IEA SHC Task 45

Design Handbook

Installation, Commissioning and Operation of Large Scale Solar Thermal Plants

Anna Katharina Provasnek, MSc.
Ing. Sabine Putz
S.O.L.I.D. Solarinstallation- und Design Ges.m.b.H.
A-8020 Graz, Puchstrasse 85 - Tel: +43 316 292840

1.12.2012

Content

List of Figures

Introduction

The choice for an air conditioning system depends on climatic conditions, the construction infrastructure and on the utilization of the target area or building. The air conditioning system has the task to compensate external and internal loads, provide hygienic conditions and year round comfort for system users.

Traditional solar thermal installations collect the sun's heat and convert it into hot water, typically meeting hot water requirements.

Heat pump technologies have been available for many years and installations of both ground-source and air-source systems are meeting heating demands all over the world.

The Hybrid solutions of solar and heat pump technologies combine it in such a way that the aggregate system outputs are far greater than those produced by the components individually.[1]

Hybrid ground source heat pump systems combined with solar thermal collectors are a feasible choice for space conditioning for heating dominated houses. The solar thermal energy storage in the ground can reduce a large amount of ground loop heat exchanger length.[2]

A district heating system is a system for distributing heat generated in a centralized location to provide the heating and cooling requirements in several building areas. A centralized geo and solar heating system offers the benefits of clean renewable energy while providing for the needs of multiple buildings.

Hybrid heating systems employing both heat pump systems and solar thermal heating can provide increased efficiencies and reliability. District heating systems for building clusters help to reduce operating costs and have several other benefits.[3]

Figure 1: Handbook purpose[4]

This handbook aims to provide guidance in designing best practice, large-scale solar thermal systems, geothermal heat pump systems and hybrid district heating systems. It addresses common design issues, operation and financing issues. The final chapter gives examples for successfully constructed plants.

[1] http://www.newformenergy.com/hybrid-solar-solution
[2] http://www.ibpsa.org/proceedings/BS2009/BS09_2297_2305.pdf
[3] http://terratek.ca/services/thermal/category/hybrid_and_district_systems/
[4] http://sunwatersolar.com/solar-thermal/faq

Disclaimer

The information contained here is provided as a guideline to the installation and maintenance of solar hot water and does not overrule existing legislation, standards and manufacturers' installation requirements, which should be adhered to at all times.
While every effort has been made to ensure that many available technologies and requirements have been covered, some omissions may have been made.

I. Chapter - Large Scale Solar Thermal Plants

The first chapter provides information about large scale solar thermal plants, it´s special characteristics, installation requirements and illustrates options for combining it with other technologies.

I.1 Basic Information

Solar thermal technologies can provide energy for hot water, solar air conditioning or district heating generated with large scale solar thermal plants. Solar thermal plants are best known to provide domestic hot water, but it is also used within industrial applications.

In order to heat water using solar energy, a collector heats working fluid that is either pumped (active system) or driven by natural convection (passive system) through it.

Heat is stored in a hot water storage tank. The volume of a tank needs to be large within solar heating systems to overcome sunless weather and because the optimum final temperature for the solar collector is lower than a typical immersion or combustion heater. Solar liquid collectors are most appropriate for solar heating. They are the same as those used in solar domestic hot water heating systems. Flat-plate collectors are most common, but evacuated tube and concentrating collectors are also available for this purpose.

In general solar cooling plants contain a collector field, a carrier medium, a heat exchanger, a buffer storage, a cooling machine, a cooling tower and a back-up system.

More in detail the system also requires piping, primary and secondary loop accessories, heat exchanger, chillers, cooling tower, condenser loop accessories, evaporator loop accessories, set-up material and a telemonitoring system.

The following picture shows a solar thermal plan´s basic working principle:

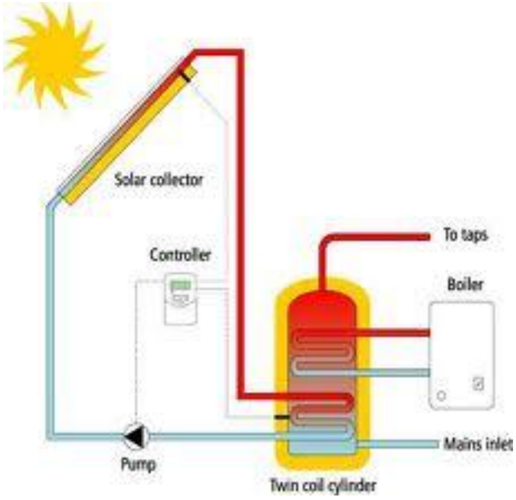

Figure 2: Basic working principle[5]

Flat plate collectors can work with vacuum, water or other liquids. Concentrating collectors generate hot steam. For the transformation process, both solar systems are working with comparable or the same types of thermally driven applications or chemical conversions.

I.2 Design

Planning of solar thermal systems involves multidimensional optimization. Usable solar yields are maximized, system costs are minimized and interaction with conventional heating technology is optimized. The final consideration is to maximize fossil fuel savings.[6]

In the Design Phase, the solution in detail is defined which kind of solar plant should be built, how to build it and when it will be built. During this phase a team works through the design process to create an energy solution, architecture and the design, writes the functional specification and prepares work plans, cost estimates and schedules for various deliverables. Especially, the focus lies on the technical development and analysis of the possible plant dimensions.

The design of large solar collector arrays requires consideration of:[7]

– quantification of user hot water volume or energy demand level and demand patterns
– selection of alternative solar collectors prior to full system design

[5] http://doyourbit.net/solar.htm
[6] http://www.bine.info/fileadmin/content/Publikationen/Englische_Infos/themen_0108_engl_internetx.pdf

[7] Large Scale Solar Thermal Systems Design Handbook; A joint publication between Master Plumbers' and Mechanical Services Association of Australia and Sustainability Victoria; 2009.

- specification of pump and controller to achieve thermal stratification in the storage tank
- full system performance evaluation for local climatic conditions

Figure 3: Large Scale Solar Thermal Plant[8]

The heat production plant is a single investment and the costs depend on the total annual amount of energy output required.

The investment in the pipe system is a question of the length of the pipe network within the area of the heat supply and therefore is dependent on two dimensions- thermal length and thermal width.

Following steps are necessary for the design phase:

- technical concept and preliminary design
- project location and radiation resource
- expected technical and economic performance
- investment, cost of operation and maintenance
- concept of project finance
- legal and administrative requirements

I.2.1 Technical Instruction

Technical instructions provide design and construction criteria for the solar plant, as well as specification of solar plant structural components and systems in accordance with current technology, standards and materials. This includes information on design approaches, use of technical manuals, guidance on the application of codes and industry standards, the design and specification details, inspection and quality.

Factors affecting the performance of different installations are:

- amount of solar irradiation
- temperature of cold water at the inlet

[8] http://www.sunmark.com/

- solar thermal system sizing
- hot water consumption
- ambient air temperature around tank, collector, solar flow and return
- pipe work and tank insulation
- energy needed for boosting and circulating pump

The performance of large scale solar thermal applications depends on:

- system design
- product characteristics
- applied hot water loads
- inclination and orientation of the collector[9]

I.2.2 Hot-water tank and basic accumulation technique

A hot water tank is a highly insulated thermal storage vessel ranging in a certain size and filled with the primary water of the heating system. Its function is to collect and store heat energy from any source and allow flexible use of the heat energy directly for different purposes.

If the energy is not needed at the time of generation it can be stored inside the tank for later use. An advantage is that heat from the mid-day sun can be stored for the time if no heat can be generated. A lot of different tank models exist, give the option to find the right one for every plant system. An example for a hot water tank system provides the following scheme:

[9] Large Scale Solar Thermal Systems Design Handbook; A joint publication between Master Plumbers' and Mechanical Services Association of Australia and Sustainability Victoria; 2009.

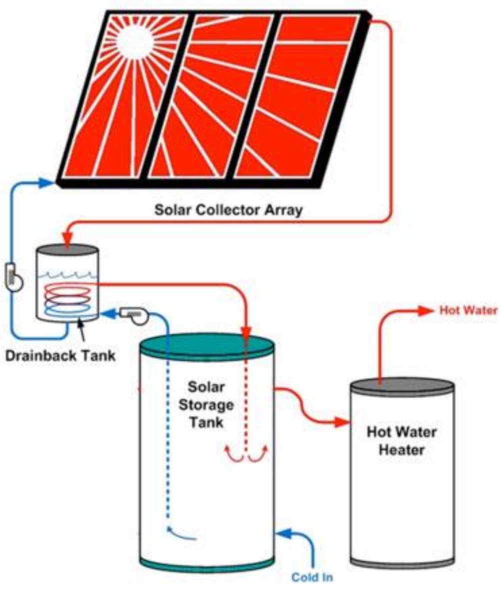

Figure 4: Hot Water Tank Systems[10]

If a water storage system collects solar energy, it is most of the time stored in a large water tank. This heat is then directed into the house through a radiant floor or forced-air heating system. As opposed to a direct system, heat from a water storage system can be controlled, drawing heat from the solar water storage tank if needed.

The role of energy conservation in the design of large scale solar thermal plants is important and should not be underestimated for two reasons. Firstly, energy conservation reduces the energy consumption and saves scarce energy resources. Secondly, it is usually the most cost-effective way to reduce overall energy cost.

There are many energy-conservation measures in industrial process and water heating processes that can be considered. It includes:

- no-cost actions such as minimizing the hot water storage temperatures
- simple and low-cost actions such as increasing insulation levels on pipe work and storage tanks
- complex and expensive actions such as the installation of more accurate control or heat recovery systems[11]

I.2.3 Solar Collector

The major component of any solar system is the solar collector. Solar energy collectors capture as much sunlight as possible, in order to either redistribute (focus) or absorb it

[10] http://www.solarserviceinc.com/solar_thermal_101.cfm
[11] Large Scale Solar Thermal Systems Design Handbook; A joint publication between Master Plumbers' and Mechanical Services Association of Australia and Sustainability Victoria; 2009.

into a transport medium. They are special kinds of heat exchangers that transform solar radiation energy into internal energy of the transport medium.

Figure 5: Solar Collector[12]

The heat generated by a solar collector can be directly used to heat liquids or can be indirectly used to generate electricity. Solar collectors are produced in a large variety of shapes, sizes and for different purposes.

I.2.3.1 Collector type

There are basically two types of solar collectors: no-concentrating or concentrating collectors. A no-concentrating collector has the same area for absorbing solar radiation like a concentrating solar collector, which usually has concave reflecting surfaces to focus the sun’s beam radiation to a smaller receiving area. In this way the radiation flux gets increased. A large number of solar collectors are available on the market.

Flat plate collector

Flat-plate collectors are the most widely used kind of collectors in the world for solar water and space heating. Solar collectors convert solar radiation into heat which is then transmitted into a thermally driven heating or cooling process. The following paragraphs give special attention to solar thermal systems ‘components which characterize the processes.[13]

[12] http://www.solarskies.com/products/solar-collectors
[13] http://www.oekotech.biz/ideen_loesungen.asp?id=9

[14]**Figure 6: Flat Plate Collector**

A flat-plate collector is characterized by a metal box with a glass or plastic cover „glazing“ on top and a dark-colored absorber plate on the bottom, most of the time in black or blue. The sides and bottom of the collector are usually insulated to minimize heat loss. The insulation can be made out of metal or wood and is closed with different synthetic materials.

The picture gives an example of a solar flat plate collector working principle:

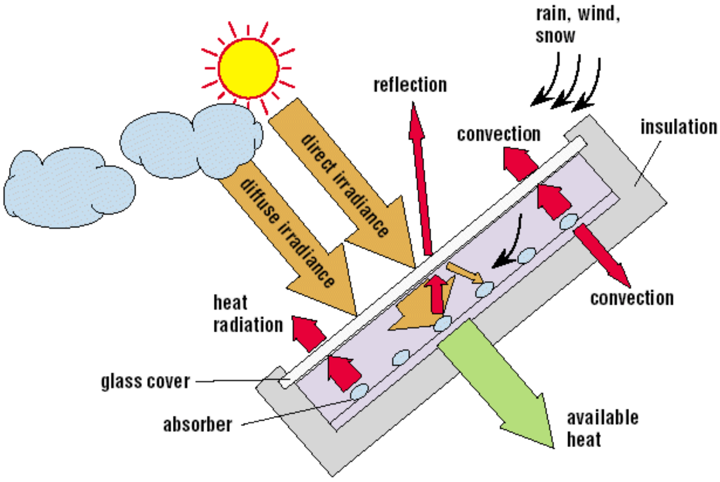

Figure 7: Flat Plate Collector[15]

At the operating process, sunlight passes through the glazing and strikes the absorber plate. The absorber plate heats up and changes solar energy into heat energy. The heat is transferred to a liquid and passes through pipes attached to the absorber plate. Absorber plates are painted with "selective coatings," which absorb and retain heat better than ordinary black paint. Absorber plates are made out of metal, typically copper or aluminum.

