (industrial) customer needs to be assessed. This could be done with a **questionnaire** which should include:

- Address of the customer, for the location on the map
- Existing central heating system (e.g. oil, gas, wood boilers, wood stoves, electric heaters)
- Additional heating facilities (e.g. single stoves, electric heaters)
- Heated space of the building in m² (e.g. 110 m² heated)
- Existence of Energy Performance Certificates and its values
- Insulation of the building (e.g. 10 cm of thermal insulation)
- Planned refurbishments of the buildings
- Annual energy demand for heating (e.g. 14 m³ of hard wood; 2,100 liter of heating oil; 2,700 m³ of natural gas; 18,000 kWh electricity)

- Type of domestic hot water production (e.g. electric boiler, boiler supplied by the heating system)
- Number of people living in the household to assess the energy for domestic hot water production
- Type of the heating discharge system in the building (e.g. radiator, floor heating, wall heating)
- Heating behaviour during night/day
- Needed maximum flow temperature for the heating system

Another way of estimating the heat consumption can be done by **checking the past invoices** of the consumers for heating. It is recommended to check the invoices of several past years. This method is suitable especially if only few consumers will be connected and if the heat demand is small (Rutz et al. 2015).

Another method for the assessment of the heat demand, and the most reliable for high-quality data, is by **measurements**, especially for larger consumers. These can include hourly, daily or monthly measurements. In existing larger facilities, the heating systems are sometimes already monitored so that these data can be easily used (Rutz et al. 2015).

### *6.1.1 Heat demand of buildings*

After the data are collected from the potential customers, the overall heat demand can be calculated. Thereby, the theoretical heat demand can be calculated for a grid in which all potential consumers would be connected. A second calculation can include only these consumers, who already expressed their willingness to be connected. These calculations can help to decide if the project is feasible (a) with the consumers that already expressed their willingness to connect, or (b) only with additional consumers that did not yet express their willingness.

The calculation on the needed heat demand for the whole grid is done by adding the heat demand of all potential consumers. The specific energy content of the current heating system, as well as the efficiency of the existing heating system, needs to be included in the calculation. Some examples for assessed heat demand are shown in Table 6.

It is important to guess the efficiency of the existing heating system conservative and not too high in order to have a good estimation of the overall heat demand.

**Table 6: Examples of a heat consumption assessment of three different consumers**

| Consumer No. | Annual consumption | Specific energy content | Annual efficiency of heating system | Annual heat consumption for the DH grid |
|---|---|---|---|---|
| **1** | 14 m³ hard wood | 946 kWh/m³<br>at 25% water content | 65% | 8,608 kWh |
| **2** | 2,100 l heating oil | 10 kWh/l | 75% | 15,750 kWh |
| **3** | 2,700 m³ natural gas | 10 kWh/m³ | 80% | 21,600 kWh |

### 6.1.2 Peak load of buildings

The needed peak load for heating could be estimated with the annual **full load hours**. The full load hours describe the calculated amount of hours in one year that the heating system would run at full capacity. It is the time that it would have operated at full load had it always operated at that level.

For heating, including domestic hot water production, about 1,600 full load hours are needed under average conditions in Austria. For heating only, in Austria about 1,400 h are needed. The value of the full load hours for heating depends on the climatic conditions as well as on the efficiency and insulation status of the buildings. Thus, the value may be different in other countries.

Another term used in this context is the **capacity factor**, describing the ratio between the actual output in a given period and the potential output if it were possible for it to operate at full capacity all the time.

Taking the annual heat consumption values of Table 6, the needed peak loads would be as shown in Table 7.

**Table 7: Examples for calculating the needed peak load for the DH system**

| Consumer | Annual heat consumption for the DH grid | Domestic hot water production with the heating system | Estimated annual full load hours | Needed peak load for DH grid |
|---|---|---|---|---|
| **1** | 8,608 kWh | Yes | 1,600 h/a | 5.4 kW |
| **2** | 15,750 kWh | No | 1,400 h/a | 11.3 kW |
| **3** | 21,600 kWh | Yes | 1,600 h/a | 13.5 kW |

For the calculation of the energy demand of buildings, the standard EN ISO 13790:2008-09 on “Energy performance of buildings - Calculation of energy use for space heating and cooling” can be used. This standard specifies methods for determining the annual energy consumption for space heating and cooling in buildings (residential or non-residential) or a part of them.

Often, there is a quite large difference between this calculated values and the existing load of the boilers at the households. This is an indicator that the existing heating system is oversized.

The peak load of the DH grid should include a simultaneity factor, depending on the numbers of consumers and if the consumers have installed local storage tanks or only heat exchangers. It may be an option to switch off night setbacks to lower peak loads of the DH grid. This would slightly increase the overall heat demand, but lower the peak load demand which is related to the highest costs. However, this method also increases the comfort of the customers.

### *6.1.3 Heat demand of industries*

The heat demand of industries depends on various factors, including the size and the production profile of the industry. There are no standard assessments of the heat demand of industries as they exist for buildings. Some industries have dedicated data monitoring on their heat demand. These data can be used for assessing the heat demand for the DH system. If data are not available, they need to be measured.

It is necessary to know the heat consumption, peak load and daily/seasonal load line, as well as the required temperature level. Consumers with high fluctuating load lines could be a challenge for the boilers (e.g. biomass boiler) of the heating plant and the mass flow of the DH grid. The hydraulic scheme should be reviewed and adapted to avoid high return temperatures. It would be very helpful to agree on a maximum return temperature at the consumer side.

There should be a lot of efforts on assessing data for industrial users to have fewer problems later during operation.

## *6.2 Design of the heating grid*

After the heating demand is assessed, the data have to be analysed and further information has to be elaborated. The next steps of drawing maps, calculating the connection rate and heat density, as well as the dimensioning of the grid are described in the next chapters.

### *6.2.1 Mapping of the heating grid*

After the initial assessments on the heat demand, the heating grid needs to be designed. This should include concrete planning of the piping system by using maps. As an initial step, **online mapping tools**, such as Google Earth, can be used as distances can be measured and piping lines can be directly included in the tool.

Thereby, different options on the **size of the system** and on the consumers, which shall be connected, can be investigated. Depending on the temperature level, distances and the heat density factor, some potential consumers may not be connected in order to increase the feasibility of the system. On the other hand, it may be recommended in some special cases to connect also consumers for which the connection is questionable from the technical viewpoint. This may be the case for example, if the initiators, special industries or other important consumers need to be connected as they are key actors that influence the realisation of the overall project.

Finally, one or more options for the **location of the heating plant(s)** should be determined. From the technical viewpoint, these facilities should be as close to the consumers as possible. However, social aspects and the availability of suitable land may require the consideration of other locations.

After the initial design, more **professional tools** can be used to plan the heating grid in detail. This could be done with professional software, such as Termis. An example of a grid design, using Termis software, is shown in Figure 59.

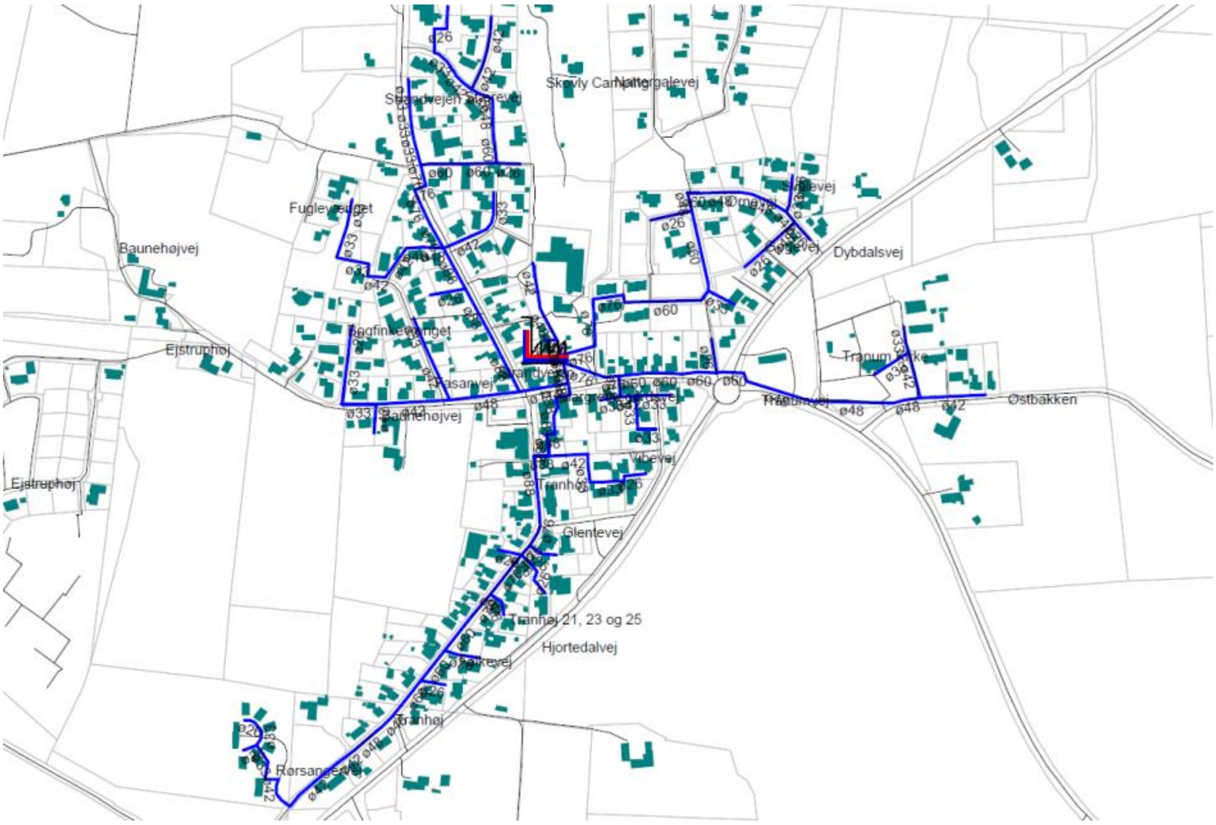


Figure 59: Example of a heat grid simulated in Termis (Source: PlanEnergi)

### 6.2.2 Connection rate and heat density

The amount of the heat demand is related to the number of consumers connected to the grid. Hence, the **connection rate** is a key parameter which influences the heat density. The connection rate is the number of connected consumers in relation to potential consumers. The connection rate is no indicator on the absolute heat distribution. Therefore the heat density is a better indicator.

The **heat density** (see chapter 5.1) is an important characteristic of the DH grid, which can be used as an indicator for the economic feasibility of the project. In general, the higher the heat density is, the higher is the economic feasibility of the system. The heat density can be related either to the area of the settlement area or to the length of the grid (grid density).

The **heat density per settlement area** is the annually distributed heat in the grid, divided by area of the heated settlement.

$$Heat\ \ density = \frac{Annual\ heat\ consumption\ [MWh/a]}{Area\ of\ the\ connected\ settlement\ [ha]}$$ **Equation 4**

The settlement area is characterized by the density of the buildings and their status of energy efficiency. The density of the buildings in the settlement is defined by the ratio of the floor space to the area of the building area. The ratio number of the building density in Germany is e.g. 0.2 for a single household building in a village and 1.5 for a multi-apartment building in the city up to 2.4 for multi-level buildings in the inner city. The heat density per settlement area may vary between 60 MWh/ha/a for a high standard passive house settlement in a rural area to 3,600 MWh/ha/a for a poorly insulated settlement area of an inner city. Heating grids can be typically economically feasible at a heat density higher than 150 to 300 MWh/ha/a (Von Hertle et al. 2015).

The **grid density** (= heat density per grid-length; also called linear heat density) is the annually heat distributed in the grid, divided by the the length of the grid. Thereby, the length of the grid is only the length of the flow pipe.

$$Grid\ \ density = \frac{Annual\ heat\ consumption\ [kWh/a]}{Length\ of\ the\ pipeline\ of\ the\ DH\ grid\ [m]}$$ **Equation 5**

This shall be illustrated by an example in which the assessment for annual heat demand for the DH grid shows a sum of 638,000 kWh per year. The first draft of the DH grid on the map results in 570 meter of pipeline (trench length; 570 m flow pipe and 570 m return pipe). Using the equation in Equation 5, the heat density factor results in 1,119 kWh/m per year.

This grid density factor is a crucial value to rate the economy of the project. The goal should be to supply a high amount of heat to a grid with a short length. However, the feasibility always depends on the dedicated framework conditions. The feasibility is influenced by the heat price, the temperature level and the related losses in the grid, and on other factors. Depending on these issues, different rules of thumbs apply for minimum grid density values for economically feasible projects in different locations and countries.

For instance, as a general recommendation in Austria, the grid density should be at least 900 kWh/m per year in order to make the project feasible. If there are less than 900 kWh/m per year, it may be an option to not connect customers with low heat consumption and long connection pipelines.

In Germany, the direct investment support for small heating grids require a minimum grid density of at least 500 kWh/m in order to be supported by the German KfW programme. The medium grid density for district heating systems in Germany is 4,000 kWh/m/a (Nast et al. 2009). This does not only include small heating grids, but also large ones. This is based on data from before 2009 and may have changed in the meantime with the introduction of many smaller heating grids.

In Denmark, the medium grid density is 1,000 kWh/m/a. There are various heating grids in Denmark with grid densities below 500 kWh/m/a. For being economically profitable, the grid density value is considered in Denmark (220 kWh/m/a) much lower than in Germany. This discrepancy between Denmark and Germany is due to the fact that heating grids are operated in Denmark often with lower temperatures than in Germany. (Nast et al. 2009)

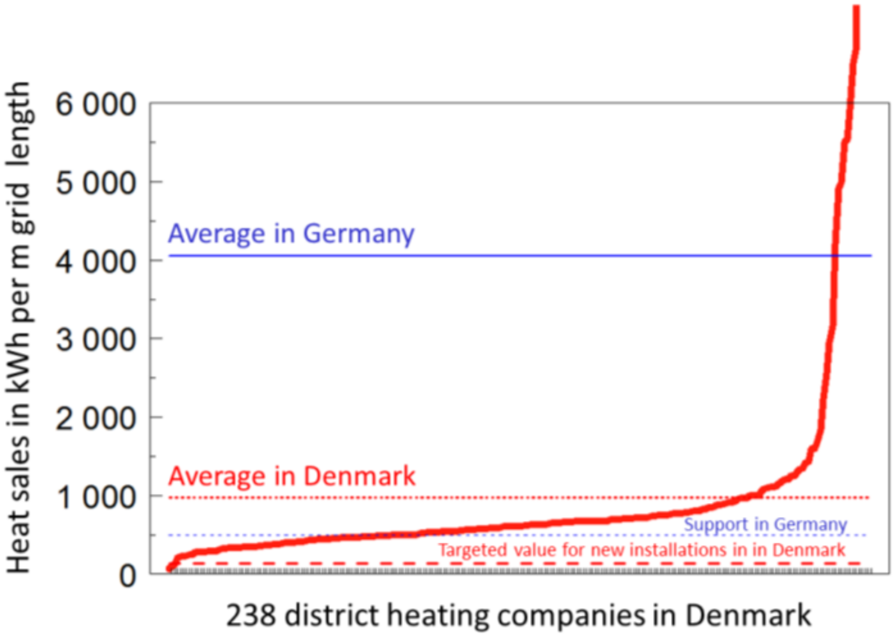


**Figure 60: Sold heat per grid length of 238 Danish heating utilities including the medium values for Denmark and Germany (Source: Michael Nast, Deutsche Zentrum für Luft- und Raumfahrt e.V.)**

### *6.2.3 Dimensioning of the grid*

An important characteristic of the DH system is the required **temperature level** (see chapter 5.2) in order to meet the needs of the consumers. Thereby, the **seasonality** of the heating services needs to be considered. Temperatures of the system may differ, depending on winter or summer operation.

