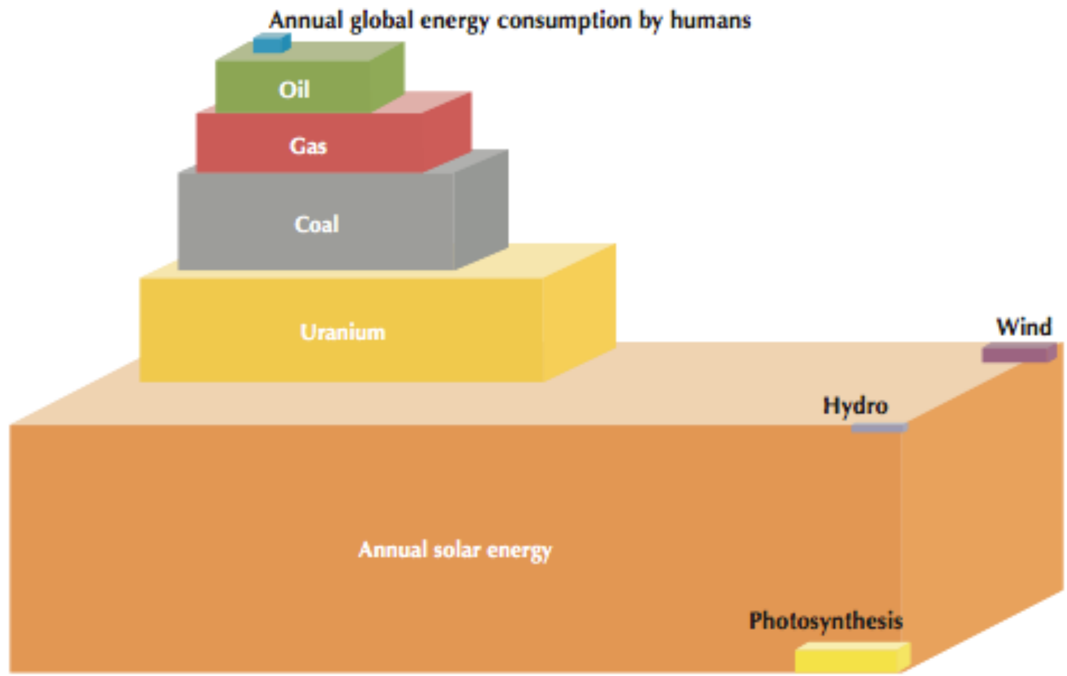
Non-Photovoltaic Solar Energy Harvesting

- Solar Chimney
- Solar Greenhouse
- Biomass
- Solar Heat
- Passive Solar
- Solar Water Heater
- Solar Oven
- Desalination
- Solar Towers
- ZnO Redox Reaction
- Biomass/syngas
- Solar Thermolysis
- Solar Electricity & Electrolysis
- Algae Tower

Figure 2.1 **Total energy resources**



Source: National Petroleum Council, 2007, after Craig, Cunningham and Saigo (republished from IEA, 2008b).

Key point

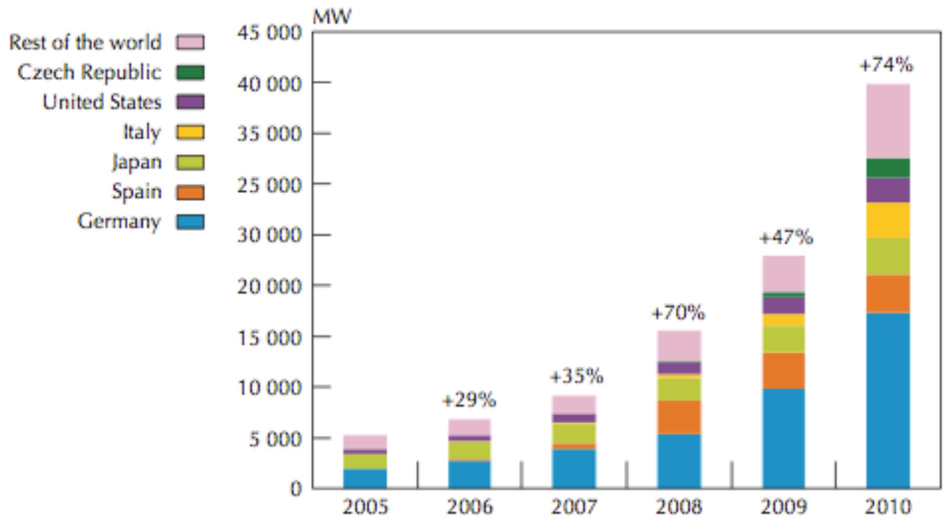
Solar energy is the largest energy resource on Earth – and is inexhaustible.