[14]http://sijiking.en.made-in-china.com/product/xePEKHncqiWR/China-Flat-Plate-Solar-Collector-SJW-FPC-100-.html
[15] http://www.volker-quaschning.de/articles/fundamentals4/index.php

Concentrating collector

Concentrating Solar Power (CSP) Collectors use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. The mirrors concentrate the light to somewhere between 25 and 3000 times the intensity of sunlight. They can produce electricity in much the same way as conventional power stations. CSPs obtain their energy input by concentrating solar radiation and converting it to high-temperature steam or gas to drive a turbine, motor engine or to power an absorption solar cooling cycle. Four main elements are required: a concentrator, a receiver, some form of transport media, storage and a power conversion.

Most developed CSP systems are the Parabolic Trough (a), the Concentrating Linear Fresnel Reflector (b), the Stirling Dish (c) and the Solar Power Tower (d), which the following picture shows:

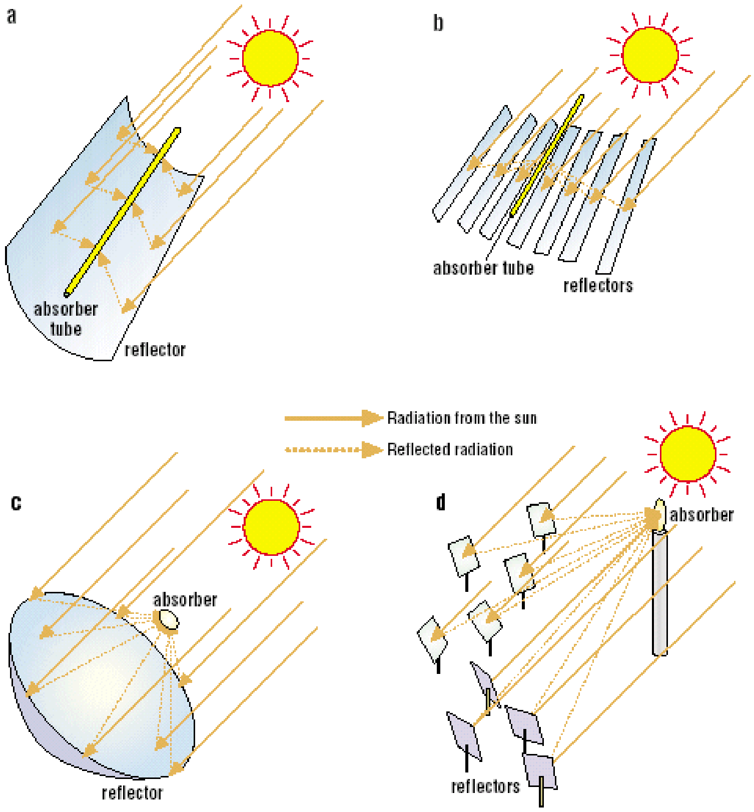

Figure 8: Concentrating Collector Types[16]

CSP systems can perform best if they also face the sun directly. Therefore tracking mechanisms are used to move the collectors during the day, always following the direct sunlight.

[16] http://www.volker-quaschning.de/articles/fundamentals2/index.php

Two moving mechanisms exist: single-axis trackers move east to west, dual-axis trackers move east-west, north and south. This is necessary to follow the sun throughout the year.

Evacuated Tube Collector

Evacuated Tube Collectors are made up out of a set of parallel glass tubes and they can also be used generating heat for solar heating or cooling like flat plate collectors. The collectors involve a visible set of parallel solar tubes. Evacuated, because of a “vacuum” layer within the tubes, where there are located heat pipes to absorb solar energy and to transfer it to a liquid medium.

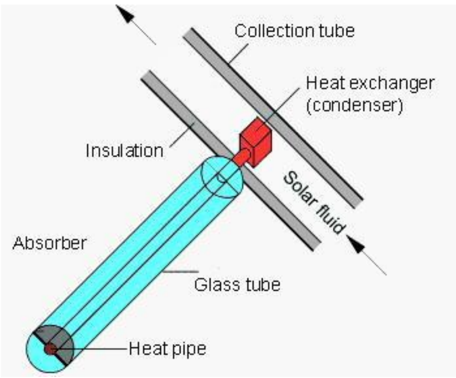

Figure 9: Evacuated Tube Collector[17]

It is a tested technology, allowing higher efficiencies, smaller and lighter collectors. They are well suited for cloudy or freezing climates and for applications demanding higher temperatures. The vacuum allows very small heat losses and eliminates the impact of ambient temperatures. Evacuated-tube collectors provide temperatures between 75ºC and 175ºC.

Figure 10: Evacuated Tube Collector[18]

Evacuated tube collectors are able to absorb the energy from diffuse radiation, which appears especially on cloudy days. This is why they are more adequate in areas with less direct radiation.

[17] http://greenterrafirma.com/evacuated_tube_collector.html
[18]http://kaidunsunny.en.made-in-china.com/product/IMZmiQEChucq/China-Pressurized-Evacuated-Tube-Solar-Collector-KD-HPC-58-1500-15-.html

As a result of good insulating properties around the collector, wind and low temperature also have a limited effect on the energy output. The tube is round and as a result, the amount of solar radiation striking the collector is relatively constant during the day and leads to a maximization of the total amount of solar radiation on the collector’s surface.
The collectors are well adapted to heating hot water but also to air conditioning of buildings.

I.2.4 Function within the System

The solar thermal system´s technical construction entails a flat plate collector field, a carrier medium which flows through the system if a certain temperature is reached, a heat exchanger, a buffer storage, a cooling machine, a cooling tower and a back-up system.
The system´s driving temperature is determined by three different temperature areas, generated by the collectors´ performance: Low (60-90°C), Medium (80-110°C) and High (130-200°C or more). All these system types have different outputs, based on the open or closed cycle mechanism.
The sun can, at least seasonally at European latitudes, provide a substantial part of the energy needed for air conditioning.
The basic principle behind solar thermal driven cooling is the thermo-chemical process of sorption: a liquid is either attached to a solid, porous material (adsorption) or is taken in by a liquid or solid material (absorption).

I.2.5 Collector Cycle

Solar collector technologies require that a collector field connects several single collectors. These collectors can either be connected in series or in parallel.
The volume flow through each collector should be kept above a certain level to assure a turbulent flow and therefore a high heat transfer rate in each collector tube.

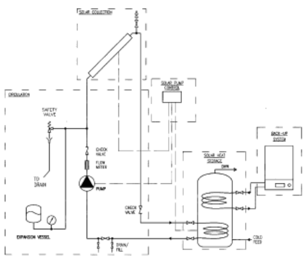

Figure 11: Schematic Collector Cycle

However volume flow should not be too high to avoid unnecessary pressure drop which would lead to high electricity demand for the circulation pumps.

By connecting collectors in series, total mass-flow through the whole collector field reduces (low-flow) and the temperature rise in the collector increases. As an advantage of this, hot water can be supplied immediately. As a disadvantage a higher thermal loss of the absorber to the environment occurs, which is due to the larger temperature difference. (Figure 11)[19]

Pump electricity demand increases because of the higher pressure drop in the collectors and also decreases due to the lower level of total mass flow in the collector loop. One solution to overcome higher pressure losses of collectors connected in series is to size collector loop pipes bigger. In this way it is possible to lower the pressure losses in these tubes. If collectors are connected in series, there is a more regular flow through the collector area because of a higher driving pressure drop over the field. The hydraulic layout has to be adjusted to the total mass flow.

To prevent mixing hot temperatures from the collector fluid with colder temperature at the inlet of the store, low-flow systems are characterized by using stratification units in the tank.

For large scale applications external heat exchangers with fixed inlets are used. It is also possible to implement more than two internal heat exchangers or pairs of inlets located at different heights in the storage tank to allow stratification even with high-flow systems.

I.2.6 System Selection and Dimension

Care should be taken not to oversize the solar collectors. Systems with too much solar contribution can lead to prolonged stagnation conditions and very high temperatures. If hot water load is constant throughout the year, the collector area should be sized to meet the load during the period where the solar contribution is the highest – this usually occurs in summer when there are higher levels of solar radiation. The collectors should be sized to meet no more than 100% of the load requirements at any time, right throughout the year.

Figure 12: Large Scale Solar Plant[20]

[19] http://www.b-es.org/sustainability/solar-thermal-guidance/
[20] http://www.resusallc.com/

For systems with a non-constant load pattern, detailed analysis should be done to ensure that there are not long periods of time when there is no load placed on the collectors.

The optimum design of a solar thermal system is very important. It is difficult to give general recommendations for a design, because of different requirements for each system. However, the network should be designed in such a way that the available pressure difference for the supply area is fully utilized. In this way future extensions of the system must be taken into consideration.

- Suitability of the minimum available temperature

It is essential for the dimensioning of the solar installation to estimate the "minimum available temperature" after the application of all realistic heat recovery measures.

- Suitability of thermal profile

The suitability of the thermal load profile has to be examined. Good profiles are those that are quite constant on a daily and seasonal basis.

The load should pass the test that it lasts for more than 3/4 of the year and includes summer. The load lasts for at least 5 days per week and the mean daily summer load is not lower than the mean daily load for the rest of the year.

- Calculating the load

The load that is addressed to the solar plant is estimated.

- Dimensioning of the solar collector area

There is hardly a standard way to dimension a solar thermal plant, because every system is quite unique. Possible guidelines to plan for a solar system are:

  - Space restrictions for installation of solar collectors:

    The available area for the collector installation is calculated.
  - Economic aspects:

    Restrictions on the investment can be given or an identification of the optimum investment solution is a goal.
  - Environmental aspects:

    One goal might also be to include environmental aspects into the planning phase. Such a choice can also have economic benefits in the long term.

- Dimensioning of the accumulators

Overheating and reduced collector efficiency can be avoided or minimized by specific tank volumes. In regard to the layout of the storage configuration, the main aspects are the use of a unique storage tank because of economic and energy aspects. If more than one storage tank has to be used then there are no major differences between the "in series" and "in parallel" connections. One of the most important points to ensure in all configurations is the tank´s stratification. With this basis it is possible to start dimensioning solar plants and systems.

I.2.7 Technical Plant Applications

All main components like pump units, plate heat exchanger and safety facilities are mounted within the control station (e.g. in a container) and are monitored in certain time periods. The values differ from project to project.

I.2.7.1 Collector

The calculated size of a solar collector depends on energy needs and solar radiation. Most implementing companies have a energy-calculator-program for the size that is optimal as well as for the associated equipment. It is important from an economic perspective to calculate the size that provides the lowest price / kWh as well as the size that provides the best overall dimensioning.

I.2.7.2 Solar Pipes

To prevent system inefficiencies, solar pipe dimensioning is very important. As a first step, manufacturer descriptions are considered. Expansion pipes for membrane-expansion facilities need to have certain dimensions in regard to the heat power of the heat producer.
The power resistor is based on the calculation that the expansion pipe is only allowed to raise pressure until pressure relieve valve and security valve are not affected.
It is recommended to dimension expansion pipes bigger than calculated because of the liquid´s viscosity and the connected pressure losses.

I.2.7.3 Temperature detector

In general, a distinction is made between an active and a passive temperature detector. Passive temperatures have a digital entrance whereas active temperatures need an operation span and an analogue entrance for the adjustment setting.

I.2.7.4 Insulation

Heat always tries to move from a hotter object to a colder one. Insulation prevents or slows down the movement of heat.
Solar insulation is a barrier that increases the performance of solar thermal systems by reducing heat loss, and thus retaining more of the captured power from the sun to

improve overall performance. It also prevents corrosion and is resistant to mold and moisture.

Important functions which should be preferred are:

- Excellent thermal insulation that does not increase weight or bulk
- Clear, invisible barrier that does not change the visual nature of the underlying surface
- High temperature capability to handle surface temperatures
- Reducing energy consumption
- No moisture infiltration, which gives the insulation the benefits of corrosion and mold

I.2.7.5 Fittings

A lot of fittings are needed for connection, separation and flexible mechanisms. The size and amount of fittings depends on the plant´s size and energy generation. Instructions for implementations in combination with fitting lists are available together with other plant applications.

I.2.7.6 Valves

Ball valves are used to shut off the medium contained within solar thermal systems. The control level can be used to lock the valve in open or closed positions. Some ball valves are specifically designed to work at high temperatures with a glycol solution at typical conditions of solar thermal systems.

The isolation valve is a manual or automatic valve placed in both the incoming and outgoing potable water lines to the solar tank.

An isolation valve is part of every solar water heater to isolate the solar tank in case of a problem, while allowing the backup water heater to remain in service.

If the circuit control valve is closed, atmospheric vacuum breakers shall only be installed on irrigation circuits with sprinkler heads that will not return any pressure to, or retain any pressure in the circuit.

In all closed circles, connected with warm water generator (e.g. closed collector areas) safety valves have to be installed due to prevent dysfunctional system pressures. The safety valves initial response pressure is in connection to the statistic high and the plant´s operating pressure.