Although modern district heating systems are very efficient, **heat losses** are inevitable. Losses should be kept as low as possible, but calculations must always consider a trade-off between the losses and costs for avoiding losses. The heat losses of the system need to be assessed in order to determine the required flow temperature. This will influence the selection of the heat generators, including peak load boilers. The following parameters influence the heat losses in a district heating system (Rutz et al. 2015).

- Length of the piping system
- Insulation of pipes
- Type of soil
- Thickness of soil cover above the pipes
- Volume, flow and temperature of the circuit water
- Foreseen temperature difference at the final heat exchanger
- Number of heat exchangers which are connected in series

There are different ways to **express the losses** in a district heating system (Wiese 2007):

- Temperature differential between flow and return-flow
- Relative numbers or percentages of heat losses
- Absolute numbers of heat losses in W/m, kWh/m, kWh/a

The **relative grid losses** can be calculated as shown in Equation 6 and Equation 7 whereas it is important to differentiate between the losses which can be based on the heat demand (how much heat the consumers need) or on the heat supply (how much heat is injected in the grid). This differentiation is important as sometimes legislation may support only heating grids with losses below a threshold of either the one or the other calculation. For instance, the CHP bonus in Germany required lower grid losses than 25%, based on the heat demand.

Typical relative grid losses are in the range of 15-20% of the heat demand. The loss can be reduced to approximately 7% in very large systems like in Greater Copenhagen, Denmark. They can be also up to 50% in systems of very poor conditions (Danish Energy Agency & Energinet.dk, 2015). In some transmission lines, the heat loss can be as low as 2% of the supplied energy.

$$Network\ heat\ losses\ [\%] = \frac{Heat\ supply\ [kWh/a] - Heat\ demand\ \ [kWh/a]}{Heat\ \boldsymbol{demand}\ \ [kWh/a]} \qquad \textbf{Equation 6}$$

$$Network\ heat\ losses\ [\%] = \frac{Heat\ supply\ [kWh/a] - Heat\ demand\ \ [kWh/a]}{Heat\ \boldsymbol{supply}\ [kWh/a]} \qquad \textbf{Equation 7}$$

Furthermore, the **flow** of the heat transport medium (e.g. in $m^3/s$) as well as the **pressure levels** (e.g. in bar) and pressure drops need to be determined.

Hydraulic calculations are necessary to determine the dimensions of the different pipes in the district heating system. For this, various **simulation programmes** can be used, such as e.g. Termis. Usually, the following inputs are needed to run hydraulic simulation tools:

- Background maps; roads, buildings, elevation curves, etc.
- Pipe catalogue; available dimensions, heat loss, etc.
- Consumer information; demand, difference temperature
- Boundary conditions; designing temperature, pressure gradient, flow velocity, etc.

More information may be needed, depending on the programme, the specific project details, and project circumstances.

When designing a grid, the dimensions will normally be designed for the winter load, but it is important to check the dimensions for the summer load since there might be weak spots in the grid with very low pressure and flow. In general, the grid should be designed with the smallest dimensions possible in order to minimize the losses. However, potential future extensions of the grid may be considered as well.

It is possible to operate the district heating grid with lower temperature levels during the summer period and hence, increasing the efficiency of the district heating grid. In some cases, it might be feasible to close down operation for a short period, to avoid high heat losses. However, this depends always on the overall situation. For instance, it is not possible to close down the grid operation if the agreement with the consumers is guaranteed heat supply, which also provides the heat for domestic hot water provision.

## 6.3 Design of the heating plant

### 6.3.1 Load duration curve

The variation of the heat demand during the season is key information from the analyses of the heat demand. The elaboration of a **load duration curve** provides an overview of the variations of the heat demand. It furthermore helps to identify the capacity of the different heating units.

An example of a duration curve for a plant in Denmark is shown in Figure 61, where the demand is shown in MW for the given hour of the year. By using a duration curve it is possible to get an overview of the time with peak load, intermediate load and base load. In the given example, the peak load could be e.g. 1,400 – 2,800 hours, intermediate load 2,800 – 6,000 hours and base load all 8,670 hours of the year.

Especially the **coldest temperatures of the location** have to be considered, since they influence the amount and duration of the peak load, as well as the maximum capacity of the installed heating system. Climate data are often provided by public meteorological institutions. The climate data are used to calculate, together with data related to the connected buildings (building type and shape, level of insulation, size of window surfaces, and purpose of the building), the exact heat demand and seasonal specifications of a district heating system. (Rutz et al. 2015)

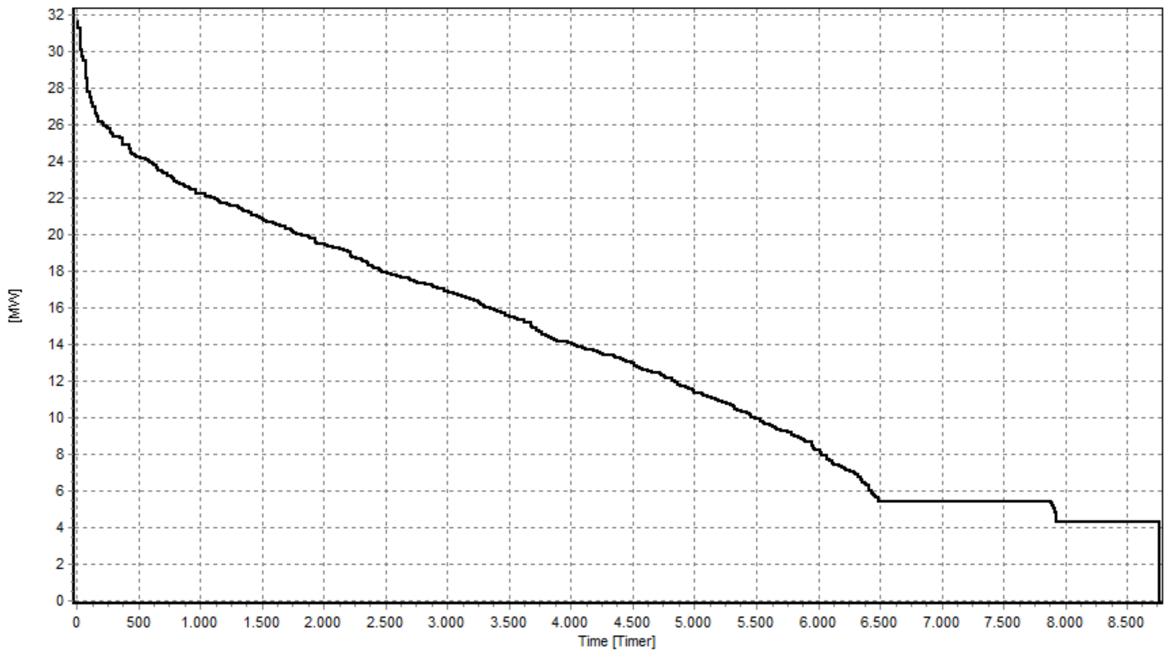


**Figure 61: Example of a load duration curve, Danish example (Source: PlanEnergi)**

### 6.3.2 Dimensioning of the heating units

Besides the assessment of the demand side and the design of the grid, the supply side needs to be planned. The supply side is the assembly of one or more heating units that supply the grid with heat. The **smart combination of different heating technologies** is an important characteristic of small district heating systems that are operated with fluctuating renewable energies, such as solar thermal energy. Some combinations of small modular heating technologies are presented, as examples of displayed schemes, in Figure 63, Figure 64, and Figure 65.

An argument for combining several technologies is that the system will be more robust in terms of security of supply. The **cascading** of different the individual heating units leads to an overall very stable system.

A combined system also allows shifting the main heat production towards production technologies that are **cheap in operation**, such as solar, whereas the operation of expensive peak load units can be reduced. The size of the peak load units can be reduced. Furthermore, the operation can be adjusted, depending on the actual fuel price. For example, many of such systems in Denmark have included biomass or gas boilers as well as electric boilers. In case that the stock price for power is very low or even negative, the electric boiler can be operated. Several examples of how different technologies and sources can be combined are provided by the CoolHeating Best Practice Report (Laurberg Jensen at al. 2016).

When combining different technologies, the **operational strategy** is important to ensure the lowest heat production price as possible.

An example of an operational strategy for a **combined heat and power system** is shown in Figure 62 where the net heat production prices are shown as a function of the electricity prices. In this example, the system consists of two boilers, two CHP units (engines), and a heat pump.

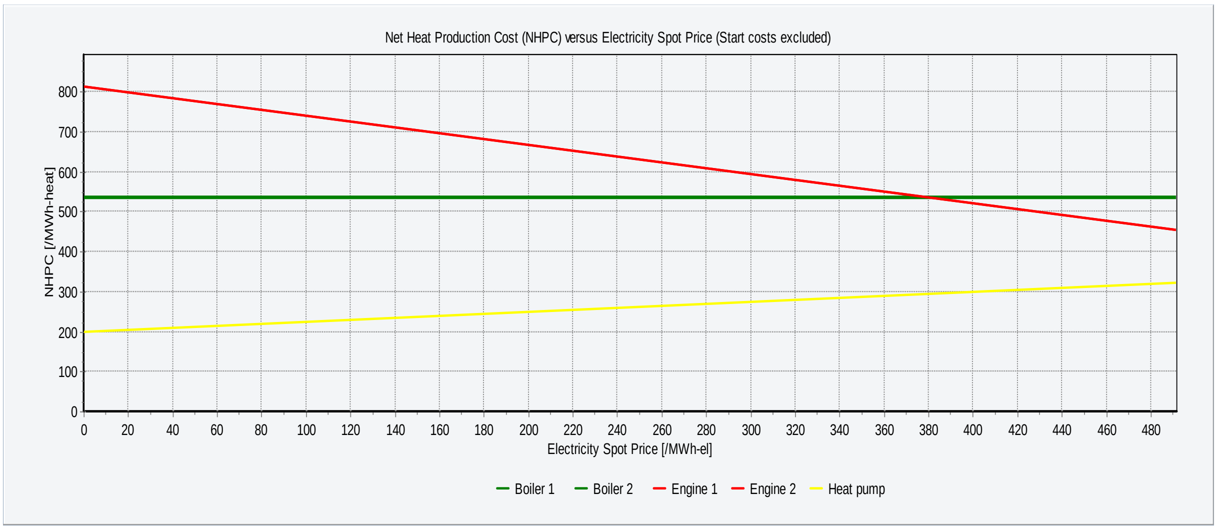


**Figure 62: Examples of operational strategy with heat production prices as function of the electricity price (Source: PlanEnergi)**

The net heat production costs (NHPC) of the boilers are constant[15], independently of the electricity prices, as they only produce heat. The NHPC of the CHP units on the other hand depends on electricity sales and the heat production price of an engine is therefore decreasing as the electricity prices increases. The opposite is the case for heat pumps and electrical boilers. When combining several technologies, it is possible to act according to e.g. electricity prices and use CHP units when the electricity price is high and e.g. heat pumps when the electricity price is low.

Another strategy is the **combination of biomass with solar** to reduce the overall operational costs. It is possible to cover the heat demand during the summer month with solar, and thereby save biomass during these months (see Figure 3). This would save costs for operation and maintenance of the biomass boiler.

In addition to the heating units, the inclusion of **smart storages** can be an important part of the overall strategy. Short term storages can buffer peak demands. Seasonal heat storages

---

[15] The electricity consumption for the operation of the boilers is neglected here.

could increase the share of solar thermal in a district heating grid. A heat pump may be an important part of such system.

The heat production price depends on fuel costs, taxes, electricity prices and sales together with costs for operation and maintenance. In a system with combination of different technologies, the heat production price will determine the number of operation hours of each unit – e.g. in a year with high electricity prices, the CHP unit will operate more hours than in a year with low electricity prices.

A disadvantage of combining several technologies is that the system will be more complex, requiring more advanced control systems. Another disadvantage is that the investments will be less exploited, i.e. the number of full load hours of e.g. a biomass boiler may be reduced. Hence, the feasibility should be calculated for the system as a whole and not for each element of the investment. Both the higher complexity and larger investments may be handled by involving a professional planning company.

It is important to analyse the available technologies, available resources and heat demand before investing in new district heating plants to optimize the performance of the plant and the supply.

For the dimensioning of the heating units, the load duration curve (chapter 6.3.1) is a helpful indicator. For the detailed planning, the application of **planning software** is recommended, such as for example, energyPRO. This programme can provide a duration curve, based on assumptions of the variations of the heat demand and based on information about local conditions including the annual heat demand. It is possible to make the detailed planning of the heating units with the software.