Solar Energy Perspectives

Solar Energy Engineering

Solar Energy Projects for the Evil Genius

Figure 3.1 **Global cumulative PV capacities by 2010**



Sources: IEA PVPS, BP Statistical Report, BNEF.

Key point

Installed PV capacities show a steep growth curve.

Solar Green Houses in India

(http://www.youtube.com/watch?feature=endscreen&v=8xFe91lMRH0&NR=1)

Tomato Green House in Kenya (http://www.youtube.com/watch?v=obsLwew-NT0)

Solar Desalination/Water Purification

Solar Still Video (http://www.youtube.com/watch?v=GrPRnaS449w)

Solar Desalination/Water Purification

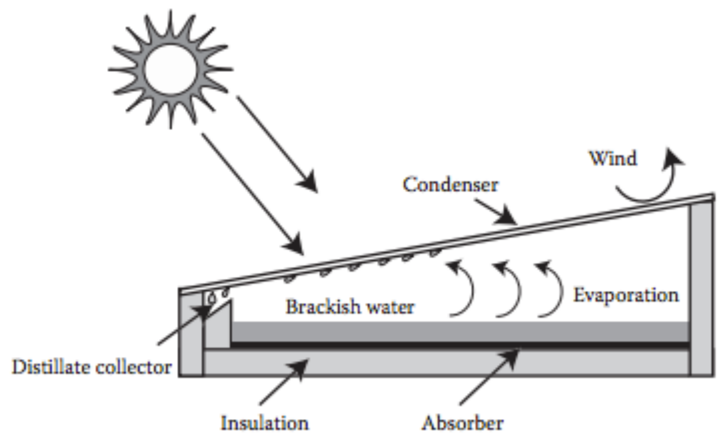


FIGURE 4.26 Basic operation of a solar still.

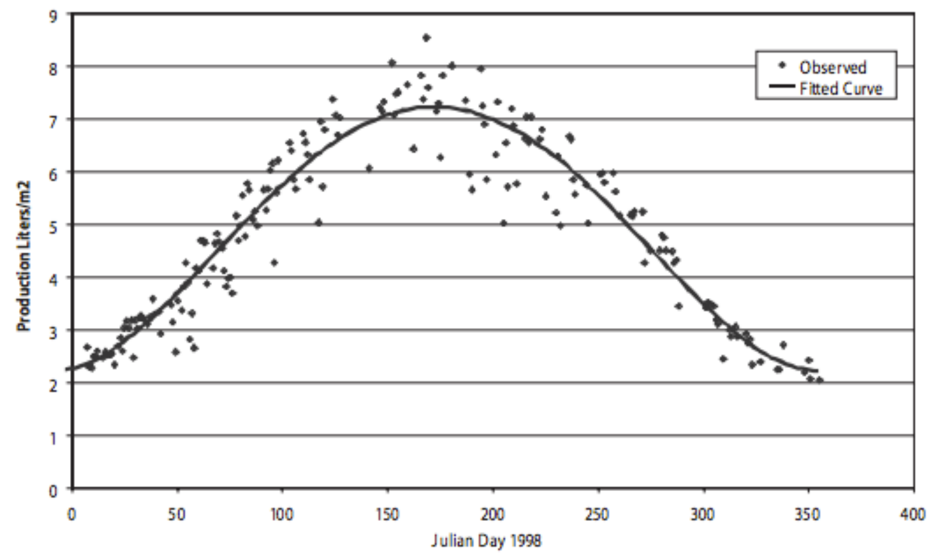


FIGURE 4.27 Measured basin solar still annual performance in Las Cruces, New Mexico, on a square-meter basis (Zachritz, 2000).