I.2.7.7 Heat Transfer Fluid

Heat-transfer fluids carry heat through solar collectors and heat exchangers to the heat storage tanks in solar water heating systems. When selecting a heat-transfer fluid, following criteria should be considered:

- Coefficient of expansion – the partial change in length of a material for a unit change in temperature
- Viscosity – resistance of a liquid medium to flow
- Thermal capacity – the ability to store heat
- Freezing point
- Boiling point
- Flash point – the lowest temperature at which the vapor above a liquid can be ignited in air

There exist some different fluids, used for heat-transfer:

- Air

  Air has the advantage of not freeze or boil and is non-corrosive. However, it has a very low heat capacity and sometimes leaks out of collectors.
- Water

  Water is nontoxic and in most areas inexpensive. With a high specific heat and a very low viscosity, it's easy to pump it through the system. One disadvantage is that water has a relatively low boiling point and a high freezing point. It can also be corrosive if the pH is not maintained at a neutral level. Water with a high mineral content can cause mineral deposits to form in collector tubing and system plumbing.
- Glycol/water mixtures

  Glycol/water mixtures have a 60/40 or 50/50 glycol-to-water ratio. Ethylene or propylene glycols are antifreezes, which is an advantage in cold climates.
- Hydrocarbon oils

  Hydrocarbon oils have a lower specific heat and higher viscosity than water. However they require more energy to pump it. These oils are relatively inexpensive and have a low freezing point.
- Refrigerants/phase change fluids

  These are commonly used as the heat transfer fluid in refrigerators, air conditioners, and heat pumps. They generally have a high heat capacity and a low boiling point. This enables a small amount of refrigerant to transfer very efficiently a large amount of heat. Refrigerants react quickly to solar heat, making them more effective on cloudy days than other transfer fluids.

  Ammonia can also be used as a refrigerant. It's commonly used in industrial applications, but due to safety considerations it's not used in residential systems.
- Silicones

Silicones are noncorrosive and long-lasting. They have a very low freezing point and a very high boiling point. Because silicones have a high viscosity and low heat capacities, they require more energy to be pumped through the system. Silicones have the big disadvantage to leak easily, even though microscopic holes in a solar loop.

I.2.7.8 Back-up water heater

The backup water heater ensures that hot water is available, whether the sun shines or not. On a sunny, hot day, if the sun has preheated the water, the backup water heater uses no energy at all because the solar preheat temperature is greater than a typical thermostat setting.

If the solar preheat has a too low temperature, the backup heater boosts the remaining temperature.

Some backup water heaters don´t use a tank. Tank less water heaters eliminate standby loss, which saves more than 15% energy. Solar hot water systems and tank less water heaters are a winning combination if right constructed.

I.2.8 Example for application spectrum of solar plants

It is possible to combine different solar plants with other fuels, biomass, heat pumps, natural gas or biogas. A lot of these systems exist and they are economically efficient. They get increasing awareness and might be a future option for renewable energy use.

Solar energy can be used for a variety of applications. An example shows the following picture:

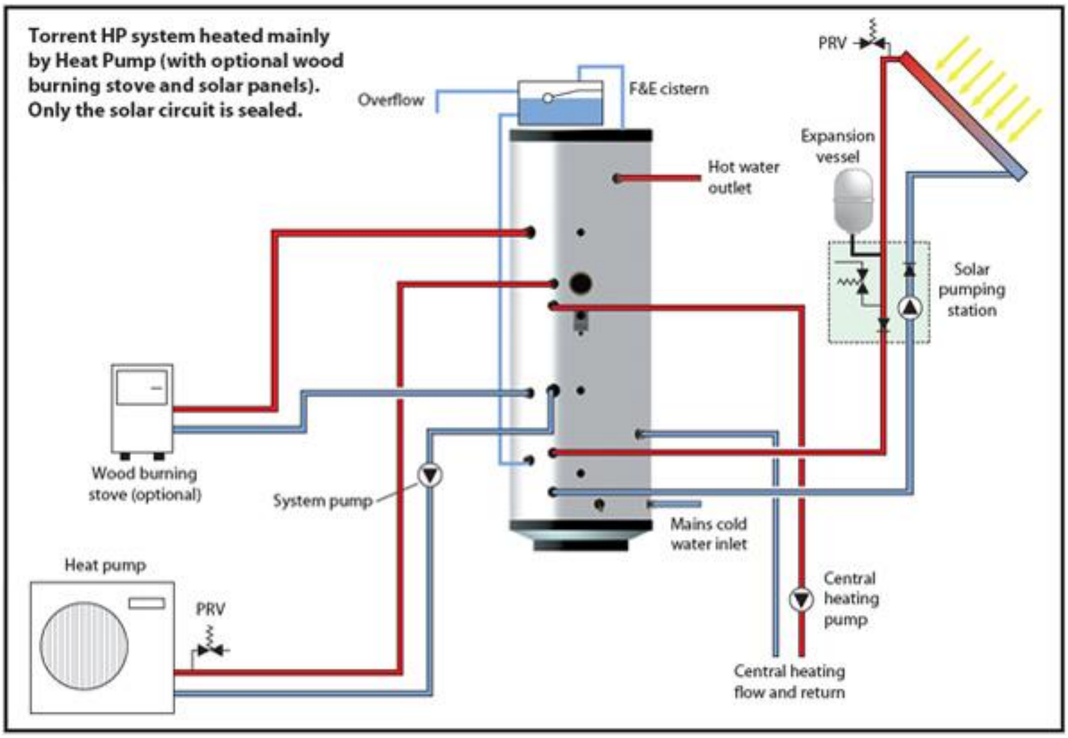

Figure 13: Solar Combination Systems[21]

Before implementing a solar thermal system it is recommended to consider possible synergies. Implementation of combination systems might lead to higher initial costs, but also provides higher efficiencies and saves higher energy costs. Following possibilities are available and commercially reasonable:

Solar thermal desalination is a technology of generating drinking water, based on brackish water and salt water.

Solar space heating uses solar thermal energy to heat space inside a building. In homes that use passive solar energy for space heating, the building acts as a solar collector. This is done by positioning and designing the home and the landscape elements in such a way as to take optimal advantage of solar radiation.

Homes with active solar energy systems for space heating use mechanical equipment like pumps, fans and blowers to help collecting, store and distribute heat throughout the building.

Active solar space heating systems use solar collectors to capture solar energy. There are two basic types of active solar heating systems based on the type of fluid heated inside the solar collector: liquid systems and air systems.

It is also possible to heat a pool with solar energy. Solar air conditioning has also been encouraged by simultaneity between high solar radiation and cooling demand. The

[21]http://www.ecoairpump.co.uk/mcs-air-source-heat-pump-pv-solar-thermal-products/class/eco-cylinder-thermal-store.shtml

machines can be effectively incorporated into solar combination systems, in which solar energy is used to produce domestic hot water, space heating and cooling.

In a radiant floor system, a solar-heated liquid circulates through pipes embedded in a thin concrete floor, which then radiates heat to the room. Radiant floor heating is ideal for liquid solar systems because it performs well at relatively low temperatures. A carefully designed system may not need a separate heat storage tank, though most systems do for temperature control.

Radiant basement systems take longer to heat the home from a cold start than other types of heating systems. Once they are operating they provide a consistent level of heat. Hot-water baseboards and radiators require water between 71° and 82°C to heat a room properly.

I.3 Installation

The installation phase is the execution of the design. The work completed here will keep the plant launch on schedule or, if mismanaged, will set it back considerably. [22]

Significant opportunities for equipment-specific fits and training begin to present themselves.

Some of the key challenges during this phase are:

- Design active direct or indirect, passive direct or indirect solar systems
- Perform routine maintenance or repairs to restore solar thermal systems to baseline operating conditions.
- Apply operation or identification tags or labels to system components, as required.
- Assess collector sites to ensure structural integrity of potential mounting surfaces or the best orientation and tilt for solar collectors.
- Connect water heaters and storage tanks to power and water sources.
- Determine locations for installing solar subsystem components, including piping, water heaters, valves, and ancillary equipment.
- Fill water tanks and check tanks, pipes and fittings for leaks.
- Identify plumbing, electrical, environmental or safety hazards associated with solar thermal installations.
- Install circulating pumps using pipe, fittings, soldering equipment, electrical supplies and hand tools.

[22] http://www.oekotech.biz/ideen_loesungen.asp?id=9

- Install copper or plastic plumbing using pipes, fittings, pipe cutters, acetylene torches, solder, wire brushes, sand cloths, flux, plastic pipe cleaners or plastic glue.
- Recruiting and/or selecting employees.
- Coordinating and implementing training.
- Developing equipment-specific procedures and work instructions.
- Ensuring that detailed, consistent operations and maintenance documentation is available.

I.3.1 Collector assembly

Every solar system consists of some kind of collector and its assembly, which is important in order to connect technical facilities and guarantee well defined operation processes. Following parts explain most important collector assemblys.

I.3.1.1 Pipes construction

The collector, the solar pump station and the solar storage tank are interconnected with pipes, most made out of copper. To prevent air locks, pipes are routed from the tank to the collector field on a rising incline. To drain the solar fluid it is necessary to install a fitting into the return pipe at the lowest point in the system

To connect the pipes, copper pipes for solar thermal systems are always soldered with brazing or silver. Compression fittings or push-fit fittings can be used instead of soldering if they are glycol and heat-resistant to 150 °C.

It has to be taken into account that system damages can be caused by installing plastic pipes. Therefore it is advised to use only materials which can withstand the temperatures of up to 150 °C.

A fill and drain valve is also included in the flow pipe. Within connections, there exists the risk of system damages due to heat from soldering. The connecting lines must be pressure and temperature resistant. If there are many additional points of resistance it may be advised to select a pipe with a larger diameter.

I.3.1.2 Laying pipes

Laying pipes should be carried out by a qualified electrician. One grounding clamp must be fitted to both the supply pipe and the return pipe at any position.

It is possible to lay pipes with an automatic air vent on the roof. Pipes to the air vent should also follow a rising gradient. Any downward change of direction requires an additional automatic air.

I.3.1.3 Insulating pipes

It is necessary to insulate outdoor piping with material which is both, resistant to UV light and high temperatures, but also indoor piping must be isolated with material which is resistant to high temperatures.

I.3.1.4 Solar pump station

For the layout of the installation space, it is necessary to connect temperature sensors. Therefore the solar pump station should be installed as close as possible to the solar storage tank. There should still be enough room for a solar expansion vessel and a container. The safety assembly on the solar pump station has to be installed together with the gasket supply.

It is important not to run the pump until the pipe work has been filled with solar fluid. Otherwise the pump can be damaged.

For an additional solar pump station one has to install a safety assembly. The pressure relief valve must be piped to the overflow vessel or drain at all time, since excessively hot solar fluid can discharge from the system.

After de-aeration, the air vent and the shut-off valve at top of the system must be closed.

During holiday and vacations the solar system should not be shut down to prevent overheating in the summer.

I.3.1.5 Connecting the expansion vessel and pre-cooling vessel

The solar expansion vessel should be installed with the relevant mounting materials.

The expansion vessel needs to be connected in the return line on the solar thermal station's safety assembly.

To make use of the maximum possible volume, the charge pressure needs to be set prior to pressurizing the solar fluid side. If the calculated charge pressure is higher or lower than the factory-set inlet pressure, correct the inlet pressure accordingly.

The inlet pressure of the diaphragm expansion vessel prior needs to be adjusted to fill the solar heating system to take the system elevation into account. The required system inlet pressure has to be calculated.

The pre-cooling vessel (if installed) and the expansion vessel should not be insulated, nor the pipes connecting them to the safety assembly. The charge pressure of the expansion vessel is given by the static system head.

The gaskets and membrane of the expansion tank must be suitable for the solar heat transfer fluid and for the high temperature in a solar system.

I.3.1.6 Connecting pipes and blow-off pipes to the solar pump station

The pipes need to be cut to a length which allows them to be pushed as far as possible into the compression fitting.

The blow-off pipe is routed so that any discharge can be seen to empty out into the holding container and secure it in place with a pipe clamp.

I.3.1.7 Sensors

The temperature sensors are not polarity sensitive. A waterproof junction box must be used if the collector temperature sensor's lead is joined to the sensor lead going to the controller at a point which is exposed to moisture. The sensor lead should be extended with a two-core lead and not supplied. If it is necessary, the connections must be protected at top and bottom with junction boxes.

I.3.2 Construction design

Figure 14: Solar Thermal Plant[23]

The most effective system design will depend on the selection of the most cost-effective solar collector for the application and careful system design. A system that is incorrectly configured may result in stagnation in some sections of the collector array and thus a significant reduction in heat output. The most common fault in designing large scale solar thermal plants is bad hydraulic design that results in uneven flow distribution or air locks in the collector array.[24] In regard to the planning phase the whole plant needs to be dimensioned and all parts must be adjusted to one another.

I.3.2.1 Plant volume

The plant´s volume is calculated based on all facilities used for the construction and whole solar plant cycles. Important for calculations are:

- Collector size

[23] http://www.solid.at/index.php?option=com_content&task=view&id=50&Itemid=68
[24] Large Scale Solar Thermal Systems Design Handbook; A joint publication between Master Plumbers' and Mechanical Services Association of Australia and Sustainability Victoria; 2009.

- Pipes
- Pump groups
- Connection Equipment etc.

I.3.2.2 Expansion volume

The plant capacity minus the pre-equipment and the hydraulic seal -by reaching the maximum system temperature in connection to the minimal system temperature expansion- is the basis calculation for the expansion volume.

The maximum temperature which can be reached by a solar plant is around 180°C. This is based on certain parameters for statistic high, operation pressure and the position of the solar cycle. Low temperatures can be in the range of -20°C which can be reached due to the amount of plant capacity outside and the amount of plant capacity beyond the ground.