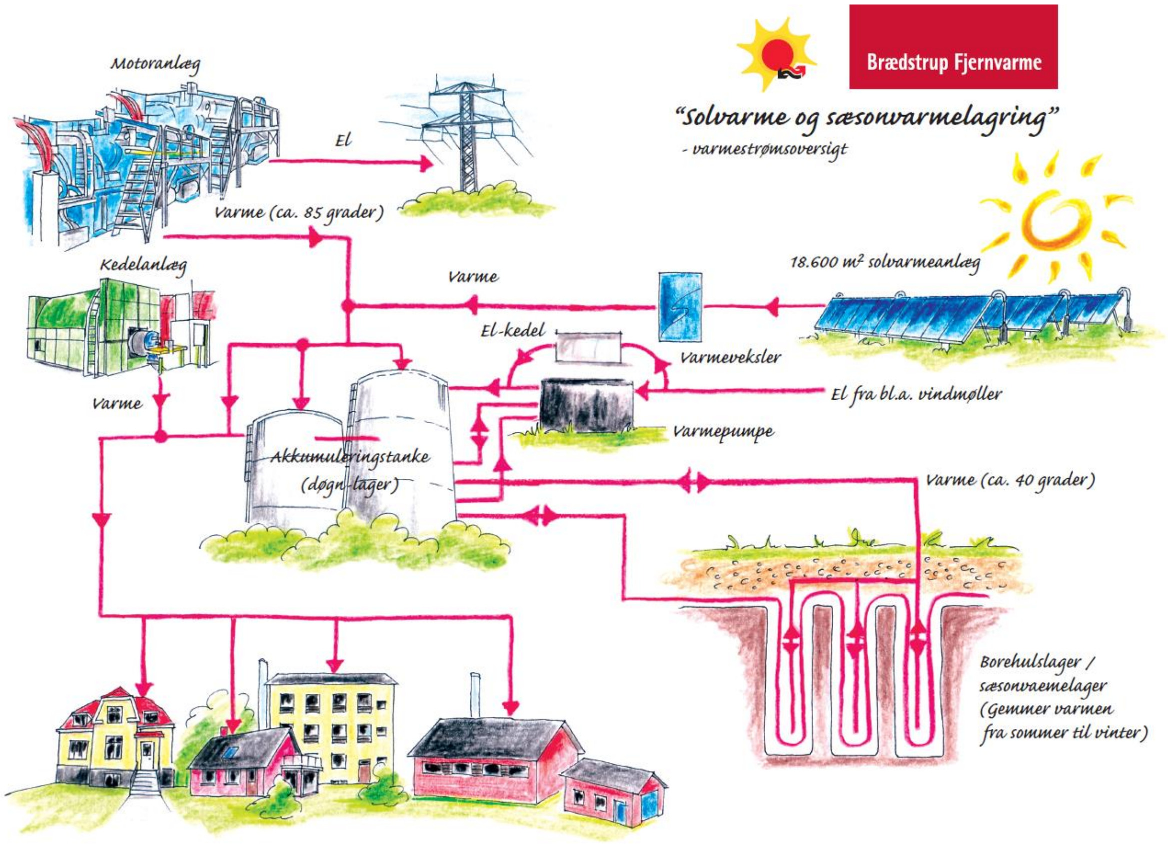


**Figure 63: Scheme of the district heating system of Bradstrup, Denmark (Source: braedstrup-fjernvarme.dk)**

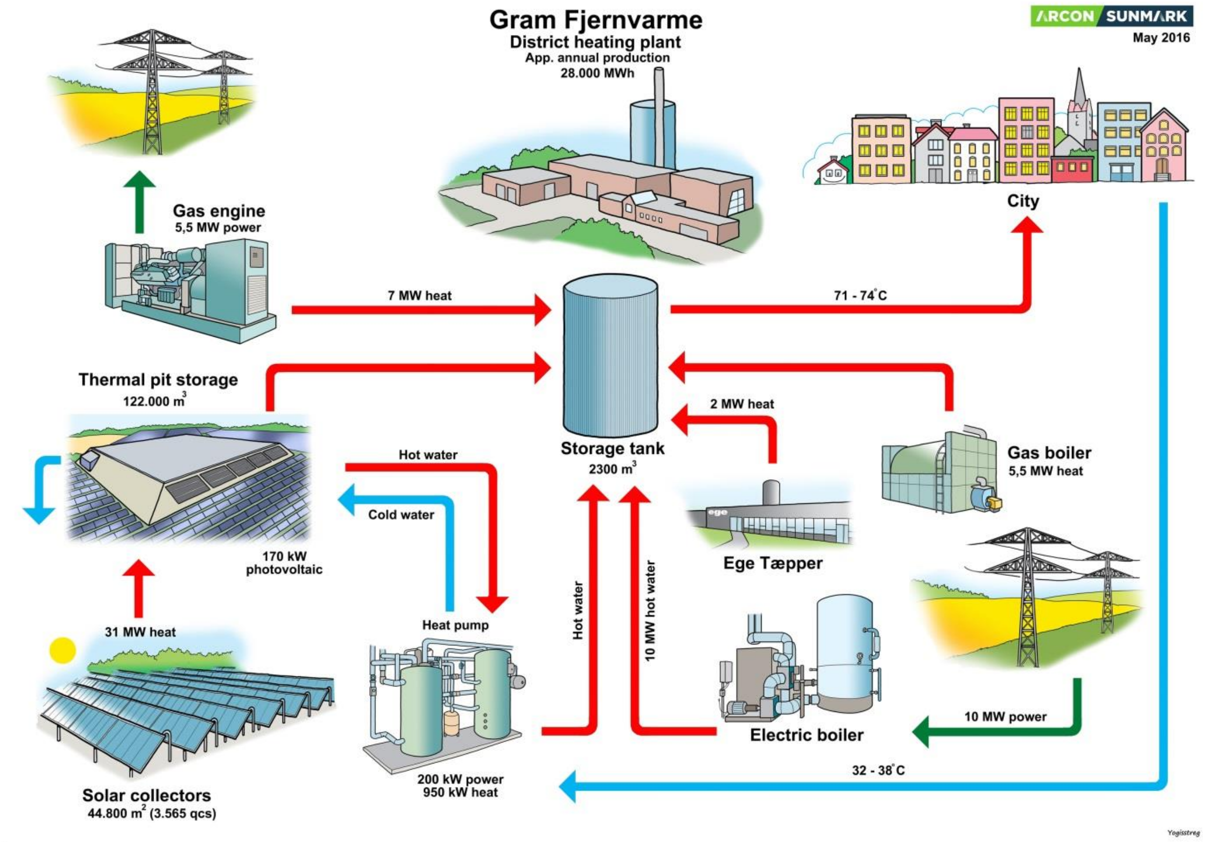


**Figure 64:** Scheme of the district heating system of Gram, Denmark (Source: http://www.gram-fjernvarme.dk)

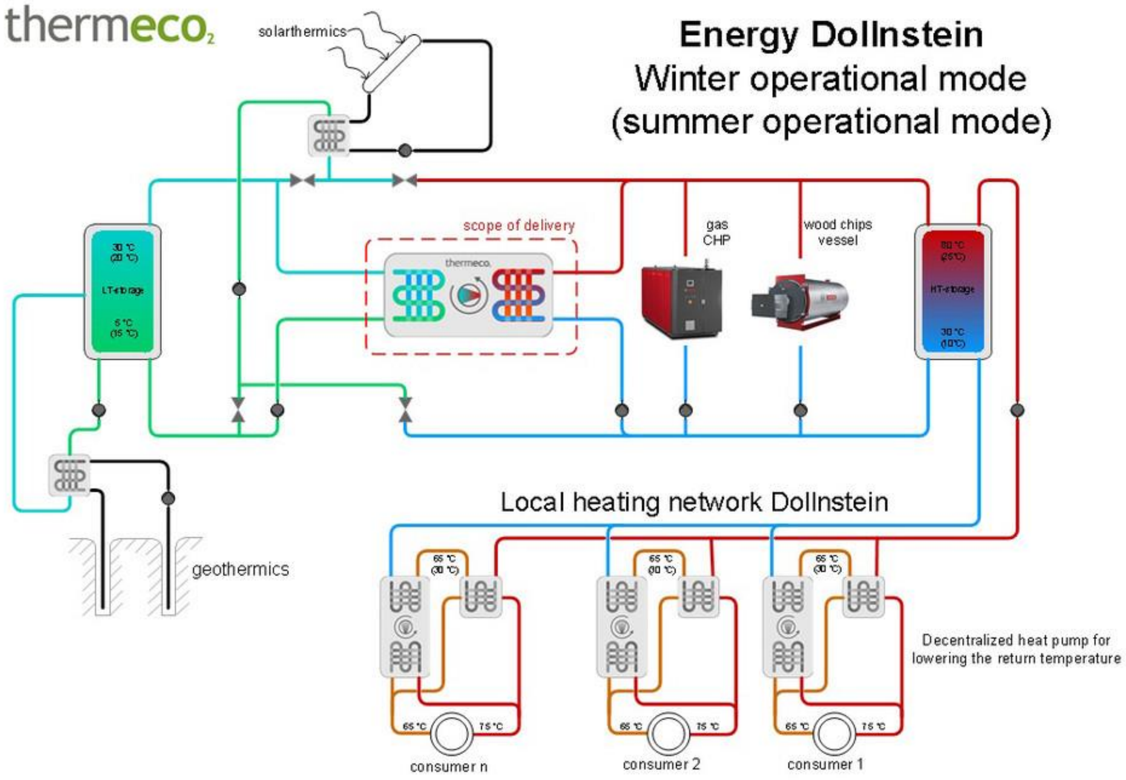


**Figure 65:** Operating scheme local heating grid Dollnstein (Source: Dürr thermea)

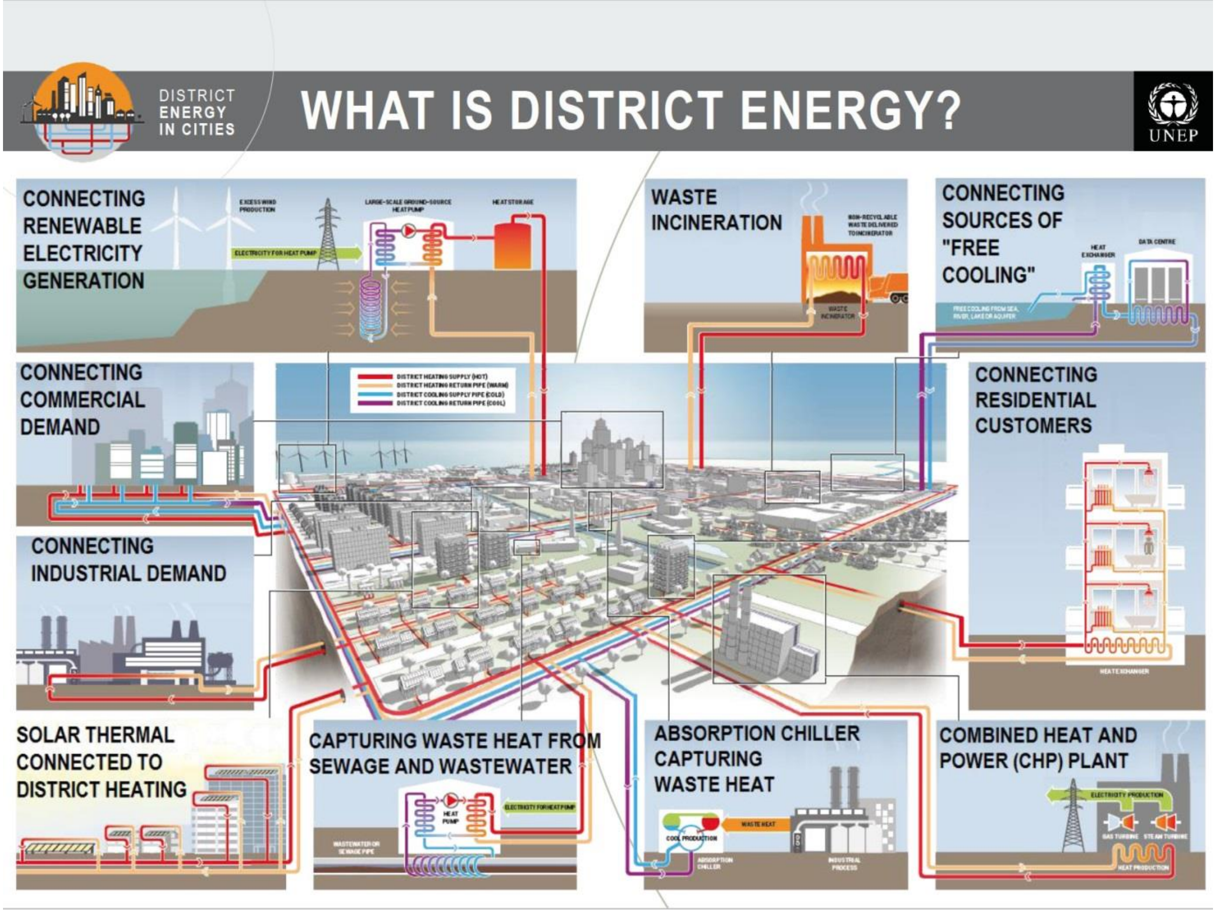


**Figure 66: Components of a larger district energy system (Source: UNEP, www.districtenergyinitiative.org)**

## 6.4 *Consumer needs and behaviour*

Besides the technical analysis of the heat demand, also an analysis of non-technical issues has to be made. Thereby, the needs of the consumers and their behaviour have to be investigated prior to the next planning steps.

The **willingness** of the consumers to connect to the grid has to be assessed. The motivation of consumers to be connected can be manifold. Lower heat prices, better services, support or renewable energies and higher comfort can be potential motivations. The consumer only needs to pay for the heat, but does not have to take care of annual fuel purchases as it is the case for individual oil heating systems. This comfort for the consumers is a key characteristic of district heating, and is an element in the competitiveness of district heating. Furthermore, the extension of the living space can be an important argument for the district heating system as this usually needs less space in the building, than an individual heating system. Using a district heating system, only a heat transfer station as well as in some cases a buffer tank is needed, whereas e.g. for a oil based heating system, a boiler, water tank, and a oil storage is needed.

Direct face-to-face contact to the consumers and information events support the process. Depending on the status of the planning, letters of commitment can be collected from potential consumers stating the willingness to be connected. This is important as in the initial project phase not all potential heat consumers may want to be connected, which reduces the potential technical heat demand of the whole assessed area.

Once the project is getting more advanced, **long-term contracts** between the supplier (utility) and the consumers should be made due to the high installation costs and the large efforts needed for the set-up of a district heating system. The contract relations are subject to all relevant legislations, including decisions made by authorities and courts of law. The organisation of the district heating utility should be transparent, and this should be communicated and formulated clearly to the customers. This will facilitate a high level of trust between the customers and the district heating utility, which are crucial parameters for the success of the district heating project. In order to get contracts signed by the consumers, the following information should be sent to the consumers:

- Welcome letter
- Information about the supplier
- Agreement on DH supply
- Contract conditions for DH supply
- Technical conditions for DH supply
- Tariff sheet and agreement

In the contract with the heat consumer, the **heat supply concept** needs to be agreed. There are two main different concepts, namely supply of basic heat, and full heat supply.

