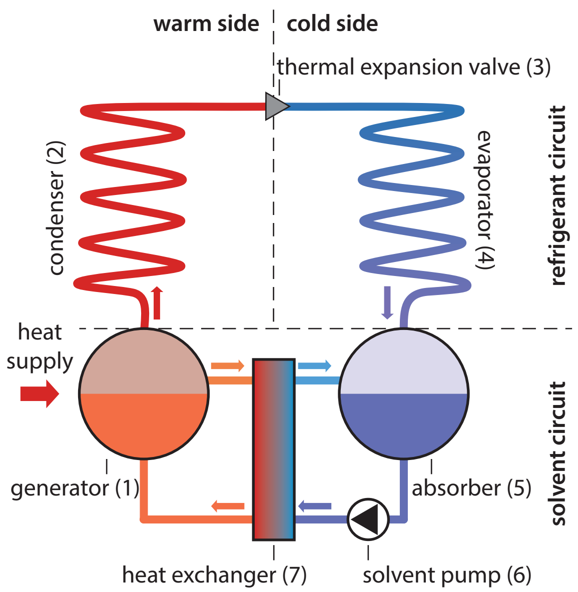

Figure 22.9: Illustrating an absorption cooling circuit. The numbers are explained in the text.

is reduced allowing it to evaporate. In that version, the whole system operates at one pressure.

The last option of cooling that we discuss is that of solar *desiccant cooling*, illustrated in Fig. 22.10. In such a system, air is dried when passing through a desiccant, like silica. Next, the air passes a heat exchanger where a large fraction of the heat is already taken out of the air stream and transported to the outgoing air stream. Then, water is sprayed into the air. As it evaporates, the air is cooled and humidified, such that it guarantees optimal interior conditions. Air that leaves the interior is first preheated passing the heat exchanger and then heated up further using a solar collector. The hot air streams through the desiccant. Hence, the desiccant is dried and can be reused for adsorbing humidity.

22.3 Concentrated solar power (CSP)

In this section we take a closer look at *concentrated solar power* (CSP), where high temperature fluids are used in steam turbines to produce electricity. Much of the early attention on CSP systems was on small-scale applications, mainly for water pumping. However, since about 1985 several large-scale power systems with a power output up to 80 MW have been built.

The CSP technology is especially interesting for desert regions, where almost all the solar radiation is incident as direct radiation. As illustrated in Fig. 22.11, these systems consist basically of a collector, where the solar energy is absorbed, a storage system, usually water or phase-change storage, a boiler that acts as a heat exchanger between the operational fluids of the collector and the heat engine, and the heat engine itself, which

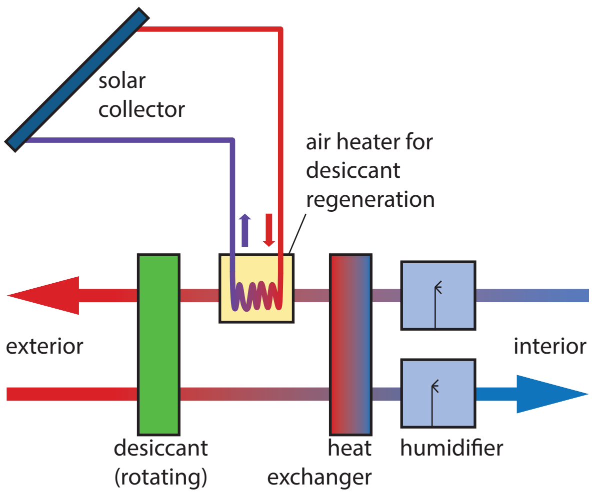

Figure 22.10: Desiccant cooling.

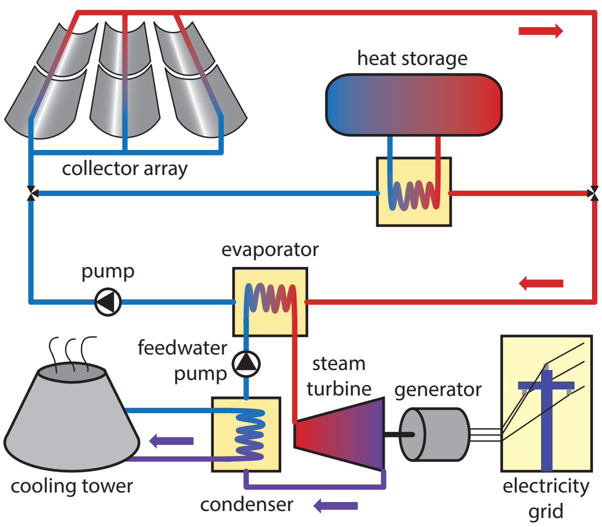

Figure 22.11: Sketching a solar thermal electric power system.