I.3.2.3 Hydraulic seal

The hydraulic seal has to be adjusted by a membrane-expansion facility and is necessary due to the balance of liquid losses. At a expansion facilities volume of 15 l, the hydraulic seal has to be around 0,5% of the plant volume, at least this has to be 3l. Depending on the plant´s size 1% to 5% should be chosen as hydraulic seal.

I.3.2.4 Stagnation volume

If stagnation appears inside the plant, the volume which is pressed from the collector to the membrane-expansion facilities is called stagnation volume. It is based on:

- Collector capacity
- All intern pipes above the collector angle
- The capacity of the connection pipes (flows)

I.3.2.5 Pressure system

To keep the temperature expansion constant and for the liquids´ contraction, every closed system, pipe and holding tank system needs a pressure system (like membrane expansion system or automatic pressure systems).

Pressure systems need to fulfill the following tasks:

- Keeping system pressure in defined boundaries (min., max.)
- Compensating volume differences caused by the heat transfer fluid
- Prevent from system based fluid losses

If pressure systems are used which are based on automatically functions, they have to be implemented with consideration of possible liquid leakages.

I.3.3 Comissioning

The commissioning is the phase following construction during which the capabilities of an instrument are demonstrated in its final operational configuration. Commissioning is the systematic process of ensuring that a plant performs correct according to the documented design intent and the owner´s operational needs, and that specified system documentation and training are provided to the facility staff.
Commissioning of a piece of equipment is intended to verify that the equipment performs as anticipated, to characterize all of its available modes of operation and their performances.
Also system verification is important to test the total observing system. System verification is intended to demonstrate that the entire observing system is in place, the scientific observations with the commissioned instrument can be planned and performed, and the resulting data are of the quality expected and can be handled in the manners specified for the planned use.
During commissioning, both, verification and validation tests are performed on the complete system to ensure that the instrument meets all its science requirements and is ready for operation.
It is aimed during commissioning to characterize completely the behavior of the plant in all operational aspects. The estimated time for commissioning will be if the control engineering is finished and sun is shining, assuming that there are no major problems in hardware and software during this period.

I.4 Operation

The operation phase is not a phase in the project life cycle itself, because it starts after the construction project is completed. The operation phase is the phase when the plant starts to be used.
The purposes of the operation phase are to operate, maintain and conduct infrastructure system assessments to ensure the functional requirements are being satisfied, performance measures identified in the system´s boundaries are achieved, and determine when the system or infrastructure system should be modernized, replaced, or retired.

During plant operation it is important to control and monitor collectors, boilers, pumps, valves and all other facilities implemented into a solar plant. Energy is transported through pipes, the output from several collectors is regulated and monitoring instruments to maintain and regulate energy flows from the plant. When demand changes, heating district plant operators communicate with operators for the grid service to match production with system loads. Plant operators also go on rounds to check that everything in the plant is operating correctly. In all tasks they use computers to report unusual incidents, malfunctioning equipment or maintenance performed.

I.4.1 Control

Solar plants should be designed to collect available thermal energy in a usable form within the desired temperature range. This improves the overall system efficiency and reduces the demands placed on auxiliary equipments. In cloudy conditions, the collector field is maintained in a standby mode ready for full-scale operation if the intensity of the sunlight rises once again.

A solar collector field is a good test platform for various control methodologies. This is why several control systems are implemented into a solar plant and into a solar heating district system to guarantee a save operation mode.

I.4.2 Monitoring

If there exists no monitoring system, it is hard to figure out if a plant performs optimal, just by following energy output. A minute of defect, a crack or piece of dirt may reduce the total output significantly. That condition may stay unnoticed for years, which leads to financial losses.

Monitoring systems provide optimal and predictable output, with a least possible downtime. Automatic reporting ensures quick repairs, reducing dropouts, increasing profit and decreasing losses:

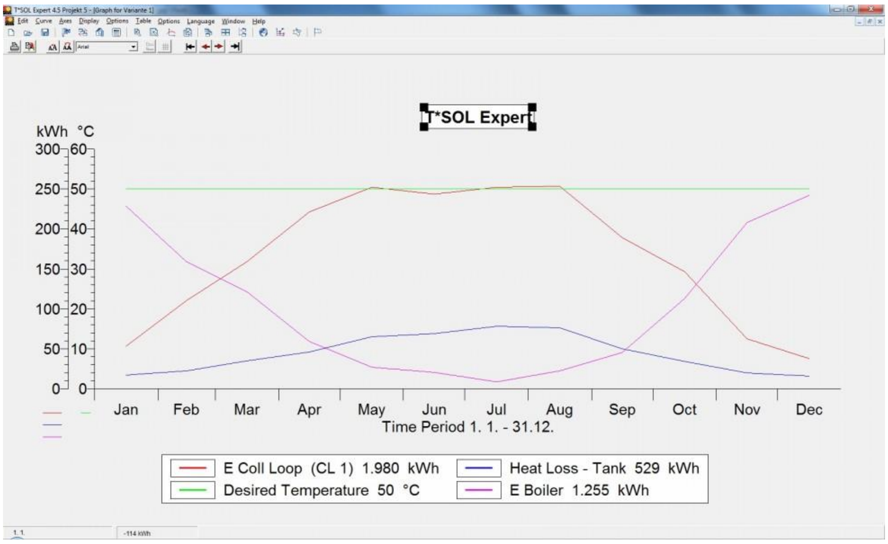

Figure 15: Analysis of Solar Thermal Systems[25]

I.4.1 Stagnation

Stagnation can appear in a solar system and is no problem in general, but it should be avoided. If a solar plant goes into stagnation (e.g. because of a lack of energy based on technical dysfunctions) there are 5 phases which have to be considered:

Phase 1: thermal expansion

After the solar fluid´s thermal expansion under common working conditions, the solar fluid overheats because of a lack in energy absorption and starts to evaporate. This leads to an increased operation pressure.

Phase 2: Liquid gets pressed out of the collector due to the evaporation process

The initial vapor presses a huge amount of collector liquid into the pipes and further in pre-facilities and membrane expansion facilities. This leads to a further increase of operating pressure.

Phase 3: Ebullition of the collector area – Phase with saturated vapor

If the collector is permeably for vapor, the rest liquid stays in the collector and evaporates (saturated vapor). The vapor presses more solar liquid into the intermediate vessel and the membrane expansion facility. This leads to a maximum operation pressure. In all areas with vapor, temperatures are reached, which have the same saturated vapor like the operation pressure has (temperatures until 160°C are possible).

Phase 4: Ebullition of the collector area – Phase with saturated and overheated vapor

If the amount of vapor increases, the collector dries. This leads to less vapor production and discharges the system.

Subsequent the membrane expansion facility presses the solar liquid back into the pipes and decreases the operating pressure. The vapor inside the collector overheats and

[25] http://www.valentin.de/node/526

inside the absorber temperatures above 200°C are possible. Outside the collector, the temperature of the vapor decreases a little bit and the solar liquid reaches the collector´s level again. The whole cycle can take several hours.

Phase 5: Refilling the collector

With increasing cooling the solar liquid gets refilled into the collector.

In a stagnation situation, system´s evaporation behavior is influenced by the type of collectors and the hydraulics in the collector array. A solution concept combines a pressure less catchment tank, dynamic pumps pressure maintenance and pressure compensations. The overall solution includes filling, feed and draining of the system. With a low-mounted collector connection, the generated steam can press the remaining medium out of the collector and into the expansion vessel (which must be dimensioned sufficiently), and the evaporation phase remains short. With high-mounted connections, the medium is not displaced, but the collector has been “boiled empty” (unforgiving evaporation behavior). Large volumes of steam are pressed into the system, and can have considerable impact on the components. In domestic hot water preheating systems, this situation occurs very rarely, or only in the event of a fault, as they are designed so that even in low load periods during summer, the heating requirement is always higher than the maximum solar yield which can be expected. Therefore, with these systems, a design with forgiving evaporation behavior, a high-temperature-resistant heat exchanger, and sufficient expansion capacities are particularly important.

To reduce the frequency of surplus heat and therefore stagnation, various strategies have been developed:

- install collectors at a very steep tilt angle, or else vertically on a façade
- water without antifreeze, because pressure is easier kept under control with pure water
- by a “drain-back” method, the collector is automatically emptied if the system is switched off
- the solar storage tank is dimensioned in such a way that it can accommodate surplus in summer, so as to make it available in winter
- surplus heat in summer is used for solar climate control
- surplus energy from the solar buffer storage tank is redischarged ba means of the pump being switched on at night, and releasing heat via the collector
- an additional heat load accepts surplus energy

Research projects focused on combinations of solar thermal hot water generation, heating and their aging as well as stagnation behavior. The investigations show a multitude of system variants, with sometimes unnecessarily complex hydraulics.

Research shows that simplification, standardization, and unification of the system is advisable. Prefabricated components should reduce installation errors and enable optimized complete systems.[26]

I.4.2 Safety

The safe operation of the solar plant does not only depend on the safe construction and manufacturing conditions, but also on the process parameters which are set for production and which are solely in the operator's sphere of influence.
It is necessary to carry out a test run with a check of all protection devices after ending of the assembling and before commissioning of the plant.
During this test operation and the introduction, special safety arrangements are necessary.

The certification mark "DIN-Geprüft" DIN EN 12975-2:2006-06 on the basis of the European certification scheme for solar thermal products contains several specific requirements in regards to durability (including mechanical strength), reliability and safety for liquid heating solar collectors. It also includes provisions for evaluation of conformity to these requirements.
The following quality criteria are subject to the testing of solar thermal products:

- Internal pressure resistance
- Mechanical load
- High temperature resistance
- Internal and external thermal shock resistance
- Exposure
- Rain proof
- Impact resistance
- Thermal performance

Furthermore the plant operation requires:

- It is in a technically flawless state
- Official regulations are fulfilled before commissioning
- It is commissioned by authorized, instructed staff

[26] http://www.bine.info/fileadmin/content/Publikationen/Englische_Infos/themen_0108_engl_internetx.pdf

- It is used as defined in the specification
- The operating instructions are followed
- It is correctly maintained and commissioned

The operator is obliged to train the operating staff and to inform about existing law and accident prevention regulations as well as the manual and servicing instructions. He has to make sure, that this operating- and maintenance manual had been understood and considered by employees. This is valid in particular for safety instructions, operating instructions and maintenance instructions (staff must sign for the preserved briefing / training). An operator is obliged to install all safety advices.

I.5 Financing

In the field of large scale solar thermal plants there are potentials for adding value to the project through government grants, rebates or Renewable Energy Certificates (RECs). There is also the potential for energy providers to subsidize a project based on the reduction of peak loads.

At the beginning of the project, identify project costs, allocate budgets and confirm payment terms are the main aspects of the financial field.[27]

On the part of the customers, there is a high interest of realizing solar plants by an ESM (energy service model), i.e. the companies do not need to make any financial investment. Due to the very large energy needs that most industrial businesses have, many solar plants in the industrial field are large-area plants (500 up to many 1,000 m² solar collectors). Large-scale solar plants are on a competitive basis compared to fossil fuels, and they have the additional advantage that the energy costs of a customer can be calculated up to 20-25 years in advance. The energy prices that solar energy can offer at present are in the range of the fossil fuel prices, and in some case they are even lower.

Industrial customers typically have energy needs that vary over time. By means of an easily mountable and removable system for solar plants, it is now possible to respond to changes in energy needs - e.g. by mounting more solar collectors.

It is furthermore most of the time possible to get an investment subsidy for a large scale solar plant. Also a lot of different investors can be found.

[27] Large Scale Solar Thermal Systems Design Handbook; A joint publication between Master Plumbers' and Mechanical Services Association of Australia and Sustainability Victoria; 2009.