In the concept of **basic heat supply**, the grid operator supplies only the available fraction of a heating plant to the heat consumer. This model is often used if the heat is supplied by the waste heat from already installed biogas plants or other facilities that have waste heat available. The operator does not guarantee the full heat supply. Therefore, it is necessary that the heat consumer is also equipped with additional (existing) boilers that can be switched-on in case that insufficient heat is supplied by the biogas plant operator. This mainly occurs in times of peak demand or during system failures and maintenance. In the basic heat supply system, the risk of the heat plant operator is reduced to a minimum. However, the plant operator usually does not receive reasonable prices for this heat. Heat consumers generally benefit from very low heat prices, but have to pay for the installation and maintenance of additional boilers. (Rutz et al. 2015)

In the concept of **guaranteed heat supply**, the whole heat demand is supplied by the heating plant operator. This is the typical model if dedicated heating facilities and heating grids will be newly installed. This model includes also the supply of peak demand e.g. in cold winters, as well as the supply in case of system maintenance or failure. In many contracts in Germany, the heat supply for temperatures of down to -15°C is guaranteed. In this system the heating plant operator has higher investment costs, since he has to install and maintain peak or emergency heaters. In this concept, the risk is higher for the plant operator since he has to guarantee continuous heat supply. Since the consumer has fully outsourced the heat supply to the biogas plant operator, higher heat prices can be charged. The comfort for the consumer is higher. (Rutz et al. 2015)

In parallel to the technical assessment, the **consumption patterns and data** of potential heat consumers can be analysed. Thereby, seasonal and daily consumption patterns and peak loads have to be assessed.

It needs to be considered, that the **consumer behaviour** sometimes has a larger impact on the heat demand than the type of the technical equipment. The heat demand can vary significantly for the same building types due to different behaviour of the consumers. For instance, different ventilation habits and wrong maintenance of the heating systems can have a large impact on the heat demand. The installation and connection of consumers to the DH grid could be an opportunity to train consumers in energy saving measures. Furthermore, the heating equipment in the building, which is usually in the responsibility of the building owner and not of the DH grid operator, should be overhauled. This could be offered as an additional service of the DH operator and in close cooperation with local installers.

Finally, the set-up of a **business model** for the heating system may provide direct participation opportunities of the consumers. They can be involved as investors or shareholders, especially in cooperative models. This may increase the overall acceptance of the project.

### *6.5 Economy of small district heating projects*

The overall economy of a small district heating project depends on many factors at different levels. For example, on the local level, costs for energy from renewable energies are always compared in the society to the costs of energy from fossil fuels. If the renewable energy system is cheaper than a fossil energy system, it will be implemented; if the costs are higher, the project will be often not realized. On the local level, the economy is influenced for instance by local support schemes.

Thus, only some important aspects are summarised here that influence the economy of the project. More detailed information is provided by other reports of the CoolHeating project, as well as by an economic calculation tool, developed by the CoolHeating project. The key factors influencing the economy of a project include:

- Investment costs
- Operation and maintenance (O&M) costs
- Heat demand of the consumers
- Fuel (e.g. biomass) prices for the heating units
- Fossil fuel prices
- Taxes
- Quality and durability of the equipment
- Business model
- Ownership of the grid

# 7 Cooling technologies

With increasing global warming, also the need for cooling is getting more important. However, already today, the demand of energy for cooling is considerably high. The main applications of cooling are:

- Acclimatization of public and private buildings
- Acclimatization of industry buildings (e.g. server rooms)
- Cooling of agro industrial and food products
- Cooling for the food and beverage industry
- Cooling for the chemical industry

Depending on the needed cooling capacity and temperature level, renewable energies are very suitable for offering cooling services. For many applications, cooling is needed especially during the warm summer period when there is intensive solar irradiation. Thus, cooling with solar heat and waste heat from other processes could increase the overall share of sustainable energy supply.

For renewable cooling, free cooling, conventional vapour compression chillers, absorption chillers, adsorption chillers and heat pumps can be used. The different technologies are presented below.

## 7.1 Free cooling

Free cooling is cooling at low cost (“free”) by using the low ambient temperature, e.g. from air, soil or water bodies. The cooling provided is not completely “free” as small amounts of energy are needed to operate the fans, pumps or control devices. However, naturally occurring climate conditions help saving costs and greenhouse gas emissions. The following sources of natural cooling energy could be considered:

- Cool water from the sea, lakes, rivers
- Night-time coldness
- High-altitude coldness
- Soil or geothermal coldness

Depending on the system and the requirements, the free cooling source could be used as single cooling source or in combination with other technical equipment such as conventional chillers. In case of fluctuating coolness, such as cool air from night-time, could bypass existing conventional chillers during night-time. The conventional chillers could be used during peak coolness demand.

A simple application of free cooling is the acclimatization of buildings which have a ground source heat pump that are used in winter for space heating. In summer, the soil has average temperatures of 8-12°C, which could be directly used in the central heating system in the building for cooling purposes. Especially if the central heating system has large surfaces of panel or floor heating radiators, the soil coolness could be used to cool down the building. Attention must be given not to cool down the radiators below the dew point as condensed water could damage the building.

Another free cooling method is to design buildings in a way that the building is cooled down with low temperature of the ambient air during night-time so that the building is acclimatised during the day.

### 7.2 *Vapour compression chillers*

Vapour-compression chillers are the most widely used devices for air-conditioning in buildings and cars. They are also used in domestic and commercial refrigerators, in the chemical industry, in warehouses to store food, in refrigerated trucks, etc.

Vapour-compression chillers use a circulating liquid refrigerant as the medium, which absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. Core of this system is the compressor that is operated with electricity. Furthermore, the system includes a condenser, a thermal expansion valve, and an evaporator.

In the process, the circulating liquid refrigerant enters the compressor as saturated vapour. This is compressed to a higher pressure whereas the temperature rises. The hot, compressed vapour is called superheated vapour. This vapour is cooled down by air (or water) which leads to condensation of the vapour. The condensed liquid refrigerant is called saturated liquid. It enters the expansion valve where the pressure is rapidly decreased. This pressure reduction results in the evaporation of the liquid refrigerant. This lowers the temperature of the liquid/vapour refrigerant mixture, thus leading to the desired cooling effect. The circulating liquid refrigerant enters the compressor again and closes the loop.

The main advantage of vapour-compression chillers is its simplicity and reliability as well as its large-scale use in billions of systems. The current disadvantage is its high electricity demand in order to run the compressors. As electricity costs are often high, the operational costs of vapour-compression chillers is considerable.

In contrast to adsorption or absorption chillers, the main energy source of vapour-compression chillers is electricity, whereas the other systems are operated mainly with heat, for example from solar collectors. As prices for electricity from photovoltaic (PV) systems decreased considerably in the last years, cooling with traditional vapour-compression chillers may compete with the more innovative adsorption or absorption chillers, which are so far much less used in the cooling sector. Thus, “PV/vapour-compression chiller systems” may be somehow in competition to “renewable heat/ adsorption or absorption chiller systems” in the future.

### 7.3 *Absorption chillers*[16]

In contrast to the operation with mainly electric power in vapour-compression chillers, **absorption chillers** principally use a heat source, which could be solar thermal heat or waste heat, as main energy for the cooling process. Absorption chillers are an alternative to regular compressor chillers where electricity is unreliable, costly, or unavailable, where noise from the compressor is problematic, or where surplus heat is available as it is the case of biogas plants. Generally, absorption chillers are characterized by the following main benefits when compared to vapour compression chillers (Skagestad & Mildenstein, n.d.):

- Lower electrical requirements for chiller operation
- Lower sound and vibration levels during operation
- Ability to utilize recovered heat and convert it to cooling energy
- Refrigerant solutions typically do not pose a threat to ozone depletion of the atmosphere.

Both, absorption and compressor chillers use a refrigerant liquid, usually with a very low boiling point (often less than −18°C). In both types, heat is extracted from one system and thus creating the cooling effect, when the refrigerant liquid evaporates. The main difference

---

[16] For the elaboration of this whole chapter the BiogasHeat Handbook (Rutz et al. 2015) was used. Several parts of the text are taken from this source.

between the two systems is the way the refrigerant is changed from the gaseous phase back into a liquid so that the cycle can repeat. The compression chiller changes the gas back into a liquid by increasing pressure levels through a (electrically operated) compressor. An absorption chiller changes the gas back into a liquid by absorption of the refrigerant in another liquid and adjacent desorption with heat. The other difference between the two types is the refrigerant used. Compressor chillers typically use hydrochlorofluorocarbons (HCFCs) or hydrofluorocarbons (HFCs), while absorption chillers typically use ammonia or lithium bromide (LiBr).

Generally, absorption chillers are categorised as direct or indirect-fired, and as single, double or triple-effect. For using renewable heat, only indirect-fired chillers are relevant, although theoretically, also direct-fired chillers could be operated with the direct combustion of biogas. Absorption and compressor chillers can be combined, too (cascade or hybrid cooling).

The classification into single-effect, double-effect and the triple-effect absorption chillers is based on the number of heating sources (levels). **Single-effect absorption chillers** have only one heating level of the working fluid (weak solution). **Double-effect absorption chillers** have two stages of vapour generation to separate the refrigerant from the absorbent. Therefore, double-effect chillers have two condensers and two generators. The heat transfer occurs at a higher temperature compared to the single-effect cycle. Double-effect chillers are more efficient, but also more expensive (New Buildings Institute 1998). **Triple-effect absorption chillers** are even further advanced in comparison to double-effect chillers. Triple-effect absorption chillers are under development, as the next step in the evolution of absorption technology (New Buildings Institute 1998).

The use of absorption chillers depends on the waste heat temperature, the used refrigerant and transport medium, as well as on the desired cooling temperature. $LiBr/H_2O$ absorption chillers are able to cool down to 6°C and $NH_3/H_2O$ absorption chillers from 0°C down to -60°C.

In order to compare chillers, the **energy efficient ratio** (EER) is used which is similar to the coefficient of performance (COP) of heat pumps. It is the ratio of the cooling capacity ($\dot{Q}_C$) to the heat input capacity ($\dot{Q}_H$). Thereby, the capacity of the pump ($P_P$) is negligible. The EER of actual absorption refrigeration systems is usually less than 1. Typical EERs for commercially available chillers range from 0.65 to 0.8 for single effect units and 0.9 to 1.2 for double effect units (Skagestad & Mildenstein, n.d.).

$$EER = \frac{Cooling\ capacity}{Input\ capacity} = \frac{\dot{Q}_C}{\dot{Q}_H + P_P} \approx \frac{\dot{Q}_C}{\dot{Q}_H} \qquad \text{Equation 8}$$

| | |
|---|---|
| $EER$ | *Energy efficient Ratio* |
| $\dot{Q}_C$ | *Cooling capacity [kW]* |
| $\dot{Q}_H$ | *Heat input capacity [kW]* |
| $P_P$ | *Electric input capacity (pump) [kW]* |

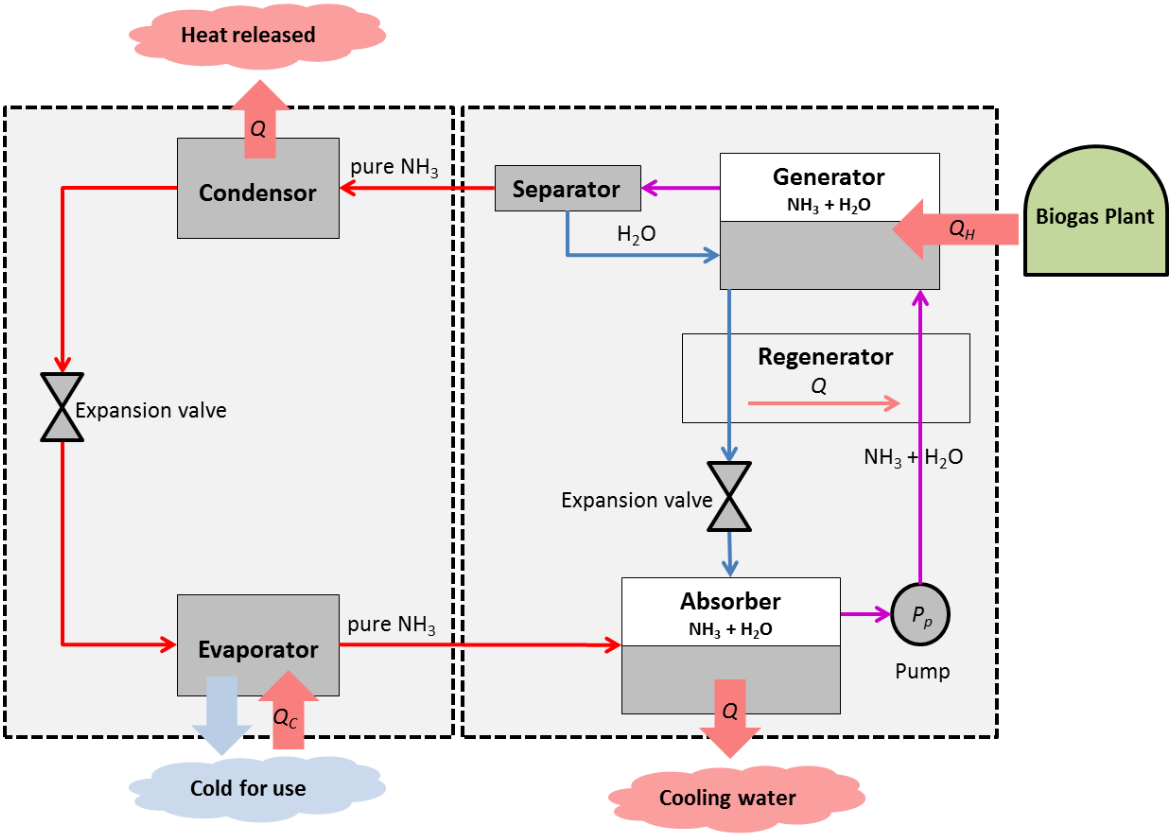


**Figure 67: Process of a typical ammonia-water absorption refrigerator using renewable heat, e.g. from a biogas plant (Source: Rutz et al. 2015)**

The general process of a typical **ammonia-water absorption chiller** is shown in Figure 67. In this process, ammonia ($NH_3$) serves as the refrigerant and water ($H_2O$) as the transport (absorbent) medium. In the **evaporator** the refrigerant pure ammonia in liquid state produces the cooling effect. It absorbs the heat from the substance to be cooled and gets evaporated. From here, the ammonia vapour is pumped to the absorber. In the **absorber** a weak solution of ammonia-water is already present. The water, used as the transport medium in the solution, is unsaturated and it has the capacity to absorb more ammonia gas. As the ammonia from evaporator enters the absorber, it is readily absorbed by water and the strong solution of ammonia-water is formed. During the process of absorption, heat is liberated which can reduce the ammonia absorption capacity of water; hence the absorber is cooled by the cooling water. Due to the absorption of ammonia, a strong solution of ammonia-water is formed in the absorber. This solution is pumped by the **pump** at high pressure to the **generator** in which it is heated by the heating source (here: biogas plant) while ammonia is vaporized. Ammonia vapour leaves the generator, but some water particles also get carried away with ammonia refrigerant due to the strong affinity of water for ammonia. Therefore, it is passed through the **separator**, similar to a distillation column. Water goes back through the regenerator and expansion valve to the generator. The weak ammonia/water solution goes back form the generator to the absorber. Pure ammonia vapour enters the condenser at higher pressure where it is cooled by water. It changes its phase into a liquid state and then passes through the expansion valve where its temperature and pressure falls down suddenly. Ammonia finally enters the evaporator again, where it produces the cooling effect. Thereby the cycle is closed.