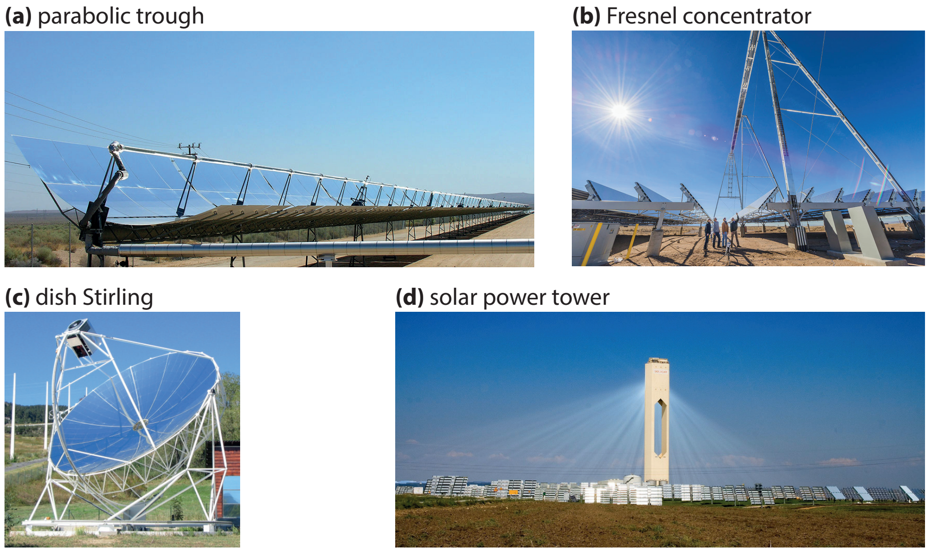

Figure 22.12: Different types of concentrators used in CSP systems [187–190].

converts the thermal energy into mechanical energy. In large CSP plants, the heat engine is a *steam turbine*, where the energy stored in the hot steam is partially converted to rotational (*mechanic*) energy as the steam expands along the turbine. This thermodynamic process is called *Rankine cycle*, called after the Scottish engineer William John Macquorn Rankine (1820-1872).

The mechanical energy can be further used to drive an electrical generator. The collectors are built as concentrator systems, in order to reach the high temperatures of several hundreds of degree Celsius, which are required to operate the heat engine.

One problem of CSP systems is that the efficiency of the collector diminishes as its operating temperature rises, while the efficiency of the engine increases with temperature as we already have seen when discussing the thermodynamic efficiency limit in Section 10.1. Hence, a compromise between the two has to be found when choosing the operating temperature. Current systems have efficiencies up to about 30% [186],

Now we will take a closer look at the solar concentrator system, illustrated in Fig. 22.12. First concepts already were developed by the ancient scientist Archimedes (287 BC - 212 BC); Leonardo da Vinci (1452 - 1519) designed some concentrators. Different types of concentrators produce different peak temperatures and hence thermodynamic efficiencies, due to the different ways of tracking the sun and focusing light. Innovations in this field are leading to more and more energy efficient and cost effective systems.

The most common concentrator type with about 96% of all installed CSP installations is the *parabolic trough* [191], which consists of a linear parabolic reflector that concentrates the light onto an absorber tube located in the middle of the parabolic mirror, in which the working fluid is located. The fluid is heated to 150 to 350 degrees Celsius, and then used in a heat engine. This technology is far developed, well-known examples are the Nevada Solar One power plant and the power plant that the Plataforma Solar de Almeria (PSA) in

Spain.

Another concentrator concept is that of *Fresnel concentrators*, where flat mirrors are used, as illustrated in 22.12. Flat mirrors allow more reflection in the same amount of space as parabolic mirrors, reflect more sunlight, and are much cheaper.

The *dish Stirling* or dish engine system consists of a parabolic reflector that concentrates light to the focal point, where the working fluid absorbs the energy and is heated up to about 500°C. The heat is then converted to mechanical energy using a *Stirling engine*. With about 31.25% efficiency demonstrated at Sandia National Laboratories, this design has currently the highest demonstrated efficiency [186].

The last concentrator type is that of *solar power tower plants*. Here, an array of dual-axis tracking reflectors, commonly named *heliostats*, are arranged around a tower. There the concentrated sunlight hits a central receiver, which contains the working fluid, which can be heated to 500 or even 1000°C. Examples for solar power towers are Solar One and Solar Two in the Unites States and the Eureka project in Spain [191].

CSP systems can be combined with heat storage, such as phase-change materials discussed in Section 22.2. Hence, CSP systems can operate during day *and* night.

22.4 Exercises

22.1 During the winter, the inside of an average house is maintained at 20°C, while the outside temperature is 0°C. Assuming that the only mechanism of heat transfer is conduction, the walls are 10 cm thick and the heat conductivity of the walls is 0.5 W/(Km).

(a) Calculate the heat flux from the room to the surroundings in W/m^2.

(b) To reduce the heat loss through the walls, the material should be changed to an insulator material. The new overall conductivity will be 0.1 W/(Km); the thickness of the wall is maintained. Calculate the reduction of the heat flux throughout the walls in compared to the initial case.

22.2 What is the most important heat transfer mechanism in domestic solar water heating systems?

(a) Conduction

(b) Convection

(c) Radiation

(d) All of them are equally important.

22.3 What does it mean when the water heating system is in an open loop?

(a) The solar water heating system is used for heating instead of power production.

(b) The fluid that is heated in the collector is directly used to cover the heating demand.

(c) The flow of the collector liquid is caused by natural convection.

(d) The fluid of the collector liquid is caused by forced convection.

22.4 A solar collector with an area of 1.5 m^2 is installed on the rooftop of a house. Assume that the radiative energy arriving from the sun is 1000 W/m^2. The collector reflects 10% of the energy arriving on its surface. Also, the collector is not perfectly insulated, and losses occur. The collector has a heat transfer coefficient h of 2 $Wm^{-2}K^{-1}$. The side areas of the collector