From a legal point of view it is possible that the solar plant remains property of the operator although it is firmly mounted on the roof of an industrial business.
The investment and the economic profitability of the solar plants depend largely from the plant size. The larger the solar plant, the smaller the specific costs of the plant (in € per m² of collector area). The specific investment cost of the solar plants also depend on the kind of application (e.g. domestic hot water preparation, space heating, space / process cooling,...). Currently it´s in the range of 270-460 €/m².[28]

II. Chapter - Large Scale Geothermal Heat Pumps

Heat pumps acquire importance world-wide in conjunction with energy efficiency in heating and cooling operations. Heat flows naturally from a higher to a lower temperature. Heat pumps, however, are able to force the heat flow in the other direction, using a relatively small amount of high quality drive energy (electricity, fuel or high-temperature heat). Thus heat pumps can transfer heat from natural heat sources in the surroundings, such as the air, ground or water, or from man-made heat sources such as industrial or domestic waste, to a building or an industrial application. Heat pumps can also be used for cooling. Heat is then transferred in the opposite direction, from the application that is cooled, to surroundings at a higher temperature.[29]
The potential for reducing CO_2 emissions assuming a 30 % share of heat pumps in the building sector using technology presently available is about 6 % of the total worldwide CO_2 emission.[30]

II.1 Basic Information

Heat pumps transfer heat by circulating a substance -called a refrigerant- through a cycle of evaporation and condensation. A compressor pumps the refrigerant between two heat exchanger coils. In one coil, the refrigerant is evaporated at low pressure and absorbs heat from its surroundings. The refrigerant is then compressed en route to the

[28] http://www.energiederzukunft.at/results.html/id4880
[29] http://www.heatpumpcentre.org/en/aboutheatpumps/heatpumptechnology/Sidor/default.aspx
[30] Ground-Source Heat Pumps - Overcoming Market and Technical Barriers; Report no. HPP-AN29-1; IEA Heat Pump Centre; Sweden; 2010.

other coil, where it condenses at high pressure. At this point, it releases the heat it absorbed earlier in the cycle. Following figure shows a cycle´s scheme:

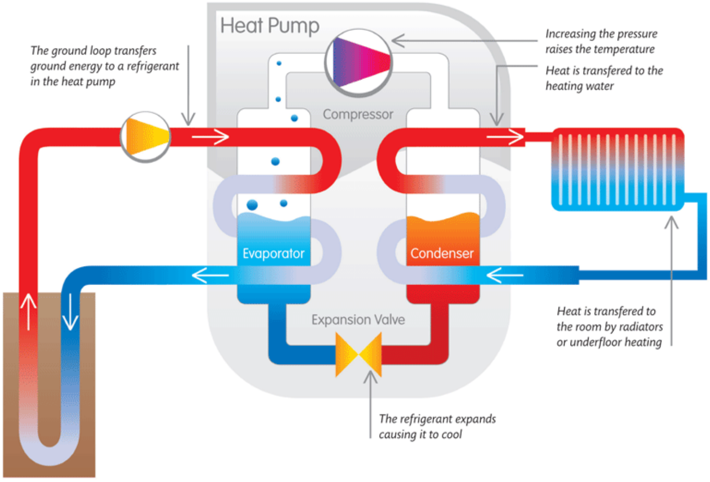

Figure 16: Heat Pump Cycle[31]

The heat pump cycle is fully reversible, and heat pumps can provide year-round climate control for a building – heating in winter, cooling and dehumidifying in summer. Since the ground and air outside always contain some heat, a heat pump can supply heat to a house even on cold winter days. In fact, air at –18°C contains about 85 percent of the heat it contained at 21°C.

An air-source heat pump absorbs heat from the outdoor air in winter and rejects heat into outdoor air in summer. Ground-source heat pumps, which draw heat from the ground or ground water, are more widely used. [32]

II.2 Design

The most important item is the development of the system. The interaction of the user, the building, the heating/cooling equipment and the control has to be considered very carefully, and only such a system approach can achieve highly efficient systems.[33]

Small systems

The common characteristic of small systems is natural ground recovery, mainly by solar radiation collected by the ground surface. Small systems are in use for heating as well as heating and cooling, they can be used depending on the climate and the distribution system for direct cooling (without heat pump operation), at least at the beginning of the cooling season.

[31] http://www.connecticutenergyconsultant.com/geothermal-heat-pump-design/
[32] http://oee.nrcan.gc.ca/publications/residential/heating-heat-pump/10686
[33] Ground-Source Heat Pumps - Overcoming Market and Technical Barriers; Report no. HPP-AN29-1; IEA Heat Pump Centre; Sweden; 2010.

Large systems

For large system recovery of the ground has to happen by heat removal and heat extraction. Sometimes additional systems for recharging the store have to be provided. Heat removal can happen by direct cooling (without heat pump operation) and indirect cooling (with heat pump operation).

II.2.1 Technical instructions

The efficiency of the unit is most commonly expressed by the COP, the Coefficient Of Performance. This COP depends on the refrigerant selected and on the components used, like the compressor, the size and design of condenser and evaporator, the flow sheet – single stage, two stage, economizer or cascade – and the internal cycle control. The choice for a refrigerant is most commonly a compromise between efficiency and cost, smaller equipment using a high-pressure working fluid can reduce the cost, a working fluid with low discharge temperatures can avoid a two-stage system.[34]

II.2.2 Systems for Heat Extraction from and Heat Removal to the Ground

II.2.2.1 Collectors

There are two principle types of collectors - open loop and closed loop - with closed loop (using a piped collector) being the most common. The closed loop is principally broken into horizontal and vertical systems. Whichever system is used, it is essential to design collectors for the specific application and location including assessment of operational pumping costs and the length of pipe systems.

Open loop systems

In the case of open loop systems, ground water, water from stores, water from rivers, ponds, lakes or the sea are used directly for heat extraction or heat removal. In the case of ground water two well systems, one for ground water extraction and one for ground water removal and single well systems are in use.

Closed loop systems

In the case of closed loop systems coils are installed in the ground. It is also possible to install coils in ponds, lakes, rivers or in the sea. In the case of closed loop systems heat extraction/heat removal can happen by

- direct exchange ground source systems – direct expansion systems

[34] Ground-Source Heat Pumps - Overcoming Market and Technical Barriers; Report no. HPP-AN29-1; IEA Heat Pump Centre; Sweden; 2010.

- secondary loop systems

In the case of secondary loop systems a heat carrier – most commonly brine, sometimes water or recently CO_2 - are used as heat carrier.

Following figure shows a closed system:

Figure 17: Closed System[35]

II.2.2.2 Horizontal trenches

Where horizontal trenches are used to extract energy from the ground the depth would normally be between 0.8 and 2 meters - the depth is limited by the practicalities of site excavation, as following figure shows:

Figure 18: Geothermal Heat Pump - Horizontal Trenches[36]

For strip trenches the width of the trench is typically the same as that of a bucket on a digger - the coils being installed either horizontally or vertically in deeper but narrower trenches. The coils are made up on a former (held in loops with plastic 'cable' ties) and then dropped into the trench. Alternatively straight runs of pipes may be used with an increased trench length.[37]

II.2.2.3 Vertical bore hole*s*

Vertical bore hole based ground loops are used where there is limited ground surface available as in more densely populated areas or where there is little soil to excavate.

[35] http://news.thomasnet.com/green_clean/2010/10/05/geothermal-heat-pump-systems-debuting-on-scales-from-small-to-massive-in-the-u-s/

[36] http://www.agry.purdue.edu/hydrology/projects/Geothermal/Geothermal.asp

[37] http://www.b-es.org/sustainability/ground-source-heat-pump-guidance/

They are likely to be more expensive to install than horizontal systems and require a specialist contractor who will commonly leave the borehole tails for connection by the mechanical contractor.

Bore holes are required to be deep (in the order of 15 to 100 meters) to accommodate the appropriate length (and hence surface area) of pipe to extract the required heat from the ground. The bore holes would normally be no closer than 6 meters apart from each other and take one or two loops.[38]

II.2.2.4 Ground-coupled systems

The ground acts as a seasonal storage. At a depth of about 10 m the undisturbed ground temperature remains constant over the year; the value of this temperature corresponds to the annual average outside air temperature. Between the table where the constant temperature occurs and the surface, the ground temperature changes due to the outside conditions. Depending on the depth, these changes are damped and delayed. Eliminating peaks of the outside air temperature, the ground is an efficient heat source for heat pumps.[39]

II.2.3 Heat pump

Almost all heat pumps currently in operation are either based on a vapour compression, or on an absorption cycle.

Theoretically, heat pumping can be achieved by a lot of thermodynamic cycles and processes. These include Stirling and Vuilleumier cycles, single-phase cycles (e.g. with air, CO_2 or noble gases), solid-vapour sorption systems, hybrid systems (notably combining the vapour compression and absorption cycle) or electromagnetic and acoustic processes. Some of these are entering the market or have reached technical maturity, and could become significant in the future.

II.2.3.1 Vapour compressor

The great majority of heat pumps work on the principle of a vapour compression cycle. The main components in such a heat pump system are the compressor, the expansion valve and two heat exchangers referred to as evaporator and condenser. The components are connected to form a closed circuit.

A volatile liquid, known as the working fluid or refrigerant, circulates through the four components. In the evaporator the temperature of the liquid working fluid is kept lower

[38] http://www.b-es.org/sustainability/ground-source-heat-pump-guidance/

[39] Ground-Source Heat Pumps - Overcoming Market and Technical Barriers; Report no. HPP-AN29-1; IEA Heat Pump Centre; Sweden; 2010.

than the temperature of the heat source, causing heat to flow from the heat source to the liquid, and the working fluid evaporates. Vapour from the evaporator is compressed to a higher pressure and temperature. The hot vapour then enters the condenser, where it condenses and gives off useful heat. Finally, the high-pressure working fluid is expanded to the evaporator pressure and temperature in the expansion valve. The working fluid is returned to its original state and once again enters the evaporator. The compressor is usually driven by an electric motor and sometimes by a combustion engine.[40]

II.2.3.2 Absorption

Absorption heat pumps are thermally driven, which means that heat rather than mechanical energy is supplied to drive the cycle. Absorption heat pumps for space conditioning are often gas-fired, while industrial installations are usually driven by high-pressure steam or waste heat. Absorption systems utilize the ability of liquids or salts to absorb the vapour of the working fluid. The most common working pairs for absorption systems are:

- water (working fluid) and lithium bromide (absorbent)
- ammonia (working fluid) and water (absorbent)

In absorption systems, compression of the working fluid is achieved thermally in a solution circuit which consists of an absorber, a solution pump, a generator and an expansion valve. Low-pressure vapour from the evaporator is absorbed in the absorbent. This process generates heat. The solution is pumped to high pressure and then enters the generator, where the working fluid is boiled off with an external heat supply at a high temperature. The working fluid (vapour) is condensed in the condenser while the absorbent is returned to the absorber via the expansion valve.

Heat is extracted from the heat source in the evaporator. Useful heat is given off at medium temperature in the condenser and in the absorber. In the generator high-temperature heat is supplied to run the process. A small amount of electricity is needed to operate the solution pump.[41]

II.2.3.3 Drilling methode

Drilling is the most expensive part of ground source heat pump systems. Therefore, the selection of the optimum and most cost effective method of drilling is extremely important, and developments are going on to reduce this cost bourdon.[42]

[40] http://www.heatpumpcentre.org/en/aboutheatpumps/heatpumptechnology/Sidor/default.aspx
[41] http://www.heatpumpcentre.org/en/aboutheatpumps/heatpumptechnology/Sidor/default.aspx
[42] Ground-Source Heat Pumps - Overcoming Market and Technical Barriers; Report no. HPP-AN29-1; IEA Heat Pump Centre; Sweden; 2010.

II.2.3.4 Heat source

The technical and economic performance of a heat pump is closely related to the characteristics of the heat source. An ideal heat source for heat pumps in buildings has a high and stable temperature during the heating season, is abundantly available, is not corrosive or polluted, has favorable thermo physical properties, and it´s utilization requires low investment and operational costs. In most cases, however, the availability of the heat source is the key factor determining it´s use. Commonly used heat sources are ambient and exhaust air, soil and ground water are practical heat sources for small heat pump systems, while sea/lake/river water, rock (geothermal) and waste water are used for large heat pump systems.[43]

II.2.3.5 Refrigerants

The refrigerants (working fluids) presently in use are R-134a, R-404A, R-704C, and R-410A. The new pure fluid and these mixtures require changes in the manufacture of components, new sealing materials and especially new lubricants. It was a change from mineral oils to synthetic oils like alkylbenzol, polyalphaolefine (PAO), polyolester (POE), and polyglykole (PAG) oils. Decomposition problems of the non-azeotropic mixtures within the cycle are not yet fully solved.[44]

II.2.3.6 Electrical demand

In order to transport heat from a heat source to a heat sink, external energy is needed to drive the heat pump. Theoretically, the total heat delivered by the heat pump is equal to the heat extracted from the heat source, plus the amount of drive energy supplied. Electrically-driven heat pumps for heating buildings typically supply 100 kWh of heat with just 20-40 kWh of electricity. Many industrial heat pumps can achieve even higher performance, and supply the same amount of heat with only 3-10 kWh of electricity.

[43] http://www.heatpumpcentre.org/en/aboutheatpumps/heatsources/Sidor/default.aspx
[44] Ground-Source Heat Pumps - Overcoming Market and Technical Barriers; Report no. HPP-AN29-1; IEA Heat Pump Centre; Sweden; 2010.

II.2.3.7 Heat Distribution System

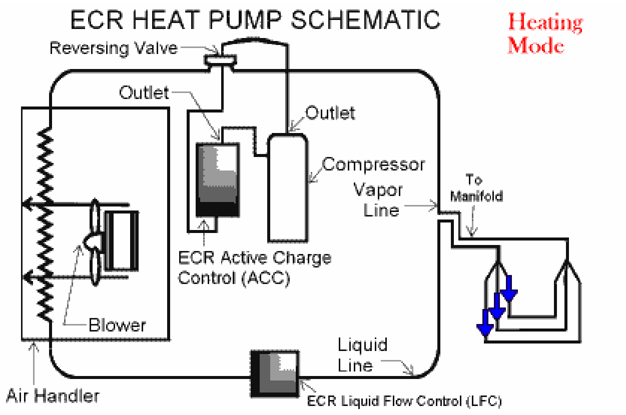

Figure 19: Schematic Heat Pump[45]

As heat distribution systems in Europe hydronic systems are most commonly used, in Japan and in the USA it is air based systems. One reason for this variation is the different cooling demand.

Hydronic systems are in principle secondary loop systems with water as heat carrier and radiators, fan coils or parts of the room like the floor, the wall or even the ceiling as heat transfer surface.[46]

II.2.4 Seasonal Storages

The efficiency of ground source heat pumps can be improved by using seasonal thermal storages. If heat loss from the ground source is sufficiently low, the heat pumped out of the building in the summer can be retrieved in winter. Heat storage efficiency increases with scale, so this advantage is most significant in commercial or district heating systems.