**Figure 68: Air-cooled chiller using waste heat of an incineration plant in Austria (Source: Rutz D.)**

## *7.4 Adsorption chillers*

Adsorption is the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a surface. This process is similar to the absorption process, but differs as in in absorption a fluid (the absorbate) is dissolved by or permeates a liquid or solid (the absorbent), respectively. Adsorption chillers always use a liquid (gaseous) and a solid material, whereas absorption chillers use always two liquids (gases).

Adsorption chillers use solid sorption materials instead of liquids. The two main technologies, which are commercially available today, use Silicagel or Zeolith as sorbent and water as refrigerant. Combining an adsorbent with a refrigerant, adsorption chillers use heat, such as from solar thermal collectors, to provide a cooling effect.

The system consists of two sorbent compartments (adsorption chambers) (Figure 69) (Solair Project, 2009) which are operated in an alternating batch-mode (Figure 70). The two compartments contain a solid sorbent, which in its neutral state has adsorbed the refrigerant. When heated, the solid desorbs (releases) refrigerant vapour, which is subsequently cooled and liquefied. This liquid refrigerant then provides its cooling effect at the evaporator, by absorbing external heat and turning back into a vapour. In the final stage the refrigerant vapour is (re)adsorbed into the solid. By using the two chambers in batch-mode, continuous cooling can be achieved.

To date, only a few Asian and European manufacturers produce adsorption chillers. Under typical operation conditions with a driving temperature of 80°C, the systems achieve a coefficient of performance (COP) of about 0.6, but operation is possible even with temperatures of approx. 60°C. The capacity of the chillers ranges from 5.5 kW to 500 kW chilling power. (Solair Project, 2009)

Adsorption chillers have the same advantages as absorption chillers. The simple mechanical construction of adsorption chillers and their expected robustness is an advantage. There is no danger of crystallisation and thus no limitation in temperatures. There is no internal solution pump and electricity consumption is reduced to a minimum. A disadvantage is the comparatively large volume and weight. Furthermore, due to the small number of produced systems, the price of adsorption chillers is currently still high. A large potential for improvements is expected in the construction of the heat exchangers in the adsorber compartments, which would reduce volume and weight considerably in future generations of adsorption chillers. (Solair Project, 2009)

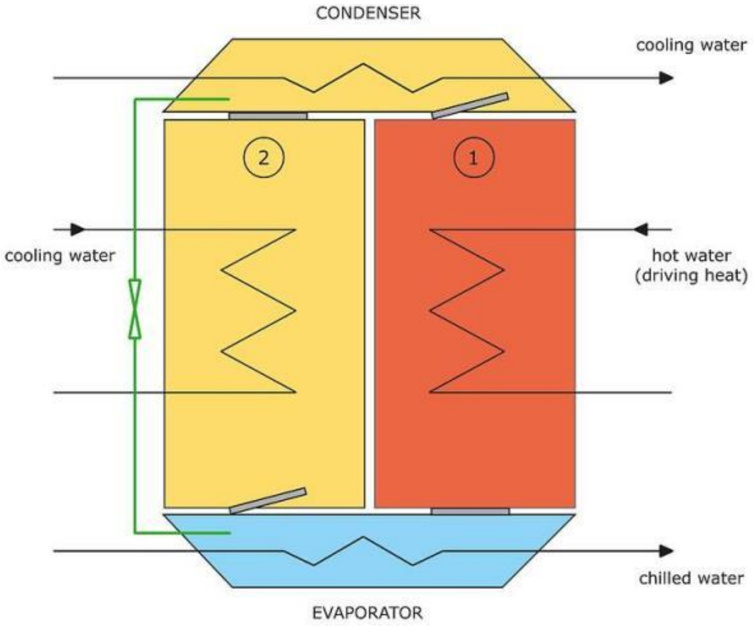


**Figure 69: Scheme of an adsorption chiller (Source: Solair Project 2009)**

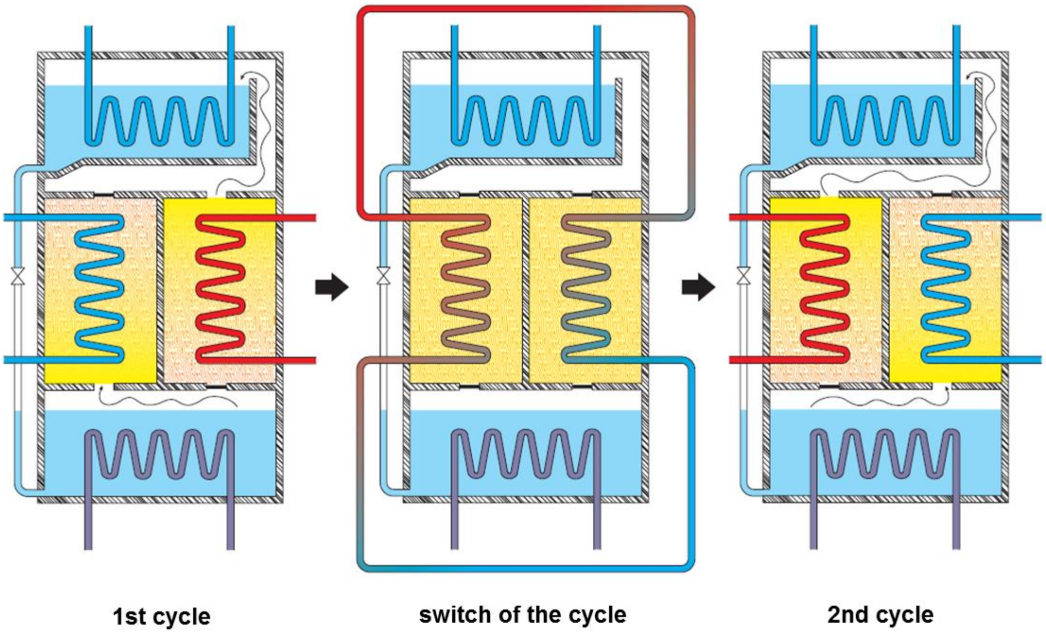


**Figure 70: Principle of an adsorption chiller and its cycles (Source: based on Holzmann 2010)**

### 7.5 Desiccant cooling systems

Desiccant cooling systems are open cycle systems, using water as refrigerant in direct contact with air. The thermally driven cooling cycle is a combination of evaporative cooling with air dehumidification by a desiccant, i.e. a hygroscopic material. For this purpose, liquid or solid materials can be used. The term “open” is used to indicate that the refrigerant is discarded from the system after providing the cooling effect and new refrigerant is supplied in its place in an open-ended loop. Therefore, only water is possible as refrigerant with direct contact to the surrounding air. The common technology applied today uses rotating desiccant wheels (dehumidifier wheels), equipped with silica gel or lithium-chloride as sorption material. (Solair Project, 2009)

Warm and humid air enters the slowly rotating desiccant wheel and is dehumidified by adsorption of water (1-2). Since the air is heated up by the adsorption heat, a heat recovery wheel (heat exchanger) is passed (2-3), resulting in a significant pre-cooling of the supply air stream. Subsequently, the air is humidified and thus further cooled by a controlled humidifier (3-4) according to the set-values of supply air temperature and humidity. The solar thermal energy can be also used in winter to provide heating (5). In the cooling process, the exhaust air stream of the rooms is humidified (6-7) close to the saturation point in order to cool down the heat recovery wheel (7-8). Finally, the sorption wheel has to be regenerated (9-10) by applying heat in a comparatively low temperature range from 50°C – 75°C and to allow a continuous operation of the dehumidification process. A special design of the desiccant cycle is needed in case of extreme outdoor conditions such as e.g. coastal areas of the Mediterranean region. A new technology is desiccant cooling systems using a liquid water-lithium chloride solution as sorption material. (Solair Project, 2009)

Desiccant cooling systems could be operated with solar thermal energy from solar collectors on the rooftop of the building, but also with heat from a small micro heating grid, or from process waste heat.

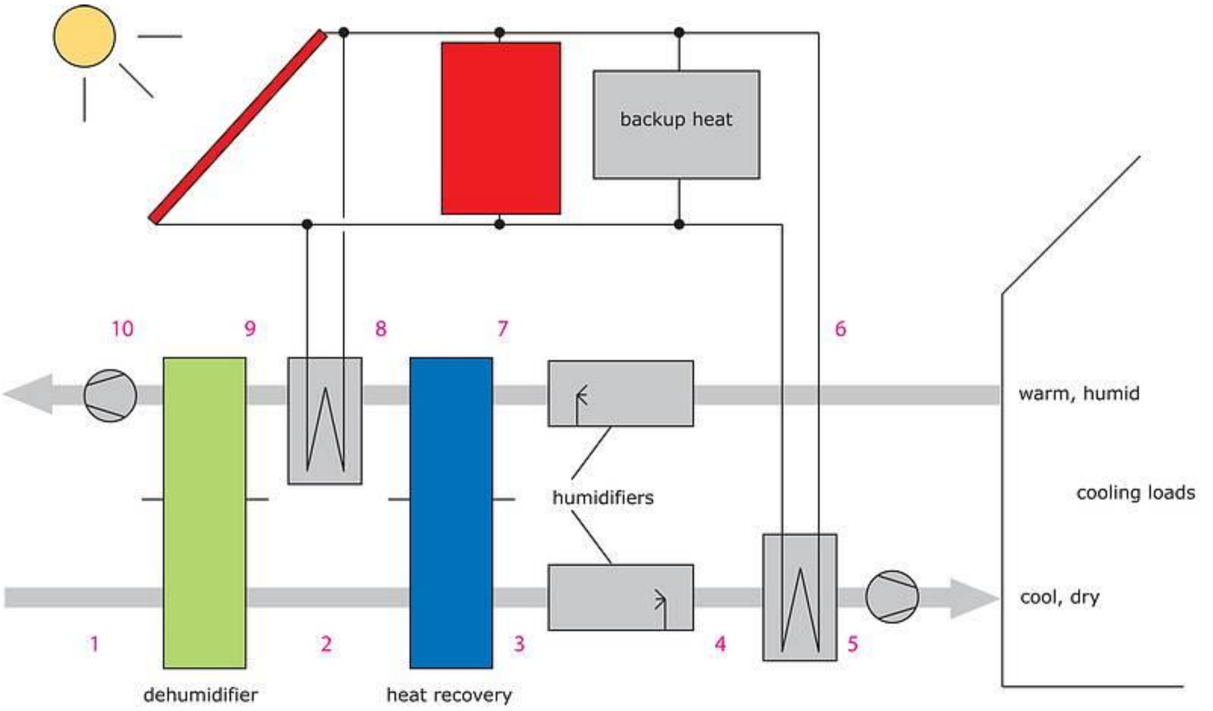


**Figure 71: Scheme of desiccant cooling (Source: Solair Project 2009)**

# 8 Cold storage technologies[17]

Cold storage is in principle equivalent to heat storage technologies, described in chapter 4. Thus, where low temperatures are desired, cold storage can be used the same way as heat storage and provide the same kind of services to the overall energy system. There are two types of cold storage:

- Lowering the temperature in the stored products in a cold storage facility by running the refrigeration system for prolonged period
- Dedicated production of ice or cold water stored in a vessel, pit or in geological reservoirs

The effect of varying temperatures on the quality of different types of stored products must be considered, as some products are sensitive to temperature changes.

Ice banks have been widely used, but as refrigeration systems became more and more efficient, they became less common. With the new demands for flexibility in the energy system, they may experience a revival. However, the ice production must be efficient to minimise energy losses.

Traditional ice production includes rather large temperature differences (cooling system temperatures of -10°C or lower are common practice). The combination of water as refrigerant and ice as cold store media can result in very effective systems for ice production and storage. Research and development is needed in the field of ice generation based on pure water, charging and discharging the ice storage and measurement of the stored amount of ice.

Water vapour has large potentials as an environmentally friendly refrigerant and is used in several projects aiming at commercialisation in the near future.

---

[17] The text on cold storages is reproduced and adapted on the basis of Schrøder Pedersen et al. (2014)

# 9 Integration of cooling systems

Cooling or acclimatisation of buildings and other applications with solar thermal energy is especially interesting in hot climates where the high cooling demand correlates with high ambient temperatures, as peak production can be  at the same time as peak demand. Cool storages and warehouses in climatically hot regions, as well as many industrial cooling processes, need very much energy when solar irradiation is at maximum (Morgenstern, 2016). In general, solar thermal cooling applications instead of electrical cooling applications can be used to relieve the pressure on the power grid at peak loads.

Also with other cheap heat sources, such as for example with waste heat from biogas CHP units, the use of heat-based cooling systems (adsorption and absorption chillers) can be economically interesting. Also free cooling and desiccant cooling technologies may be increasingly used. Cooling with solar power from PV systems may be complementary.

However, in general solar cooling technology is relatively expensive, especially if only used for space cooling (Kempener, 2015).

## *9.1 Cooling with district heat*

In areas where the cooling demand is not very high, but where selected consumers need cooling, the use of heat from small modular renewable heating grids or even from larger district heating grids may be used to operate decentralised absorption chillers at the place of the consumer. Thereby, heat is transferred through the heating grid to the consumer and only there converted into cooling. The main benefit of this approach is that in summer many small heating grids are not profitable due to the low heat demand. The integration of decentralised chillers, which use the heat from the heating grid, could also create a heat demand in summer making the heating grid more profitable. Usually, in summer, the peak cooling demand is higher and the heat demand for space heating is lower. Another advantage of this approach is that due to the avoided power need of the chillers, the power grid is relieved.

## *9.2 Small district cooling systems*[18]

District cooling is similar to district heating, but distributes chilled water instead of heat. The cooled water is produced in a centralized system and then distributed. Although the demand for cooling is increasing steadily, due to higher comfort standards and higher temperatures related to climate change, district cooling is not as applied as district heating. Several European cities have introduced district cooling systems, in order to save greenhouse gas emissions.

The source of chilling can be from absorption chillers, vapour-compression chillers, and other sources like free cooling. Different cooling systems can be also combined. Depending on contracts with consumers, cooled water may be provided for both basic and peak demand. Due to the higher investment costs of absorption chillers, additional vapour-compression chillers may be operated during peak demand in order to guarantee peak supply. The design of the district cooling system is governed by the following key factors (Rutz et al. 2015):

- The difference of the temperature between supply and return pipes
- Flow velocity
- Grid pressure and pressure differential between supply and return pipes

---

[18] For the elaboration of this whole chapter the BiogasHeat Handbook (Rutz et al. 2015) was used. Several parts of the text are taken from this source.