Possibilities for a seasonal thermal store are:

- Heating and cooling operation with a balanced heat extraction/heat removal into the store
- A hybrid heating and cooling system where the balance is achieved by additional cooling of the store by a cooling tower or additional charging of the store by solar energy

[45] http://www.copper.org/applications/plumbing/heatpump/geothermal/gthrml_main.html
[46] Ground-Source Heat Pumps - Overcoming Market and Technical Barriers; Report no. HPP-AN29-1; IEA Heat Pump Centre; Sweden; 2010.

The seasonal thermal storage can be formed as: [47]

- aquifer thermal energy stores
- multiple standing column well systems
- borehole thermal energy storage in the ground
- using the building´s foundation as a storage

II.2.5 System Selection and Dimension

The heat delivered by a heat pump is theoretically the sum of the heat extracted from the heat source and the energy needed to drive the cycle. The steady-state performance of an electric compression heat pump at a given set of temperature conditions is referred to as the COP.

The COP or PER of a heat pump is closely related to the temperature lift, i.e. the difference between the temperature of the heat source and the output temperature of the heat pump. The COP of an ideal heat pump is determined solely by the condensation temperature and the temperature lift (condensation - evaporation temperature).

The performance of heat pumps is affected by a large number of factors:

- the climate - annual heating and cooling demand and maximum peak loads
- the temperatures of the heat source and heat distribution system
- the auxiliary energy consumption (pumps, fans, supplementary heat for bivalent systems etc.)
- the technical standard of the heat pump
- the sizing of the heat pump in relation to the heat demand and the operating characteristics of the heat pump
- the heat pump control system

Because a heat pump operates most effectively if the temperature difference between the heat source and heat sink (distribution system) is small, the heat distribution temperature for space heating heat pumps should be kept as low as possible during the heating season.[48]

[47] Ground-Source Heat Pumps - Overcoming Market and Technical Barriers; Report no. HPP-AN29-1; IEA Heat Pump Centre; Sweden; 2010.
[48] http://www.heatpumpcentre.org/en/aboutheatpumps/heatpumpsinresidential/Sidor/default.aspx

The drive energy of heat pumps is most commonly electricity, and for the future improved power generation systems based on renewable and fossil fuels have to be taken into consideration. [49]

II.2.6 Example for application spectrum of plants

Heat pumps can be used for: [50]

- space heating
- heating and cooling of process streams
- water heating for washing, sanitation and cleaning
- steam production
- drying/dehumidification
- evaporation
- distillation
- concentration

Following figure shows the heating and cooling cycles of geothermal applications:

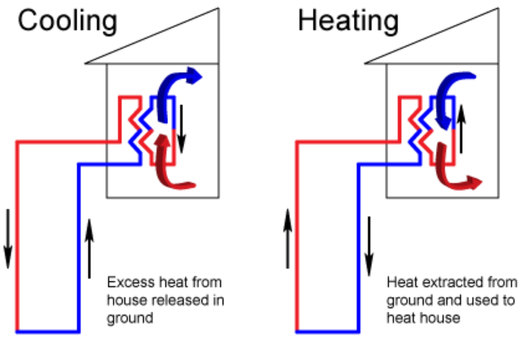

Figure 20: Heating and Cooling with Geothermal Energy

II.2.6.1 CO_2 Heat Pipe Based Systems

CO_2 was used as a working fluid in Europe already in the year 1881 and became an important refrigerant. It has been used until the end of 1939 for applications where a "safety" refrigerant was required. Difficulties have been caused by the thermodynamic properties, the critical data are about 31°C and 74 bar. This resulted at high ambient temperatures in a transcritical operation where both capacity and efficiency dropped significantly.

[49] Ground-Source Heat Pumps - Overcoming Market and Technical Barriers; Report no. HPP-AN29-1; IEA Heat Pump Centre; Sweden; 2010.
[50] http://www.heatpumpcentre.org/en/aboutheatpumps/heatpumpsinindustry/Sidor/default.aspx

The M-tec company developed a heat-pipe based ground probe with CO_2 as working fluid for vertical wells down to a depth of about 70 m. This self-circulating system is environmentally fully acceptable – the probe works oil free – and it has the advantage that no circulation pump is required. The working principle of a heat pipe can be described as follows:

Due to gravity the liquid working fluid (CO_2) flows along the tube wall to the 'heated' section of the probe where it becomes evaporated, thus the liquid film becomes thinner and thinner while the vapour rises to the top due to the buoyancy. In the "cooled" section – at the top of the heat pipe – the vapour becomes condensed and the cycle starts again.

The system design leads to a heat pump cycle that is physically de-coupled from the heat source cycle, the CO_2 cycle. The refrigeration cascade consists of the earth probe in which CO_2 is evaporated and the "probe-head" which is both the CO_2-condenser and the refrigerant-evaporator of the conventional heat pump using R-410A as refrigerant.

The experimental analysis confirms that the proposed CO_2 heat pipe is a reliable and a highly efficient as well as environmentally friendly alternative to common ground-coupled systems. With a prototype heat pump a system SPF of higher than 5 has been measured.[51]

II.3 Installation and System Assembly

To properly install a heat pump, several points need to be taken into account. Special consideration must be given to the location of a heat pump in regard to structures, obstructions, other units and all other factors that may interfere with air circulation.[52]

Some basic installation guidelines ensure that installing a heat pump is well done:

If installing a ground-source heat pump that draws on well water or a local water source, it has to be checked that the water quality is high and that this process is legal in the area. Poor water with lots of particulate matter, or highly acidic water, will hamper the performance of a ground source heat pump.

The manufacturer's product literature tells how loud the heat pump can be. The noise level sould fall within the acceptable bounds of the area. If using an air-source heat pump, the contractor should install the heat pump ideally not next to sensitive places.

The installation should be made in the proper location relative to pre-existing furnaces.

[51] Ground-Source Heat Pumps - Overcoming Market and Technical Barriers; Report no. HPP-AN29-1; IEA Heat Pump Centre; Sweden; 2010.

[52] http://www.completeheating.ca/manuals/WGHP43.pdf

The outside portion of the air-source heat pump should be on a platform to promote drainage and ensure that it won't be snowed in. A windy location should be avoided when installing a heat pump.

No matter what type of heat pump chosen, it has to be reliable, experienced contractor with a good track record helps with installing the heat pump. The contractor should be able to examine the served space and tell how much work the heat pump will have to do to heat and cool it. Also, the contractor should check to make sure ductwork and electrical systems can handle the addition of a heat pump.[53]

Focusing on different applications of heat pumping technologies, several items have to be taken into consideration like drive energy, design of the unit, integration into a system and control strategy.

The choice of the refrigerant may have a large influence on the integration of a system. The most efficient way of heat absorption/heat dissipation is direct evaporation/direct condensation. The alternative are secondary loop systems. Secondary loop systems require an additional temperature lift to transport heat to the evaporator and from the condenser. Most commonly they require circulation pumps with an additional power consumption. Especially in low-temperature applications this may cause problems. This means that secondary loop systems are less efficient than direct evaporation/condensation systems.

However, the unit itself can be designed as a compact unit and the refrigerant content can be minimized. Additionally, if heat absorption/heat dissipation happens in spaces with public access, the working fluid has to be a safety refrigerant, flammable and/or toxic fluids cannot be used. But there are lot of applications, where the secondary loop system already exists, for example hydronic heating systems or cold water based air conditioning systems. In large cold stores the use of direct systems with flammable and/or toxic working fluids is also possible.[54]

[53]http://www.howtodothings.com/home-and-garden/a3778-how-to-choose-and-install-a-heat-pump.html

[54] Ground-Source Heat Pumps - Overcoming Market and Technical Barriers; Report no. HPP-AN29-1; IEA Heat Pump Centre; Sweden; 2010.

II.4 Operation

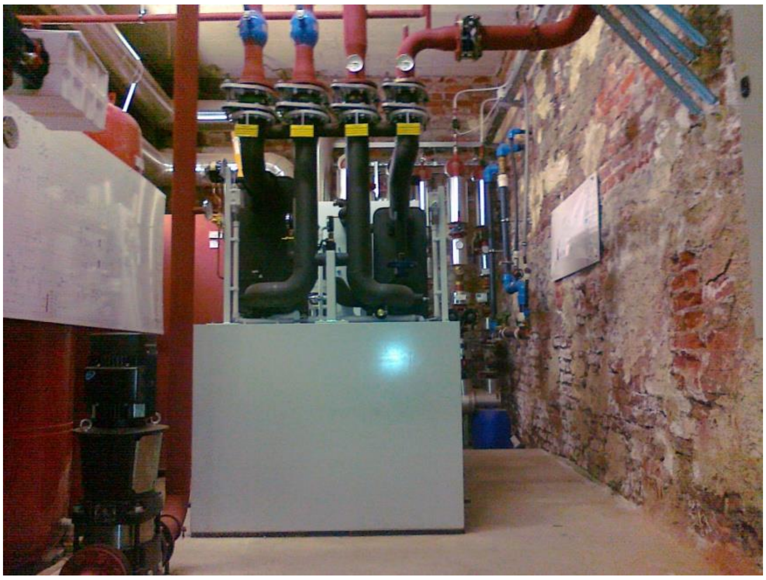

Figure 21: Heat Pump System[55]

One important item is the real operation of the system combined with the control strategy selected. The operation of the system shows not only full load, but mainly part-load: many systems loose a lot of efficiency operated in part-load, and taking this part-load operation one will get the SPF, the seasonal performance factor, which includes the cold/heat output, the drive energy at the different operating conditions, and the parasitic energy consumers like fans and circulation pumps.[56]

II.4.1 Control Aspects

Control facilities can optimize the heating and cooling systems to meet set requirements. One can easily be alerted in the event of unforeseen breakdowns. Also legal aspects have to be considered due to the installation and operation process.

II.4.2 Legal Aspects

Legal barriers in the case of ground source heat pump systems are most commonly connected with heat extraction from and heat removal into the ground, because the ground is also the source of groundwater, which is used as drinking water and has to be protected in the best way. Other legal barriers are the refrigerants used in the heat

[55] SOLID

[56] Ground-Source Heat Pumps - Overcoming Market and Technical Barriers; Report no. HPP-AN29-1; IEA Heat Pump Centre; Sweden; 2010.

pump: the HFCs (hydrofluorocarbons) presently in use have a high global warming potential, propane and ammonia are flammable and/or toxic, CO_2 has not the best properties to be used in hydronic heat distribution systems.[57]

II.4.3 Maintenance

Heat pump systems typically have a 10 year warranty. They can operate for 20 years or more, however they do require regular scheduled maintenance. A yearly check and a more detailed check by a professional installer every 3-5 years are sufficient. The installer should leave written details of any maintenance checks to ensure everything is working properly.[58]

II.4.4 Security

It is the owner's and installer's responsibility to read and comply with all safety information and instructions. Failure to heed safety information increases the risk of personal injury, property damage or product damage.

Installation and repair of units should be performed by individuals meeting the requirements of an "Entry Level Technician," at a minimum, as specified by the Air-Conditioning, Heating and Refrigeration Institute (AHRI). Attempting to install or repair units without such a background may result in product damage or personal injury.[59]

II.5 Financing

The main barrier for installing ground source heat pumps is most commonly the first cost barrier, and this first cost barrier is most commonly caused by drilling costs. Another first cost barrier can occur if other technologies like solar thermal or biomass are subsidized more than heat pumps. Customers will tend to take the technology with the lower investment not considering the final operation costs.[60]

A heat pump saves money due to the use of renewable energy. How much one can save with this kind of energy depends on several factors:

- The heat distribution system

[57] Ground-Source Heat Pumps - Overcoming Market and Technical Barriers; Report no. HPP-AN29-1; IEA Heat Pump Centre; Sweden; 2010.
[58] http://www.energysavingtrust.org.uk/Generate-your-own-energy/Ground-source-heat-pumps
[59] http://www.completeheating.ca/manuals/WGHP43.pdf
[60] Ground-Source Heat Pumps - Overcoming Market and Technical Barriers; Report no. HPP-AN29-1; IEA Heat Pump Centre; Sweden; 2010.

Under floor heating can be more efficient than radiators because the water doesn't need to be so hot.

- Fuel costs

  Most heat pumps are based on electricity. Therefore still energy costs occur.
- The old heating system

  If the old heating system was inefficient, lower running costs with a new heat pump are likely.
- Using the controls

  Learn how to control the system can get the most out of it.[61]

II.6 Large Scale geothermal heat pumps and solar thermal plants

The technological combination of solar thermal systems with heat pumps continues to be a highly topical subject in the context of sustainable heating concepts.[62]

The objective of combining solar thermal and heat pump units is to enhance the overall share of renewable heat applied. The combination of heat pumps with solar thermal systems lead to an increase of cost, size and complexity of the system assuring comfortable indoor conditions and the provision of domestic hot water. On the other hand such systems should lead to enhanced Seasonal Performance Factors of the overall system and to a reduction of the electrical energy consumption.