The successful implementation of district heating and cooling systems depends largely on the ability of the system to obtain high **temperature differentials** (ΔT) between the supply and return water (Skagestad & Mildenstein n.d.). The ΔT is typically limited to 8-11°C. The systems usually adjust the temperature of the chilled water supply based on the outside ambient temperature. District cooling systems can be subdivided into three groups based on supply temperatures (ibid.):

- Conventional chilled water temperatures: 4°C to 7°C
- Ice water systems: +1°C
- Ice slurry systems: -1°C

Due to the small temperature gradients between the pipe grid and the surrounding soil, it is not necessary to insulate the pipes. The underground cooling pipes of the distribution grid are usually buried at depths of around 60 cm. In very warm climates and for aboveground pipes, insulation is required.

The maximum allowable **flow velocities** are governed by pressure drop constraints and critical system disturbances caused by transient phenomena. Generally, velocities higher than 2.5 – 3.0 m/s should be avoided unless the system is specially designed and protected to allow for higher flow velocities (ibid.).

## *9.3 Selected examples*

In contrast to small, decentralised renewable heating grids, there are much less good practice examples available for small, decentralised renewable cooling grids. Some examples are presented below. The presented examples are not necessarily small, decentralised or renewable, but show different sizes and applications of cooling in order to demonstrate different technologies. A good overview of solar cooling best practice examples are provided by the Solair project (www.solair-project.eu/175.0.html) and an example of cooling is also included in the good practice report of the CoolHeating Project (Laurberg Jensen et al. 2016). Some Danish examples of district cooling are in Copenhagen[19] and Thisted[20].

### *9.3.1 Solar cooling of a wine cellar in Banyuls sur Mer, France[21]*

The Groupement Interproducteurs du Cru de Banyuls (www.terresdestempliers.fr) is a wine producers union in Banyuls sur Mer, France. In order to store about 3 million wine bottles at proper temperatures, the temperatures of the wine cellar building was analysed and a solar cooling system installed in 1990.

The cooling demand of the building, which consists of a ground floor where the wine is dispatched, and two cellar levels where the wine is stored, corresponds to the solar irradiation: in summer, the cooling demand is higher. The temperatures in the ground floor are kept at 22°C, in the first cellar level at 19°C and in the second cellar level at 17°C.

The cooling system consists of 130 m² of evacuated tube collectors on the roof. They are oriented in South/South-West direction and are directly fixed on the roof at 15°C. The system includes a 1,000 litres hot water buffer tank for short-term buffering. The wine bottles themselves act as long-term cold storage. The system has a single effect indirect absorption chiller with a nominal cooling power of 52 kW, as well as an open loop cooling tower with a nominal power of 180 kW.

---

[19] http://www.hofor.dk/english/district-cooling/?hilite=cooling

[20] http://fjernkoling.dk/

[21] Information taken from: http://www.solair-project.eu/185.0.html

### *9.3.2 Solar cooling with adsorption chiller of Fraunhofer ISE, Freiburg, Germany*[22]

The building of the Fraunhofer Institute for Solar Energy Systems (ISE) institute is an energy efficient building with passive cooling measures. An exception is the canteen kitchen area, where active cooling of the supply air is needed due to high internal loads. This is done by means of a small size thermally driven adsorption chiller.

The cooling system for the canteen is a closed cycle chilled water system with an adsorption chiller. Heat is provided by a solar thermal system and by the heating system of the institute. During summer, the system runs in cooling mode. The medium temperature heat of the chiller is rejected by three ground tubes of 80 m each. In winter, the heat pump function of the machine is activated and the ground tubes act as low-temperature energy source. The system thus cools and heats the supply air into the kitchen.

### *9.3.3 District cooling in Chemnitz, Germany*[23]

The city of Chemnitz in Germany has a district cooling grid since 1973. The grid is about 5 km long and distributes cold water to various public buildings and shopping centers. The system was operated initially with electrical vapour compression coolers. The system was refurbished in the beginning of the 1990ies whereas absorption chillers were installed.

In 2007 an innovative cold water storage tank was installed in order to cover peak loads. The storage is 17 m high, has a diameter of 16 m and a volume of 3,500 m³. The cold storage capacity is 32 MWh.

The central absorption chillers are operated with the heat from the combined heat power plant in Chemnitz. This incineration plant has three thermal power units which are fuelled with lignite or oil. Although this energy is fossil based and not renewable, the example was included here to show the district cooling system. The system could be theoretically also be operated with the heat from renewable resources. The hot water is transported through district heating pipes from the plant to the central absorption chiller unit.

The absorption chillers use the heat to cool water down to 5°C. This water is pumped in insulated pipes to 25 connection points where special exchangers ensure the cooling of the buildings. The warmed water of about 13°C is transported back to the central chilling unit.

### *9.3.4 District cooling in Vienna, Austria*[24]

In Vienna waste heat that is produced in waste incineration power plants is used not only for district heating, but also for district cooling. The energy utility Wien Energie offers two solutions for customers who need cooling:

- Decentralised solution: Here Wien Energie installs a refrigeration centre directly at the customer.
- Centralised solution: This concept uses a refrigeration centre that supplies several customers at the same time via a district cooling grid.

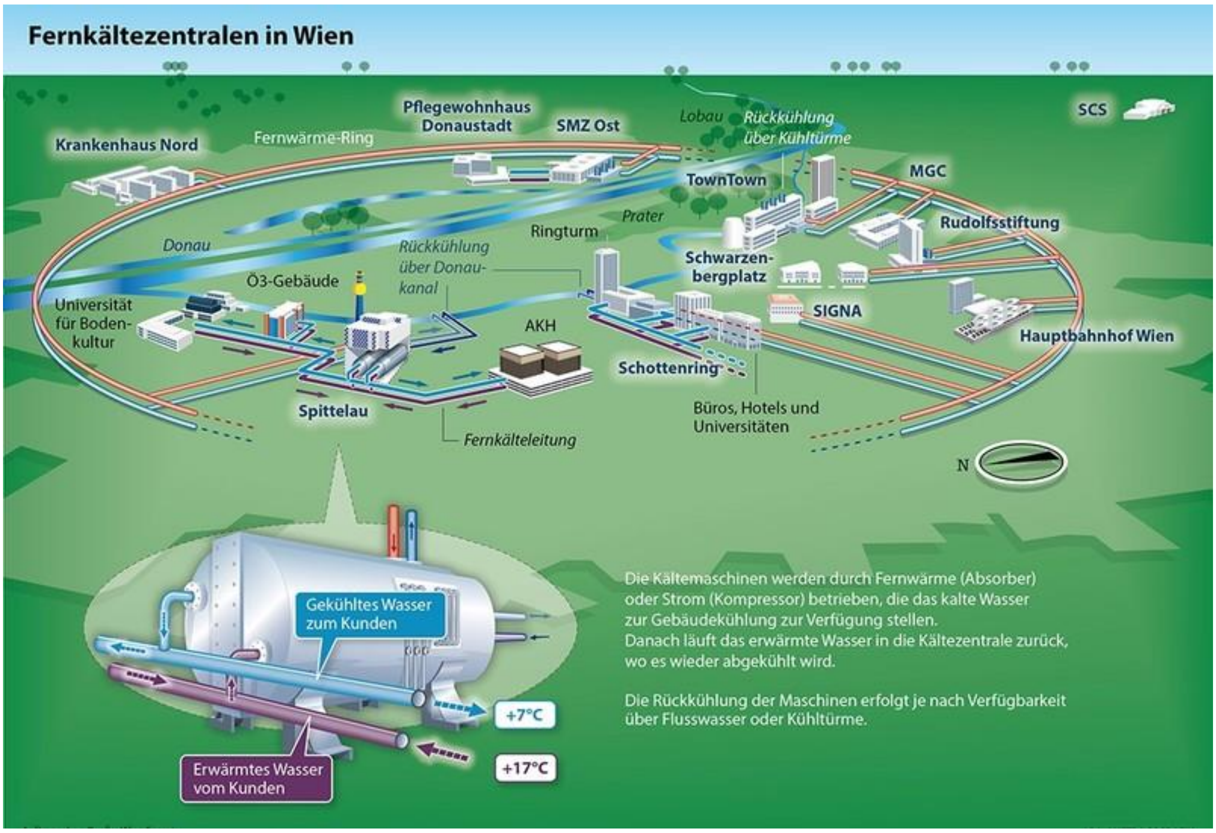
As shown in Figure 72, the district cooling system of Vienna consists of several smaller cooling grids and individual cooling systems, which are interconnected. Different central cooling units are installed which involve absorption chillers, compression chillers or a combination of them. The different parts of the system include hospitals, shopping centres, railway stations, and settlements.

---

[22] Information taken from: http://www.solair-project.eu/175.0.html

[23] Information taken from: http://www.eins.de/ueber-eins/netze/fernkaelte/
https://www.inetz.de/startseite/netzanschluss/haushalt-gewerbe/fernkaelte/

[24] Information taken from: http://www.eins.de/ueber-eins/netze/fernkaelte/
https://www.inetz.de/startseite/netzanschluss/haushalt-gewerbe/fernkaelte/


Fernkältezentralen in Wien

Die Kältemaschinen werden durch Fernwärme (Absorber) oder Strom (Kompressor) betrieben, die das kalte Wasser zur Gebäudekühlung zur Verfügung stellen. Danach läuft das erwärmte Wasser in die Kältezentrale zurück, wo es wieder abgekühlt wird.

Die Rückkühlung der Maschinen erfolgt je nach Verfügbarkeit über Flusswasser oder Kühltürme.

**Figure 72: District cooling system in Vienna (Source: APA-Auftragsgrafik/Wien Energie GmbH)**

### *9.3.5 Snow cooling in Sundsvall, Sweden*[25]

The County Hospital of Sundsvall in Sweden is cooled with a large-scale snow cooling plant. The plant, which has been in use since 2000, is the first of its kind in the world. The hospital is a large building that covers about 190,000 m² and requires a powerful system in order to maintain a comfortable indoor climate as well as keeping a variety of technical equipment from overheating.

A conventional cooling appliance was used for this purpose until 2000. However, the county council of Västernorrland has since the turn of the millennium committed to a more environment-friendly and energy-saving alternative in making use of a natural resource that is easily available in the north of Sweden, namely snow. Before the snow cooling system was built there was already a snow deposit situated west of the hospital. This was mainly used by the Sundsvall municipality to dump snow that had been cleared from streets in the region. This undisturbed place proved to be the ideal spot for building the new cooling facility, since there would be no negative impact on the surrounding area and it was already a natural place for unloading massive amounts of snow.

---

[25] Information from: http://www.lvn.se/v1/in-english1/in-english/environment-and-energy/energy-factor-2/snow-cooling-in-sundsvall/

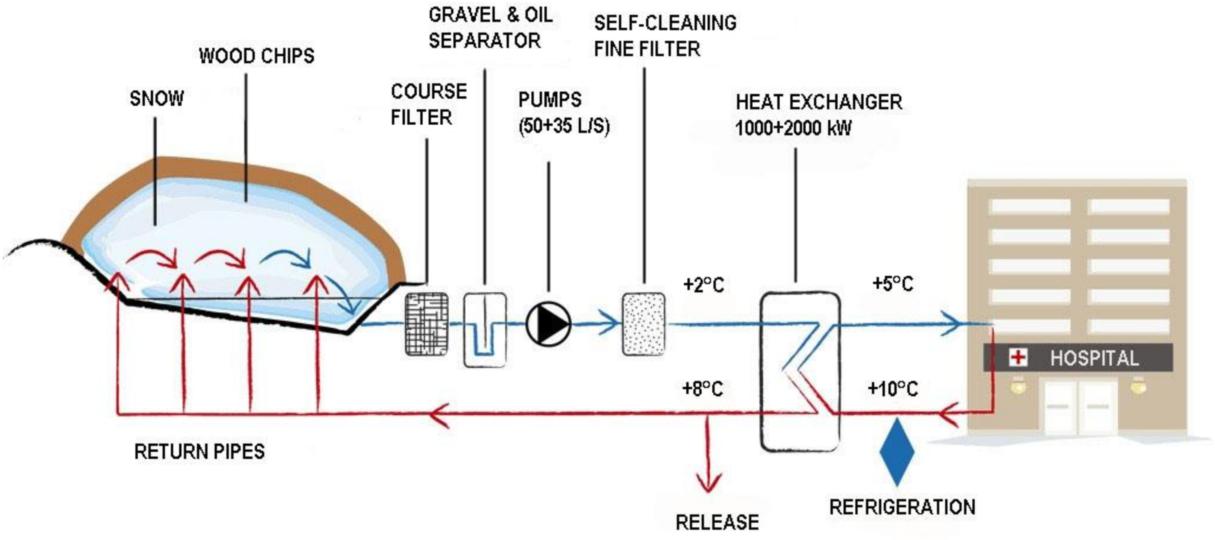


**Figure 73: Snow cooling system fort he Sundsval hospital (Source: Snowpower AB, [http://www.snowpower.se](http://www.snowpower.se))**

The facility is equipped with a 7 m deep bowl-shaped basin that is being filled with snow during winter. The snow-pool is made out of waterproof asphalt, which provides soil insulation. During spring and summer the snow deposit is covered with a layer of wooden chips in order to prevent the snow from melting due to increased outdoor temperature. During winters with less snowfall, a set of snow-cannons can be used to secure that there is enough snow in the pool. However, using snow-cannons is still a more energy efficient solution than using a conventional cooling system.

All in all the snow cooling facility consists of three main parts; the snow storage, a pumping station and a heat exchanger. Snow that has melted is being pumped through the heat exchanger where the water cools the technical equipment as well as the ventilation air which passes through the hospital. Through this process, the water reaches a higher temperature. On the way back, it is used to melt the snow. Using snow to cool the hospital has reduced the need for electricity for cooling by more than 90%.

# Glossary and Abbreviations

*The Glossary and Abbreviations list describes and defines various specific or common expressions, terms and words, which are used in this handbook. A major aim of this list is to facilitate translations of the handbook into national languages. Several expressions are adapted from Wikipedia.*

**a**: see Year

**Absorption**: process in which atoms, molecules, or ions enter some bulk phase (gas, liquid, or solid material). This is a different process from adsorption, since molecules undergoing absorption are taken up by the volume, not by the surface (as in the case for adsorption).

**AD**: see Anaerobic digestion

**Adsorption**: the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved solid to a solid surface

**Ammonia**: A gaseous compound of hydrogen and nitrogen, $NH_3$, with a pungent smell and taste.

**Anaerobic digestion**: Also called digestion or fermentation: A microbiological process of decomposition of organic matter, in the complete absence of oxygen, carried out by the concerted action of a wide range of micro-organisms. Anaerobic digestion (AD) has two main end products: biogas (a gas consisting of a mixture of methane, carbon dioxide and other gases and trace elements) and digestate (the digested substrate). The AD process is common to many natural environments and it is applied today to produce biogas in airproof reactor tanks, commonly named digesters.