The reduction of space heating load of new and renovated buildings leads to a relative increase of the fraction of energy required for hot water preparation. This effect is of significant importance for the combination of heat pump systems with solar thermal collectors since especially during the summer months a large share of high temperature heat required for domestic hot water preparation can be produced by means of solar thermal. As a result, higher seasonal performance factors (SPF) of the overall systems can be achieved.

Many manufacturers of combined solar and heat pump systems advertise their products by declaring relatively high system performance factors, especially for such types of systems in which solar thermal unit and heat pump are connected in a serial way, i.e. in which the heat pump can be provided with a higher source temperature while the solar collector might be operated at lower return temperatures.

Results from field tests with solar combisystems have shown that the effective thermal performance of the heating systems in real operation depends significantly on the quality

[61] http://www.energysavingtrust.org.uk/Generate-your-own-energy/Ground-source-heat-pumps
[62] http://www.iea-shc.org/publications/downloads/2011-Loose_ISES_16179.pdf

of installation and cannot be derived directly from the sum of performance factors of the single components. Therefore, not only the performance of the solar thermal collector and the heat pump as such is important, but also the quality of the thermal insulation or the thermal stratification of the heat store. For combined systems, also hydraulics and controlling are of significant importance and the more complex a combined solar and heat pump system is built up the more important becomes the careful attention to a reasonable sequence of different possible modes of operation.

In addition to the traditional direct utilization of the solar energy delivered by the collectors for domestic hot water preparation and space heating, solar gains which are insufficient for direct use or surpluses, e.g. when the hot water storage tank is fully charged, can be used to support the heat pump and to actively regenerate the ground via the borehole heat exchanger. The following four modes of operation are possible:

- Direct use of solar energy with sufficient temperatures by charging the combistore for domestic hot water preparation and space heating.
- Solar support of the heat pump by raising the temperature level in the primary (brine) circuit.
- Solar thermal regeneration of the borehole heat exchanger while the heat pump is switched off and solar yield is available (with collector temperatures below 12°C).
- Use of solar heat stored in the ground during the first months the heat pump is operated again after the summer months.[63]

In order to get an overview of the actual market situation of different commercially available solar thermal and heat pump systems, by June 2011, a list of over 95 commercially presented systems within the EU could be collected.[64]

[63] http://www.iea-shc.org/publications/downloads/2011-Loose_ISES_16179.pdf
[64]http://www.solarthermalworld.org/files/OVERVIEW%20ON%20SOLAR%20THERMAL%20PLUS%20HEAT%20PUMP%20SYSTEMS.pdf

III. Chapter - Solar District Heating

Figure 22: District Heating in Austria [65]

District heating is a system that transfers and distributes heat from one or more heating plants to residential, commercial and industrial consumers for space heating, hot water heating or industrial processes. A district heating system consists of heat production units, which could be a combination of heating-only plants, combined heat and power production plants, waste heat recovery plants, peaking and standby heat plants, primary heat distribution networks, substations at the consumer connection points, end-users secondary networks and installations for space heating and domestic hot water.

III.1 Basic Information

The fundamental idea of Solar District Heating is to connect multiple thermal energy users through a piping network to environmentally optimum energy sources, such as combined heat and power (CHP), industrial waste heat and renewable energy sources such as biomass, geothermal and natural sources of heating and cooling.

This handbook has one of the main focuses on solar district heating. A lot of technical details are equal for solar plants used for SDH and huge solar plants in general.

Scale

- District heating can work at a range of scales from a big single building up to a city. It is most appropriate at the scale of a large neighborhood or city. Sometimes a smaller scheme is started and grows over time.

Energy generation

[65] http://www.solid.at/index.php?option=com_content&task=view&id=89&Itemid=129

- Energy can be generated via many different possibilities. Solar district heating is a non common, but already tested and innovative option to generate heat for district heating.

Space requirements

- This depends on the type of generating plant, location and fuel supply. The size needed for a biomass plant room will be larger than for the size needed for gas. The size for solar plants depends on the collector type.

Location

- The energy production area should be located as close to customers as possible to minimize the length of expensive pipe work.

Fuel supply

- Consideration should be given to fuel supplies, long-term costs, efficiencies and the ability to source the fuel close to customers. This is a big advantage of solar plants for energy generation due to the fact that sun energy is for free and no constant fuel costs exist.

Demand for heat

- The demand for energy is very special concerning the generation by solar plants. In general, demand should be as consistent as possible across a 24-hour period and between seasons. This will allow the plant to run as efficiently as possible. However in regard to solar plants, more demand at hot sunny days would be better, although this is only the fact under certain conditions.

Sizing the energy centre

- The boilers should be sized to serve the summer base load so that waste heat is minimized. Additional demand can be met by back-up boilers that are only switched on if necessary. In the field of solar energy, a biomass plant can be a very good combination possibility.

  If a thermal store is built into the network then the boiler or generating engine can be sized to meet a greater proportion of demand. Consideration should also be given to whether additional capacity will be needed in the future.

Thermal store

- This works in the same way as a domestic hot water tank and stores excess heat over a 24-hour period or even between seasons, which is a good option for solar plants.

Efficiency

- Boilers and generating engines operate most efficiently when there's a smooth, steady load.

Space requirements

- Trenches are needed to accommodate flow and return insulated pipes. Pipes vary in size depending on capacity. In sizing pipes, consideration should be give to whether additional connections will be needed in the future.

Load profiles

- Heat demand for buildings of different uses is not evenly distributed across the day or year. Homes generally have a morning and evening peak, while commercial users peak during the day. Winter heat demand is likely to be higher than in summer. This is not in favor of solar plants but it is possible through combination plants to find an ideal energy mix.

Mix of uses

- Heat engines operate most efficiently if they run for long periods of time. Consequently, connecting a mix of uses to a district heating network will stabilize the demand profile allowing the system to operate more effectively. With a stable demand profile the boiler or generating engine can be effectively sized and allowed to operate at full efficiency for more of its operational time.

Anchor loads

- Certain buildings, such as hospitals, hotels, swimming pools and civic buildings, have a large demand for heat, which tends to be steadier over 24 hours. These are called anchor loads and connecting these up can provide the starting point for a district heating network.[66]

III.2 Design and Techniqual Instructions

District heating is a system for distributing heat generated in a centralized location for residential and commercial heating requirements such as space heating or water heating.

[66] http://www.idea.gov.uk/idk/core/page.do?pageId=24549046

Solar district heating (SDH) plants are large-scale solar thermal technologies, supplying renewable and zero-emission heat from large collector fields into a district heating network.

Figure 23: Large Scale Solar Plant - District Heating[67]

Oversized dimensions are also common in many nets, where dimensioning often has been made with “rules of thumb”. In some cases installing over-sized pipes was justified, for instance if there are plans for a future extension of the distribution net. But there is a lot to gain by keeping the distribution net as slim as possible. It is certainly a good idea to at least keep the dimensions of the service pipes to a minimum (which wouldn’t affect a potential future extension), possibly in combination with booster pumps or hot water storage.[68]

District heating systems consist of feed and return pipes. After generated, heat is distributed to the network of insulated pipes. Usually the pipes are installed underground, but also systems with over ground pipes exist. Within the system heat storages can be installed to be prepared for out peak load demands.

The common medium used for heat distribution is water, but also steam is used, especially if concentrating or evacuated tube collectors are the energy generation basis. The advantage of steam is that it can also be used in industrial processes due to it´s higher temperatures. The disadvantage of steam is a higher heat loss due to the high temperature, because of the lower temperatures required.

Heat transfer oils are generally not used for district heating. At demand side the heat network is usually connected to the central heating of the dwellings. The energy transport medium used in the district heating system is not mixed with the water of the central heating system of the consuming facility. Heat exchangers are used to provide an indirect link from the district heating system to the property to be heated. This

[67] http://www.sunmark.com/news/district-heating-sonderborg-signed-contract

[68] IEA R&D Programme on “District Heating and Cooling, including the integration of CHP”; District heating distribution in areas with low heat demand density; Zinko, Bohm, Kristjansson, Ottosson, Rama, Sipila; 2008.

ensures that any problems that may occur in the existing heating system in the property do not affect the district heating system.
Large solar systems with collector areas greater than 100 m² and solar district heating systems with short and long-term heat storages are the most efficient approach to thermal use of solar energy and to reducing CO² emissions by forcing reductions in the use of fossil fuels.

III.2.1.1 System selection and dimension

The traditional way of planning heat distribution systems starts from a heat density map for the area to which heat should be provided. In such a map, the areas with high heat densities are easily identified and the extent of the central district heating network can be determined. In such a development process, areas with high and medium heat densities will initially be the main areas of interest for district heating.
A given area with larger thermal width will generally show lower pipe length and therefore lower connection costs. Hence, it is very important if planning new district heating areas with low line heat density to evaluate the possibility of achieving large thermal widths. An important factor is of course also the degree of connection, which should be as close as possible to one in order to get good district heating economy.

III.2.1.2 Hot-water tank and basic accumultaion technique

Solar-assisted district heating systems with short term heat storage can supply between 10 – 20 per cent of the total heat needed to heat rooms and hot water. The goal of solar assisted district heating with long-term heat storage is the use of solar heat stored in summer to heat rooms in winter.
Some different types of storage units have been developed for seasonal heat storage. The decision for a specific type largely depends on the geological and hydrological conditions at the chosen site.
A hot-water heating system with a tank less water heater usually achieves lower network return temperatures than storage tank systems. Because of the need to heat the return in the water system, these systems can achieve average network return temperatures between 50°C and 55°C. It has been experienced that lower temperatures can only be achieved if heat exchangers in each individual building are improved to achieve the lowest possible return temperature to the net.
Although the domestic hot water (DHW) demand only represents a relatively small part of the total energy load, there can be large instantaneous heat loads if hot water is used by customers. Tanks will make it possible to use smaller distribution pipes.

In summertime, when there is no heating demand, the district heat can be pulsed out once or more times a day to load the hot water tanks and the distribution net can be "off" the remaining time. This will reduce heat losses in the distribution net, but the cost of installing a hot water tank is substantial and there will also be some heat losses from the tank.[69]

III.2.1.3 Techniqual plant application

A district heating system consists of the following parts:

Connection system

Primarily connected to district heating – useful if only a proportion of customers can be connected from the beginning, but it can be expected that more customers will join in the future.

Secondary connection by means of main substation – suitable if the group of costumers is defined and no further connection expected. Can normally be designed with lower pressure and lower temperature. Alternatively, the secondary system can be connected directly via a thermal or hydraulic shunt.

Pipe system

- Regarding the capacity of the network
- Eventually a booster pump
- Eventually a hot water store
- the best available and lasting insulation
- Investigate if 3-pipe or 4-pipe systems could reduce costs.

Trench area

- twin pipes
- heavy traffic
- drainage

Trench length

- house-to-house routing

Choice of digging method

[69] IEA R&D Programme on "District Heating and Cooling, including the integration of CHP"; District heating distribution in areas with low heat demand density; Zinko, Bohm, Kristjansson, Ottosson, Rama, Sipila; 2008.

– routing so that the majority of the trench is in easily excavated ground, avoiding asphalt areas

Pipe Installation

– flexible pipes with suitable lengths and press-fittings for joining pipes, flexible pipes can be in copper, steel or PEX
– design pipe installations without the need for preheating[70]

III.2.1.4 Heat distribution – pipe connections

There are different pipe technologies used for SDH – function and connection.

- Traditional single pipe connection

Most district heating systems have been built with two single pipes. One of them as a supply pipe and one of them as a return pipe. The most common piping material is steel, with polyurethane insulation and a high density polyethylene jacket.
The main advantage of single pipes is that it is a well-known technology which leads to reliable operation.

- Twin pipe connection

The heat losses from twin pipes are lower than from single pipes with the same dimensions. Twin pipes can be made of steel, copper or PEX with the feed and return pipe in the same jacket. As an advantage, twin pipes in small to medium dimensions are usually less expensive to install than single pipes. Though the technology for twin pipes is relatively new, it is now well-known and as available as single pipe systems.
Most of the time distribution pipes are placed under a street and service pipes are drawn from there to the houses. However also house-to-house connections are possible and in this way distribution pipes are drawn closer to houses. The service pipes are also quite short. By connecting house to house the total length of the network can be reduced and this reduces both, installation costs and heat losses.[71]

III.2.1.5 Heating calculation

The comparison of solar heat costs shows that the cost-benefit ratio for solar assisted district heating is greater than that for small systems. This is due to the lower area-related system costs.

[70] IEA R&D Programme on "District Heating and Cooling, including the integration of CHP"; District heating distribution in areas with low heat demand density; Zinko, Bohm, Kristjansson, Ottosson, Rama, Sipila; 2008.
[71] IEA R&D Programme on "District Heating and Cooling, including the integration of CHP"; District heating distribution in areas with low heat demand density; Zinko, Bohm, Kristjansson, Ottosson, Rama, Sipila; 2008.

Compared with conventional heating systems, low-temperature heating systems can achieve lower return temperatures and higher yields of solar utility heat. Because the development of low-temperature heating systems involves higher costs, much depends on the efforts of builders and planners. However, achieving the lowest possible net return temperature to achieve the highest possible yield of solar utility heat can only be effected by means of constant project monitoring that integrates and incentivizes all those involved in the project, and especially the companies carrying out the work.

District heating networks are long-term projects with long-term paybacks. They are unlikely to be suited to short-term investors.

The biggest cost of district heating is the investment required to establish the pipe network. The payback period for this can often exceed the lifetime of the boiler or combined heat and power (CHP) engine. However, this does not mean that such schemes are not viable. Once established, the pipe network will remain a working asset for many decades. Boilers and CHP engines can be replaced.

Heat losses from heat exchangers and hot water tanks are regarded as losses only when there is no heating demand in the house, i.e. during the summer time. The remaining time, it is assumed that the building benefits from the heat lost from equipment. Note that these heat losses are relatively small if compared to pipe heat losses.[72]

III.2.1.6 Benefits

Local communities have opportunities to financially benefit from a solar district heating network. District heating has a growing customer base, but a focus on customer service and competitive pricing is considered as important.

Solar energy causes no CO_2 or other green house emissions and has no operating costs for fuels. For costumers it can reduce CO_2 emissions in older buildings where other forms of energy efficiency, such as external installation, are not possible.

The pipe work, if installed well, will last for many decades. This means that fuel sources can be changed from fossil fuels to renewable energy as the economic viability of the latter improves.

It has to be said that this technology is much better suited to urban areas than sub-urban or rural environments.

[72] IEA R&D Programme on “District Heating and Cooling, including the integration of CHP”; District heating distribution in areas with low heat demand density; Zinko, Bohm, Kristjansson, Ottosson, Rama, Sipila; 2008.

III.3 Installation

The standard in many countries for systems of small dimensions today is the use of flexible service pipes, available in rolls of 50-100 meters. Casings can be corrugated or smooth. Installation is often carried out in a combination of digging and "shooting" the service pipes.[73]

The optimum design of the DHS is of course very important. It is difficult to give general recommendations for the design; however, the network should be designed in such a way that the available pressure difference for the supply area is fully utilized. In this respect future extensions of the DHS must be taken into consideration.

III.4 Operation

Clients receive the district heat in the substation, which includes the heat exchangers for heating, service water and possibly a heat exchanger also for air conditioning, control devices, pumps, expansion and safety equipment, thermometers and manometers, shut-off valves and energy metering. Substations are industrially manufactured units. Clients acquire their district heating equipment and the related installation work from heating contractors or, as comprehensive deliveries, from district heating suppliers. Heat is used in buildings for space heating, for providing hot tap water and for air conditioning. Also cooling of buildings by using district heating supply water in absorption chillers has been introduced lately.

III.4.1 Control

Damage to the system (leaking joints, broken pipes or parts) can cause distribution losses, necessitate costly repairs as well as leading to inconvenience for customers.[74]

III.4.2 Monitoring

Supply of district heat is very reliable. On an average, in large DHS operation interruptions resulting from damages in the district heat network and the consequent

[73] IEA R&D Programme on "District Heating and Cooling, including the integration of CHP"; District heating distribution in areas with low heat demand density; Zinko, Bohm, Kristjansson, Ottosson, Rama, Sipila; 2008.
[74] IEA R&D Programme on "District Heating and Cooling, including the integration of CHP"; District heating distribution in areas with low heat demand density; Zinko, Bohm, Kristjansson, Ottosson, Rama, Sipila; 2008.

repair work leave the individual client without heat as an average for only one hour a year. Thus, the reliability of supply in district heating is nearly 100%. District heating is most of the time also operation and maintenance free for clients – as the maintenance is included in the fee paid by the clients.

III.5 Financing

The two main investments in a DHS are the heat production plant and the network. The heat production plant is a single investment; the cost of it depends on the total annual amount of heat load of the area. The investment in the pipe system, on the other hand, is a question of the length of the pipe network within the area of the heat supply and therefore is dependent on two dimensions: Thermal length and thermal width. Therefore, it follows that the costs of the distribution network can vary appreciably for different network geometries and type of systems.

Very often, the core heat densities (expressed in annual heat demands) would be larger than 50 kWh/m^2/year, which normally is on the safe side of being a profitable investment in district heating. In most cases, the heating utility is not only interested in delivering heat at the best profit but also in delivering as much heat as possible as long as the marginal profit is positive. Therefore, the utility also examines the areas around the thermal core, investigating the planned and probable development of these areas and thus designating further areas to which the district heating should be delivered. These areas are usually areas with lower heat demand density and it is up to the skillfulness of the developer to connect these areas in such a way that the investment will be paid back in reasonable time.

If connecting new housing areas to an existing district heating network, only marginal costs for investments in pipe system and marginal energy costs have to be included. This is the reason why it can be profitable to connect areas with low heat densities that normally would not be profitable if a completely new system has to be built.

The following criteria for a successful district heating connection in areas with low heat demand were pointed out:

- A market situation that allows a competitive district heat price.
- High use of district heat/house.
- Low marginal heat generation costs.
- Low relative heat distribution losses.

- Low service and maintenance costs.
- Low demands on rate of return from the owners of the district heating company.
- Low investment costs per house by means of e.g. short pipe lengths per house.

Besides on the line heat density, the profitability depends on the total heat load of the area. Bigger loads result in lower relative heat losses and thus increased profitability. The investment costs represent a considerable proportion of the total supply cost. When maximizing the difference between revenues and costs, the focus should be on both low marginal heat generation costs and low heat distribution investment. Low heat generation costs cannot alone offset a high heat distribution investment and vice versa.[75]

There are several suggestions on how to reduce costs for distribution systems in areas with low heat density. Since the major expenses, especially for low-density district heating, are costs for installation and/or heat losses, most solutions focus on lowering these costs. To lower installation costs, less expensive materials or more cost effective systems can be used, sometimes at the expense of increasing the heat losses. With better pipe insulation, heat losses are reduced, but this can significantly increase installation cost.

A great part of the installation cost for a DH network is the excavation cost. Traditionally the trench is about 50 cm deep. If the pipe is going to be situated under a road, there will be a need to protect the piping from being damaged by traffic. Pipes in more undisturbed areas, though, can be placed at shallower depths, which will reduce the excavation cost substantially. The heat losses from these pipes will be slightly higher, though.[76]

III.6 Example for application spectrum of plants – District Cooling

District Heating can also be used for air conditioning, greenhouse warming, swimming pools, ground heating etc. Beside all the possibilities, the number of combination plants increases.

Another load, well suitable for district heating systems and especially contributing to times with lower loads, is air-conditioning. The conventional way to use air-conditioning countries is to use electrically driven compression chillers. Such air-conditioning

[75] IEA R&D Programme on "District Heating and Cooling, including the integration of CHP"; District heating distribution in areas with low heat demand density; Zinko, Bohm, Kristjansson, Ottosson, Rama, Sipila; 2008.
[76] IEA R&D Programme on "District Heating and Cooling, including the integration of CHP"; District heating distribution in areas with low heat demand density; Zinko, Bohm, Kristjansson, Ottosson, Rama, Sipila; 2008.

systems can be manufactured in any size from those suitable for small detached houses up to big office complexes. Another way, more interesting for the district heating market, is district cooling.

District cooling can be supplied either by a separate cooling network, as it is increasingly the case by means of distributed absorption chillers fed by the district heating net. Usually (for economic reasons), heat driven air-conditioning applications are limited to chiller capacities above 100 kW per unit, leaving the market for small applications to the electrically driven systems.[77]

IV. Chapter - Constructed Plants

IV.1 Large Scale Solar Thermal Plants for District Heating

Solar district heating plants, as expressed above, are based on large-scale solar thermal plants supplying renewable, zero-emission heat from large collector fields via district heating networks to residential or industrial areas. The following abstracts give examples of installed plants connected with district heating networks.

IV.1.1 Hillerod District Heating – Denmark

Hillerød Municipality has built a 3,019 m² solar heating plant - complete with a technical centre. The solar heating plant is an integrated part of the district heating in Hillerød Municipality, supplying energy for heating and hot water to homes in the local area.

The solar collectors are placed on a baffle wall towards the 'Herredsvejen'. The district heating in this area also uses pellets, whereas the remaining part of Hillerød (and Farum) uses natural gas from a major CHP plant in Hillerød. Via a finger touch screen it is possible to get information about the solar heating plant and the part of the district heating network, which is in contact with the solar heating plant. 600 households and approximately 1,260 inhabitants are connected to the plants.

The main project data are:[78]

- Net area (operative): 3,019 m²

[77] IEA R&D Programme on "District Heating and Cooling, including the integration of CHP"; District heating distribution in areas with low heat demand density; Zinko, Bohm, Kristjansson, Ottosson, Rama, Sipila; 2008.
[78] http://www.arcon.dk/referencer%20v2/Fjernvarme%20decentralt/Hillerod.aspx?sc_lang=en

- Number of solar collectors: 240
- Storage capacity: DH network
- Calculated peak capacity: 2.1 MW
- Calculated annual production: 1,500 MWh
- Calculated production/m²: 497 kWh/m²
- Expected share of production at power station: 20%

IV.1.2 District heating plant/AEVG Graz - Austria

Since the start of construction in 2006, the most extensive solar system in Central Europe has been realized on the premises of the “Abfall Entsorgungs- und Verwertungs GmbH (AEVG)” plus the adjoining district heating power station of Graz-Süd, currently encompassing a collector area of 4,960.5 m²/53,394 ft². All collector areas were mounted on five separate industrial roof areas. This, as well as the necessity of undertaking the installation in several phases, presented a particular challenge for planning and installation. The strategy to expand the system with numerous areas at the district heating power station has already moved forward to an advanced stage.

Figure 24: District heating plant/AEVG Graz - Austria[79]

The main project data are: [80]

- Collector area: 4,960.5 m²/53,394 ft². (status: 04/11/2009)
- Projected overall completion: 6,903 m²/74,303 ft²
- Deployment of high-temperature collectors
- Yield with the current construction: approx. 2,200 MWh/year
- Commissioned in 2007-2008

[79] http://www.solid.at/images/stories/pdf/ref_e_%20aevg_graz.pdf
[80] http://www.solid.at/images/stories/pdf/ref_e_%20aevg_graz.pdf

IV.2 Heat Pumps combined with Large Scale Solar Thermal Plants

A growing number of concepts for combining solar thermal systems and ground-coupled heat pump systems are proposed by companies and system manufacturers.
The following abstracts show examples, where combined systems are installed.

Sunstore 3 and 4 are two projects, which combine solar thermal plants and heat pumps to support a district heating network. Beside these two renewable energy sources, others are integrated depending on the project.

IV.2.1 Sunstore 3 – Dronninglund - Denmark

Smart solar district heating is developing in Denmark. Smart solar district heating combines large solar collector fields, heat pumps, seasonal heat storage and CHP units. The overall concept of Sunstore 3 is it to use solar heating in combination with a large scale thermal storage and a heat pump. The collector area is planned to be approx. 35,000 square meters, a storage volume of 60,000 m^3 and a heat pump with 3 MW effect.
Combining the technologies makes high solar fractions attractive also from a cost benefit point of view. The solar fraction in these systems will be 30 - 50 %. The technologies work together and benefit from each other.[81]

IV.2.2 Sunstore 4 – Marstal - Denmark

In Denmark, the project SUNSTORE 4 supports the further development of the renewable energy supply system for the community of Marstal. The expansion of the solar plant , a new pit heat storage, heat pump and a biomass boiler is part of the innovative cost efficient energy supply system.
The aim of the project is to demonstrate a large scale innovative, cost-effective and technically 100 % sustainable renewable energy system. Marstal District Heating's nearly 1,500 members will now receive 55% of their energy from the solar production and 45% of their energy from locally produced biomass (energy willow). The project also includes a heat pump which is "moving" energy to the energy storage and a turbine, a so called ORC (Organic Rankine Cycle) which is an electricity-producing device that can use the energy from the flue gas produced in the biomass boiler.

[81] http://www.solar-district-heating.eu/NewsEvents/News/tabid/68/NewsId/144/Smart-solar-district-heating-developing-in-Denmark.aspx

The project involves the following:

- Expansion of the existing 18,365 m^2 solar plant with 15,000 m^2 of solar collectors
- a 4 MW biomass boiler with a built-in ORC power producing unit
- a 1.5 MW heat pump
- a 75,000 M3 pit heat storage [82]

The project has been a really innovative project, presenting the following:

- new control mode in the form of variable flows, giving a slightly better performance, a 80 % reduce in power demand for pumping and meeting the demand for temperatures in a district heating network
- test of two new types of heat storages, one with gravel water and one pit heat storage. The pit heat storage showing promising results in the terms of operating, low heat losses etc.[83]

The total budget for the project is 15,1 mill. Euros. From the EU, the project has achieved 6,1 mill. Euros in grants. The participating partners contribute to the project with 0,4 mill. Euros.[84]

The following picture shows the Sunstore 4 collector field:

Figure 25: Sunstore 4[85]

[82] http://www.solar-district-heating.eu/NewsEvents/News/tabid/68/NewsId/49/Marstal-Solar-District-Heating--EU-supports-the-extension-to-a-100-renewable-energy-system.aspx
[83] http://www.solarge.org/index.php?id=1235&no_cache=1
[84] http://www.solar-district-heating.eu/NewsEvents/News/tabid/68/NewsId/49/Marstal-Solar-District-Heating--EU-supports-the-extension-to-a-100-renewable-energy-system.aspx
[85] http://www.solarge.org/index.php?id=1235&no_cache=1