**ATES**: Aquifer thermal energy storage

**Barrel of oil equivalent (boe)**: The amount of energy contained in a barrel of crude oil, i.e. approx. 6.1 GJ, equivalent to 1,700 kWh. A "petroleum barrel" is a liquid measure equal to 42 U.S. gallons (35 Imperial gallons or 159 litters); about 7.2 barrels are equivalent to one tonne of oil (metric).

**BiogasHeat**: Project (Development of sustainable heat markets for biogas plants in Europe) funded by the Intelligent Energy for Europe Programme of the European Commission in which this handbook was elaborated.

**Biogas**: Gas resulting from anaerobic digestion consisting of mainly methane and carbon dioxide, but also of hydrogen sulphide, water and smaller fractions of other compounds

**Biomethane**: Upgraded biogas to natural gas quality with $CH_4$ content >95%

**BTES**: Borehole thermal energy storage

**Capacity**: The maximum power that a machine or system can produce or carry safely (the maximum instantaneous output of a resource under specific conditions). The capacity of generating equipment is generally expressed in kilowatts or megawatts.

**Carbon dioxide**: $CO_2$ is a naturally occurring chemical compound composed of two oxygen atoms covalently bonded to a single carbon atom. It is a gas at standard temperature and pressure and exists in Earth's atmosphere in this state, as a trace gas at a concentration of 0.039% by volume.

**CHP**: Combined heat and power: (Syn. Co-generation): The sequential production of electricity and useful thermal energy from a common fuel source. Reject heat from industrial processes can be used to power an electric generator (bottoming cycle). Conversely, surplus heat from an electric generating plant can be used for industrial processes, or space and water heating purposes (topping cycle).

**$CO_2$**: see Carbon dioxide

**Coefficient of performance (COP)**: The coefficient of performance or COP (sometimes CP), of a heat pump is the ratio of the change in heat at the "output" (the heat reservoir of interest) to the supplied work. The COP was created to compare heat pumps according to their energy efficiency.

**Co-generation**: see combined heat and power generation (CHP)

**Condensing boiler**: Condensing boilers are water heaters with high efficiencies (typically greater than 90%) which are achieved by using the waste heat in the flue gases to pre-heat the cold water entering the boiler. They may be fuelled by gas or oil and are called condensing boilers because the water vapour produced during combustion is condensed into water, which leaves the system via a drain.

**Cooling**: Cooling is the transfer of thermal energy via thermal radiation, heat conduction or convection thereby changing the temperature from the targeted system from higher temperature levels to lower temperature levels.

**COP**: see Coefficient of performance

**CPC**: Compound Parabolic Concentrator

**CSP**: Concentrated solar power

**DH**: District heating

**DHC**: District heating and cooling

**DHW**: Domestic hot water supply

**Digestate**: The treated/ digested effluent from the AD process. (Syn. AD residues, digested biomass, biogas digested slurry)

**Digester**: (sometimes also called digester) closed tank, usually vertical or horizontal cylinder form, or garage (for dry digestion), in which the anaerobic digestion process takes place

**Digestion**: see Anaerobic Digestion

**District cooling**: District cooling is a system for distributing chilled water or water/ice mixtures from a centralized location for residential and commercial cooling such as air conditioning.

**District energy**: Combination of district heating and cooling concepts

**District heating**: District heating is a system for distributing heat (by hot water or steam) generated in a centralized location for residential and commercial heating requirements such as space heating and water heating.

**EER**: see Energy efficient ratio

**Electrolysis**: Electrolysis is a method of using a direct electric current (DC) to drive an otherwise non-spontaneous chemical reaction. For instance, electrolysis can split water into its elements hydrogen and oxygen.

**Energy efficient ratio (EER)**:  the ratio of cold output to electricity input for a specified source.

**Energy service company (ESCo, ESCO)**: An energy service company is a commercial business providing a broad range of comprehensive energy solutions including designs and implementation of energy savings projects, energy conservation, energy infrastructure outsourcing, power generation and energy supply, and risk management.

**Enthalpy**: Enthalpy is a measure of the total energy of a thermodynamic system. It includes the internal energy, which is the energy required to create a system, and the amount of energy required to make room for it by displacing its environment and establishing its volume and pressure.

**Entropy**: Entropy is a measure of how evenly energy is distributed in a system. In a physical system, entropy provides a measure of the amount of energy that cannot be used to do work.

**ESCo**: see Energy Service Company

**Exergy**: In thermodynamics, the exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir. When the surroundings are the reservoir, exergy is the potential of a system to cause a change as it achieves equilibrium with its environment. Exergy is the energy that is available to be used. After the system and surroundings reach equilibrium, the exergy is zero. Determining exergy was also the first goal of thermodynamics.

**Feedstock**: Any input material into a process which is converted to another form or product.

**Flat plate collector**: Most common solar thermal collector

**Flow**: Transport medium of a certain quantity and temperature which flows from the heat source to the heat sink.

**Fossil fuel**: Fossil fuels are formed in millions of years by natural processes such as anaerobic decomposition of dead organisms.

**Free cooling**: Free cooling is cooling at low cost (“free”) by using the low ambient temperature, e.g. from air, soil or water bodies.

**Global warming potential**: GWP is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide. A GWP is calculated over a specific time interval, commonly 20, 100 or 500 years. GWP is expressed as a factor of carbon dioxide whose GWP is standardized to 1. For example, the 20 year GWP of methane is 72, which means that if the same mass of methane and carbon dioxide were introduced into the atmosphere, that methane will trap 72 times more heat than the carbon dioxide over the next 20 years.

**Greenhouse gas (GHG)**: Gases that trap the heat of the sun in the Earth's atmosphere, producing the greenhouse effect. The two major greenhouse gases are water vapour and carbon dioxide. Other greenhouse gases include methane, ozone, chlorofluorocarbons, and nitrous oxide.

**Grid pipes**: DH pipes that distribute the heat to the consumers, who are connected by service pipes.

**GWP**: see Global warming potential

**$H_2$**: see Hydrogen

**$H_2S$**: see Hydrogen sulphide

**Heat**: Heat is energy transferred from one system to another by thermal interaction. In contrast to work, heat is always accompanied by a transfer of entropy. Heat flow from a high to a low temperature body occurs spontaneously. This flow of energy can be harnessed and partially converted into useful work by means of a heat engine. The second law of thermodynamics prohibits heat flow from a low to a high temperature body, but with the aid of a heat pump external work can be used to transport energy from low to the high temperature. In ordinary language, heat has a diversity of meanings, including temperature. In physics, "heat" is by definition a transfer of energy and is always associated with a process of some kind. "Heat" is used interchangeably with "heat flow" and "heat transfer". Heat transfer can occur in a variety of ways: by conduction, radiation, convection, net mass transfer, friction or viscosity, and by chemical dissipation.

**Heat exchanger**: Device built for efficient heat transfer from one fluid to another, whether the fluids are separated by a solid wall so that they never mix, or the fluids are directly contacted.

**Heating value**: the amount of heat released during the combustion of a specified amount of a fuel (biogas, biomethane).

**Heat transfer efficiency**: ratio of the useful heat output and the actual heat produced in the combustion device.

**Heat transport fluid**: the medium that is used to bring the heat from the heat source to the heat sink. In District heating systems, this is usually water.

**Hydrogen**: $H_2$ is the lightest element and its monatomic form ($H_1$) is the most abundant chemical substance, constituting roughly 75% of the Universe's baryonic mass. At standard temperature and pressure, hydrogen is a colourless, odourless, tasteless, non-toxic, non-metallic, highly combustible diatomic gas with the molecular formula $H_2$. Naturally, atomic hydrogen is occurring rarely on Earth.

**Hydrogen sulphide**: $H_2S$ is a colourless, very poisonous, flammable gas with the characteristic foul odour of rotten eggs. It often results from the bacterial breakdown of organic matter in the absence of oxygen (anaerobic digestion).

**Installed capacity**: The installed capacity is the total electrical or thermal capacity of energy generation devices.

**Joule (J)**: Metric unit of energy, equivalent to the work done by a force of one Newton applied over a distance of one meter. 1 joule (J) = 0.239 calories; 1 calorie (cal) = 4.187 J.

**ibid.**: (ibidem) is the term used to provide a citation or reference for a source that was cited just before.

**Kilowatt (kW)**: A measure of electrical power or heat capacity equal to 1,000 watts.

**Kilowatt-hour (kWh)**: The most commonly-used unit of energy. It means one kilowatt of electricity or heat supplied for one hour.

**$kW_{el}$**: electrical power (capacity)

**kWh**: see Kilowatt-hour

**$kW_{th}$**: thermal (heat) capacity

**Latent heat**: Latent heat is the heat released or absorbed by a body or a thermodynamic system during a process that occurs without a change in temperature. A typical example is a change of state of matter, meaning a phase transition such as the melting of ice or the boiling of water. In contrast to latent heat, sensible energy or heat causes processes that do result in a change of the temperature of the system.

**Legionella**: Pathogenic group of bacteria which can cause health problems. They grow in warm water and pose a risk in the domestic hot water system if the water temperature is too low.

**Load curve**: A load curve is a graph that shows the actual heat or electricity consumption over the course of time, usually one year (8,760 hours).

**Load duration curve**: A load duration curve is similar to a load curve but the load data are ordered in descending order of magnitude, rather than chronologically.

**LowEx Heating Grid**: Heating grid in which not only the quantity of the heat is considered, but also the quality (exergy). Heat with higher temperatures should be only used for applications that need these high temperatures, whereas heat with lower temperatures can be also used for e.g. space and hot domestic water heating.

**Mesophilic process**: AD process with temperature of 25°C – 45°C

**Methane**: $CH_4$ is a flammable, explosive, colourless, odourless, tasteless gas that is slightly soluble in water and soluble in alcohol and ether; boils at – 161.6ºC and freezes at –182.5ºC. It is formed in marshes and swamps from decaying organic matter, and is a major explosion hazard underground. Methane is a major constituent (up to 97%) of natural gas, and is used as a source of petrochemicals and as a fuel. It is a combustible gas at normal conditions and a relatively potent greenhouse gas.

**Mini-grid**: An integrated local generation, transmission and distribution system (for electricity or heat) serving numerous customers.

**Moisture**: Ratio of the mass of water content of a material (biomass) and the mass of the dry material itself.

**mol**: The mole is a SI unit used in chemistry to express amounts of a chemical substance, defined as an amount of a substance that contains as many elementary entities (e.g., atoms, molecules, ions, electrons) as there are atoms in 12 grams of pure carbon. This corresponds to a value of 6.02214179(30)×1023 elementary entities of the substance.

**Natural gas**: Natural gas is a fossil hydrocarbon gas mixture consisting primarily of methane, with other hydrocarbons, carbon dioxide, nitrogen and hydrogen sulphide.

**$NH_3$**: see Ammonia

**NHPC**: Net heat production costs

**$m^3$**: A cubic meter is the volume of 1x1x1 m. One cubic metre is about 1 t of water.

**$O_2$**: see Oxygen

**Oil equivalent**: The tonne of oil equivalent (toe) is a unit of energy: the amount of energy released by burning one tonne of crude oil, approx. 42 GJ.

**ORC**: Organic Rankine Cycle

**Organic Rankine Cycle:** The ORC process is named for its use of an organic, high molecular mass fluid with a liquid-vapour phase change, or boiling point, occurring at a lower temperature than the water-steam phase change. The fluid allows Rankine cycle heat recovery from lower temperature sources such as from biogas plants.

**Oxygen**: At standard temperature and pressure, two atoms of the element bind to form di-oxygen, a very pale blue, odourless, tasteless diatomic gas with the formula $O_2$. This compound is an important part of the atmosphere, and is necessary to sustain terrestrial life.

**PCM**: see Phase change material

**Phase change material**: PCM is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa.

**Power**: The amount of work done or energy transferred per unit of time (definition in physics) as well as electricity from the grid (definition in the energy sector).

**Process heat**: Heat used in an for different internal or external process (e.g. for digester heating).

**PTES** : Pit thermal energy storage

**Return flow**: Cooled transport medium of a certain quantity and temperature which flows from the heat sink to the heat source.

**Satellite CHP**: A combined heat and power unit that is not located at the site of the biogas plant, but at another place. It is connected with the biogas plant through a biogas pipeline.

**SCOP**: Seasonal Coefficient Of Performance

**Sensible energy**: see Sensible heat

**Sensible heat**: Sensible heat is heat exchanged by a thermodynamic system that has as its sole effect a change of temperature.

**Service pipes**: DH pipes that connect the consumers, to the grid pipes.

**SI**: The International System of Units (abbreviated SI from French: Système international d'unités) is the modern form of the metric system and is generally a system of units of measurement devised around seven base units and the convenience of the number ten.

**Smart grid**: A smart grid is an electrical grid that uses information technologies and other technologies in order to adjust the demand and supply in a most efficient way. Smart grids are measures to improve energy efficiency and with the increase of renewable energies it will be more important to stabilise the grid.

**Steam**: Steam is the technical term for water vapour, the gaseous phase of water.

**Stirling engine**: A Stirling engine is a heat engine operating by cyclic compression and expansion of air or other gas, the working fluid, at different temperature levels such that there is a net conversion of heat energy to mechanical work.

**Substation**: Heat transfer station which connects the DH grid with the heat consumer. It usually includes a heat exchanger.

**Surplus heat**: See waste heat.

**Temperature differential (ΔT)**: difference of two temperature levels whereas the result is always positive.

**Thermodynamics**: Thermodynamics is the branch of natural science concerned with heat and its relation to other forms of energy and work. It considers mainly changes in temperature, entropy, volume and pressure that describe average properties of material bodies and radiation, and explains how they are related and by what laws they change with time.

**Transmission pipes**: Larger DH pipes that bring heat from the heat source to the DH grid.

**TTES**: Cylindrical steel tanks

**Turbine**: A machine for converting the heat energy in steam or high temperature gas into mechanical energy. In a turbine, a high velocity flow of steam or gas passes through successive rows of radial blades fastened to a central shaft.

**Vapour**: Vapour is a substance in the gas phase at a temperature lower than its critical point. This means that the vapour can be condensed to a liquid or to a solid by increasing its pressure without reducing the temperature. For example, water has a critical temperature of 374°C (647 K), which is the highest temperature at which liquid water can exist. In the atmosphere at ordinary temperatures, therefore, gaseous water (known as water vapour) will condense to liquid if its partial pressure is increased sufficiently. A vapour may co-exist with a liquid (or solid).

**Vacuum tube collector**: Solar collector consisting of vacuum tubes in which the absorber is placed.

**Waste heat**: Heat from any process, such as from a CHP unit, which is released to the atmosphere and not used. It may be also called surplus heat since “heat” as a type of energy cannot disappear (wasted), according to the law of conservation of energy.

**Water**: $H_2O$ contains one oxygen and two hydrogen atoms and is a liquid at ambient conditions, but it often co-exists on Earth with its solid state, ice, and gaseous state (water vapour or steam). Water covers 70.9% of the Earth's surface, and is vital for all known forms of life.

**Water content**: Ratio of the mass of water content of a material (biomass) and the mass of the moist material itself.

**Water vapour**: Water vapour is the gas phase of water. See Vapour

**Watt (W)**: A standard unit of measure (SI System) for the rate at which energy is consumed by equipment or the rate at which energy moves from one location to another. It is also the standard unit of measure for electrical power. The term 'kW' stands for "kilowatt" or 1,000 watts. The term 'MW' stands for "Megawatt" or 1,000,000 watts.

**Year**: A calendar year is an approximation of the Earth's orbital period in a given calendar. A calendar year in the Gregorian calendar (as well as in the Julian calendar) has either 365 (common years) or 366 (leap years) days. The operational hours of biogas related equipment is usually referred to 8,760 hours.

**Yield strength**: or “yield point” is the material property defined as the stress at which a material begins to deform plastically.

**Zeolite**: Microporous, aluminosilicate minerals commonly used as commercial adsorbents.

**ΔT**: see temperature differential

## General conversion units

**Table 8: Prefixes for energy units**

| Prefix | Abbreviation | Factor | Quantity |
|---|---|---|---|
| **Deco** | Da | 10 | Ten |
| **Hecto** | H | $10^2$ | Hundred |
| **Kilo** | K | $10^3$ | Thousand |
| **Mega** | M | $10^6$ | Million |
| **Giga** | G | $10^9$ | Billion |
| **Tera** | T | $10^{12}$ | Trillion |
| **Peta** | P | $10^{15}$ | Quadrillion |
| **Exa** | E | $10^{18}$ | Quintillion |

**Table 9: Conversion of energy units (kilo joule, kilo calorie, kilo watt hour, ton of coal equivalent, cubic metre of natural gas, ton of oil equivalent, barrel, British Thermal Unit)**

| | kJ | kcal | kWh | TCE | $m^3$ $CH_4$ | toe | barrel |
|---|---|---|---|---|---|---|---|
| **1 kJ** | 1 | 0.2388 | 0.000278 | $3.4 \cdot 10^{-8}$ | 0.000032 | $2.4 \cdot 10^{-8}$ | $1.76 \cdot 10^{-7}$ |
| **1 kcal** | 4.1868 | 1 | 0.001163 | $14.3 \cdot 10^{-8}$ | 0.00013 | $1 \cdot 10^{-7}$ | $7.35 \cdot 10^{-7}$ |
| **1 kWh** | 3.600 | 860 | 1 | 0.000123 | 0.113 | 0.000086 | 0.000063 |
| **1 TCE** | 29,308,000 | 7,000,000 | 8,140 | 1 | 924 | 0.70 | 52 |
| **1 $m^3$ $CH_4$** | 31,736 | 7,580 | 8.816 | 0.001082 | 1 | 0.000758 | 0.0056 |
| **1 toe** | 41,868,000 | 10,000,000 | 11,630 | 1.428 | 1,319 | 1 | 7.4 |
| **1 barrel** | 5,694.048 | 1,360.000 | 1,582 | 0.19421 | 179.42 | 0.136 | 1 |
| **1 BTU** | 1.055 | | | | | | |

**Table 10: Conversion of power units (kilo calories per second, kilowatt, horse power, Pferdestärke = horse strength)**

| | kcal/s | kW | hp | PS |
|---|---|---|---|---|
| **1 kcal/s** | 1 | 4,1868 | 5,614 | 5,692 |
| **1 kW** | 0,238846 | 1 | 1,34102 | 1,35962 |
| **1 hp** | 0,17811 | 0,745700 | 1 | 1,01387 |
| **1 PS** | 0,1757 | 0,735499 | 0,98632 | 1 |

**Table 11: Conversion of temperature units**

| | Unit | Celsius | Kelvin | Fahrenheit |
|---|---|---|---|---|
| **Celsius** | °C | - | °C = K − 273.15 | °C = (°F − 32) × 1.8 |
| **Kelvin** | K | K =°C + 273.15 | - | K = (°F + 459.67) × 1.8 |
| **Fahrenheit** | °F | °F =°C × 1.8 + 32 | °F = K × 1.8 – 459.67 | - |

**Table 12: Conversion of pressure units (pascal, bar, technical atmosphere, standard atmosphere, torr, pound per square inch)**

| | Pa | bar | at | atm | Torr | psi |
|---|---|---|---|---|---|---|
| **1 Pa** | | 0.00001 | 0.000010197 | $9.8692\times10^{-6}$ | 0.0075006 | 0.0001450377 |
| **1 bar** | 100,000 | | 1.0197 | 0.98692 | 750.06 | 14.50377 |
| **1 at** | 98,066.5 | 0.980665 | | 0.9678411 | 735.5592 | 14.22334 |
| **1 atm** | 101,325 | 1.01325 | 1.0332 | | 760 | 14.69595 |
| **1 Torr** | 133.3224 | 0.001333224 | 0.001359551 | 0.001315789 | | 0.01933678 |
| **1 psi** | 6894.8 | 0.068948 | 0.0703069 | 0.068046 | 51.71493 | |

# References

Bava F., Furbo S., Brunger A. (2015) Correction of collector efficiency depending on fluid type, flow rate and collector tilt. - IEA-SHC INFO SHEET 45.A.1; http://task45.iea-shc.org/data/sites/1/publications/IEA-SHC-T45.A.1-INFO-Correction-of-collector-efficiency.pdf [09.11.2016]

Danish Energy Agency, Energinet.dk (2015) Technology Data for Energy Plants - Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion. - May 2012 (certain updates made October 2013, January 2014 and March 2015); ISBNwww: 978-87-7844-931-3

Dansk Fjernvarme (2016) Technology. - http://www.geotermi.dk/english/deep-geothermal-energy-in-denmark/technology [11.11.2016]

Danish Geothermal District Heating (2016) The geothermal concept. - http://www.geotermi.dk/english/deep-geothermal-energy-in-denmark/technology [09.11.2016]

Dimitriou I., Rutz D. (2015) Sustainable Short Rotation Coppice, A Handbook. - WIP Renewable Energies, Munich, Germany; ISBN 978-3-936338-36-2; www.srcplus.eu

Euroheat & Power (2012) District Cooling The sustainable response to Europe's rising cooling demands. – Brochure; http://www.euroheat.org/Files/Filer/documents/District%20Heating/Cooling_Brochure.PDF [10.07.2012]

Euroheat & Power (2008): Guidelines for District Heating Substations; https://www.euroheat.org/wp-content/uploads/2008/04/Euroheat-Power-Guidelines-District-Heating-Substations-2008.pdf [03.10.2016]

Frederiksen S., Werner S. (2013) District Heating and Cooling. - Studentlitteratur, page 205

GeoDH (n.d.) "Developing Geothermal District Heating in Europe", www.geodh.eu, https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/geodh_final_publishable_results_oriented_report.pdf [10.11.2016]

Hiegl W., Rutz D., Janssen R. (2011) Information Material Biomass Systems. – Training Handbook for Sanitary and Heating Installers; WIP Renewable Energies, Munich, Germany; Academy for In-Service Teacher Training and Staff Development (ALP), Dillingen a.d. Donau, Germany; Report of the IEE Project Install+RES

Holzmann A. (2010) Modellierung und Simulation einer Adsorptionskältemaschine. – Diplomarbeit, TU Wien

Hurter, S., and R. Haenel, 2002, Atlas of Geothermal Resources in Europe, Publication No. EUR 17811 of the European Commission. Office for Official Publications of the European Communities, L-2985 Luxembourg.

Isoplus (2016) Laying rules. - http://en.isoplus.dk/laying-rules-163 [03.11.2016]

Laurberg Jensen L. Rutz D. Doczekal C. Gjorgievski V., Batas-Bjelic I., Kazagic A., Ademovic A., Sunko R., Doračić B. (2016) Best Practice Examples of Renewable District Heating and Cooling. – Report of the CoolHeating project; PlanEnergi, Denmark; www.coolheating.eu

Kempener R. (2015) Solar Heating and Cooling for Residential Applications: Technology Brief. – IEA-ESTAP and IRENA Technology Brief E21 – January 2015; http://www.irena.org/documentdownloads/publications/irena_etsap_tech_brief_r12_solar_thermal_residential_2015.pdf [04.08.2016]

Kotlan R. (2016) Technical interview with Ralf Kotlan from W.A.S. Wasseraufbereitungssysteme GmbH on 27.10.2016; Güssing, Austria; http://www.w-a-s.cc

Köfinger M., Schmidt R.R., Basciotti D., Hauer S., Doczekal C., Giovannini A., Konstantinoff L., Hofmann M., Andreeff V., Meißner E., Ondra H., Teuschel P., Frühauf O. (2015) NextGenerationHeat Niedertemperaturfernwärme am Beispiel unterschiedlicher Regionen Österreichs mit niedriger Wärmebedarfsdichte. - Projektnummer: 834582; AIT Austrian Institute of Technology GmbH; http://ait.visueligent.at/fileadmin/mc/energy/downloads/NextGenerationHeat_publizierbarer_Endbericht_final.pdf [10.11.2016]

Laurberg Jensen L., Rutz D., Doczekal C., Gjorgievski V., Batas-Bjelic I., Kazagic A., Ademovic A., Sunko R., Doračić B. (2016) Best Practice Examples of Renewable District Heating and Cooling. – Report of the CoolHeating Project; PlanEnergie, Denmark

Metz M., Moersch M., Heinl W. (2012) Komponenten solarthermischer Anlagen. – Kapitel 4 in Leitfaden Solarthermische Anlagen; Deutsche Gesellschaft für Sonnenenergie.

Morgenstern A., Safarik M., Wiemken E., Zachmeier P. (2016) Mit solarer Wärme kühlen: Konzepte und Technologien für die Klimatisierung von Gebäuden. - BINE-Themen info III/2016;

http://www.bine.info/fileadmin/content/Publikationen/Themen-Infos/III_2016/themen_0316_internetx.pdf [accessed: 04.08.2016]

Nast M. et al. (2009) Ergänzende Untersuchungen und vertiefende Analysen zu möglichen Ausgestaltungsvarianten eines Wärmegesetzes Endbericht. - Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR); http://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/system/publications/Endbericht_Waermegesetz-11.pdf [10.11.2016]

Nast M. (2012) Fernwärme, die Komfort-Energie, Rolle der Wärmenetze in der Stromversorgung. - 11. Tagung “Wärme-und Kälteversorgung in der Energiestrategie Schweiz “; 26. Januar 2012 in Biel-Bienne; http://elib.dlr.de/75363/1/Rolle_der_W%C3%A4rmenetze_in_der_Stromversorgung.pdf [10.11.2016]

New Buildings Institute (1998) Guideline: Absorption Chillers. - New Buildings Institute; Fair Oaks; Canada; http://www.stanford.edu/group/narratives/classes/08-09/CEE215/ReferenceLibrary/Chillers/AbsorptionChillerGuideline.pdf [10.07.2012]

Paeger J. (2012) http://www.oekosystem-erde.de/html/energie.html [10.07.2012]

Rutz D., Janssen R. (2008) Biofuel Technology Handbook. - 2nd version; BIOFUEL MARKETPLACE Project funded by the European Commission (EIE/05/022); WIP Renewable Energies, Germany; 152p. http://www.wip-munich.de/images/stories/6_publications/books/biofuel_technology_handbook_version2_d5.pdf [10.11.2016]

Rutz D., Janssen R., Letsch H. (2006) Installateurs-Handbuch Biomasseheizanlagen. - EU-IEE EARTH Project; 241p. www.earth-net.info

Rutz D., Mergner R., Janssen R. (2015) Sustainable Heat Use of Biogas Plants – A Handbook, 2nd edition. WIP Renewable Energies, Munich, Germany; Handbook elaborated in the framework of the BiogasHeat Project; ISBN 978-3-936338-35-5 translated in 8 languages; http://www.wip-munich.de/images/stories/6_publications/books/Handbook-2ed_2015-02-20-cleanversion.pdf [10.11.2016]

Schrøder Pedersen A., Elmegaard B., Christensen C.H., Kjøller C., Elefsen F., Bøgild Hansen J., Hvid J., Sørensen P.A., Kær S.K., Vangkilde-Pedersen T., Feldthusen Jensen T., (2014) Status and recommendations for RD&D on energy storage technologies in a Danish context. - https://www.energinet.dk/SiteCollectionDocuments/Danske%20dokumenter/Forskning%20-%20PSO-projekter/RDD%20Energy%20storage_ex%20app.pdf [09.11.2016]

Skagestad B., Mildenstein P. (no date) District Heating and Cooling Connection Handbook. – International Energy Agency (IEA) District Heating and Cooling. http://dedc.dk/sites/default/files/programme_of_research_development_and_demonstration_on_district_heating_and_cooling.pdf [10.07.2012]

Solair Project (2009) Increasing the market implementation of Solar-air-conditioning systems for small and medium applications in residential and commercial buildings (SOLAIR). – Project website http://www.solair-project.eu/142.0.html [accessed: 04.08.2016]

Tour & Andersson Ges.m.b.H. (2005) TA Systemheft - Hydraulische Grundschaltungen. - Guntramsdorf; Austria

Von Hertle H., Pehnt M., Gugel B., Dingeldey M., Müller K. (2015) Wärmewende in Kommunen, Leitfaden für den klimafreundlichen Umbau der Wärmeversorgung. – Heinrich Böll StiftungBand 41 der Schriftenreihe Ökologie https://www.boell.de/sites/default/files/waermewende-in-kommunen_leitfaden.pdf [10.07.2012]

WHO (2007) Legionella and the prevention of legionellosis. - World Health Organization ; India, http://www.who.int/water_sanitation_health/emerging/legionella.pdf [10.11.2016]

Zweiler R., Doczekal C., Paar K., Peischl G. (2008) Endbericht Energetisch und wirtschaftlich optimierte Biomasse-Kraft-Wärmekopplungssysteme auf Basis derzeit verfügbarer Technologien, Energiesysteme der Zukunft, bmvit, FFG-Projektnummer 812771; www.get.ac.at

Zweiler, R. (2013) ToughGas (Entwicklung eines innovativen Wirbelschichtvergasungssystems kleiner Leistung zur Nutzung biogener Reststoffe) (Endbericht No. 834621).