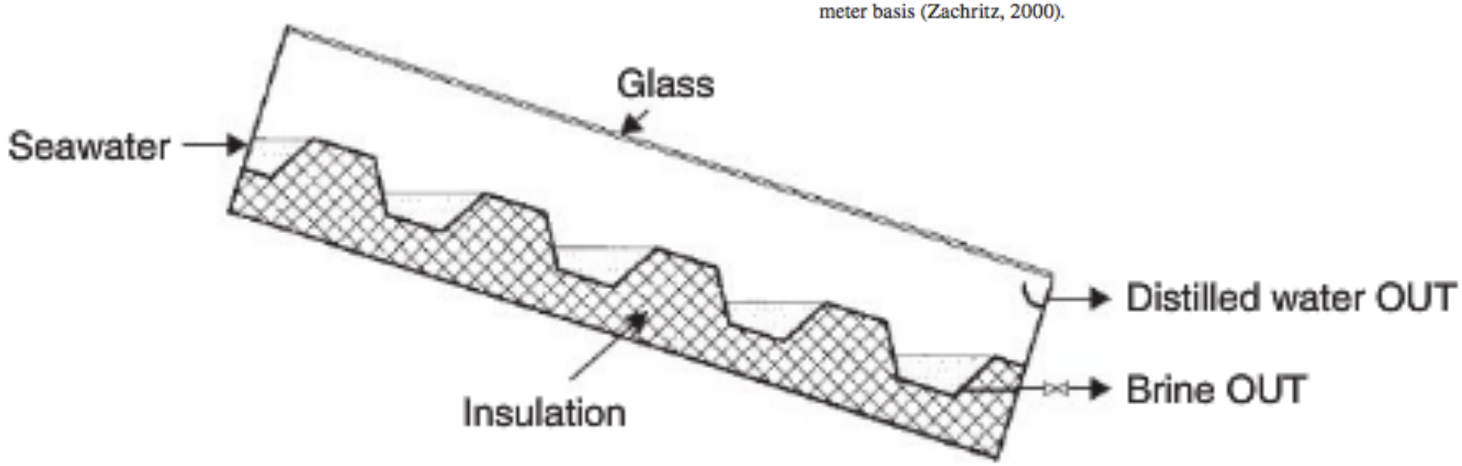


FIGURE 8.3 Schematic of a cascaded solar still.

Solar Desalination/Water Purification

TABLE 4.7
Sandia National Laboratories Still-Water Quality Test Results (Zirzow, SAND92-0100)

Sample type	13% Salinity feedwater	Distilled water (13% case)	16% Salinity feedwater	Distilled water (16% case)
Calcium (total)	340	1.5	371	<0.10
Iron (total)	0.27	<0.05	0.48	<0.06
Magnesium (total)	2.1	2.1	<0.005	<0.005
Manganese (total)	0.04	<0.02	0.07	<0.02
Ammonia as N	<0.1	0.1	<0.1	<0.1
Chloride	19,000	<1.0	25,000	2.6
Fixed solids	32,000	<1.0	41,000	31
Nitrate as NO_3	34	0.1	26	<0.1
Nitrate as NO_2	0.013	<0.01	0.02	<0.01
TDS	36,000	<1.0	48,000	<1.0
Volatiles and organics	4,200	<1.0	6,000	13

TABLE 4.6
Microbial Test Results for Solar Stills

Sample	Volume tested ml	Total organisms per liter
Supply	50	16,000
Distillate	1,000	4
E. coli seed		2,900,000,000
Distillate	750	11 (No *E. coli*)
E. coli seed	—	7,500,000,000
Distillate	1,000	18 (No *E. coli*)
Supply	10	24,000
Distillate	1,000	13
Supply	1	12,000
Distillate	1,000	6

Source: New Mexico State University, 1992.

FIGURE 4.28 SolAqua solar still village array under test at Sandia National Laboratories.

Solar Desalination/Water Purification

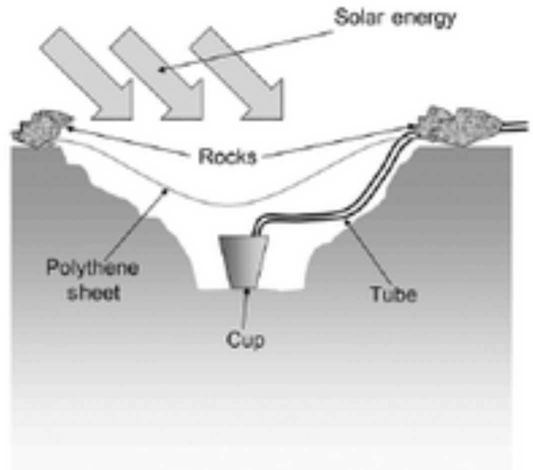


Figure 7-4 *Diagram of a pit solar still.*

Figure 7-2 *Demonstration solar still.*

Figure 7-5 *A solar still in operation.* Image courtesy © U.S. Department of Agriculture—Agricultural Research Service.

Solar Desalination/Water Purification

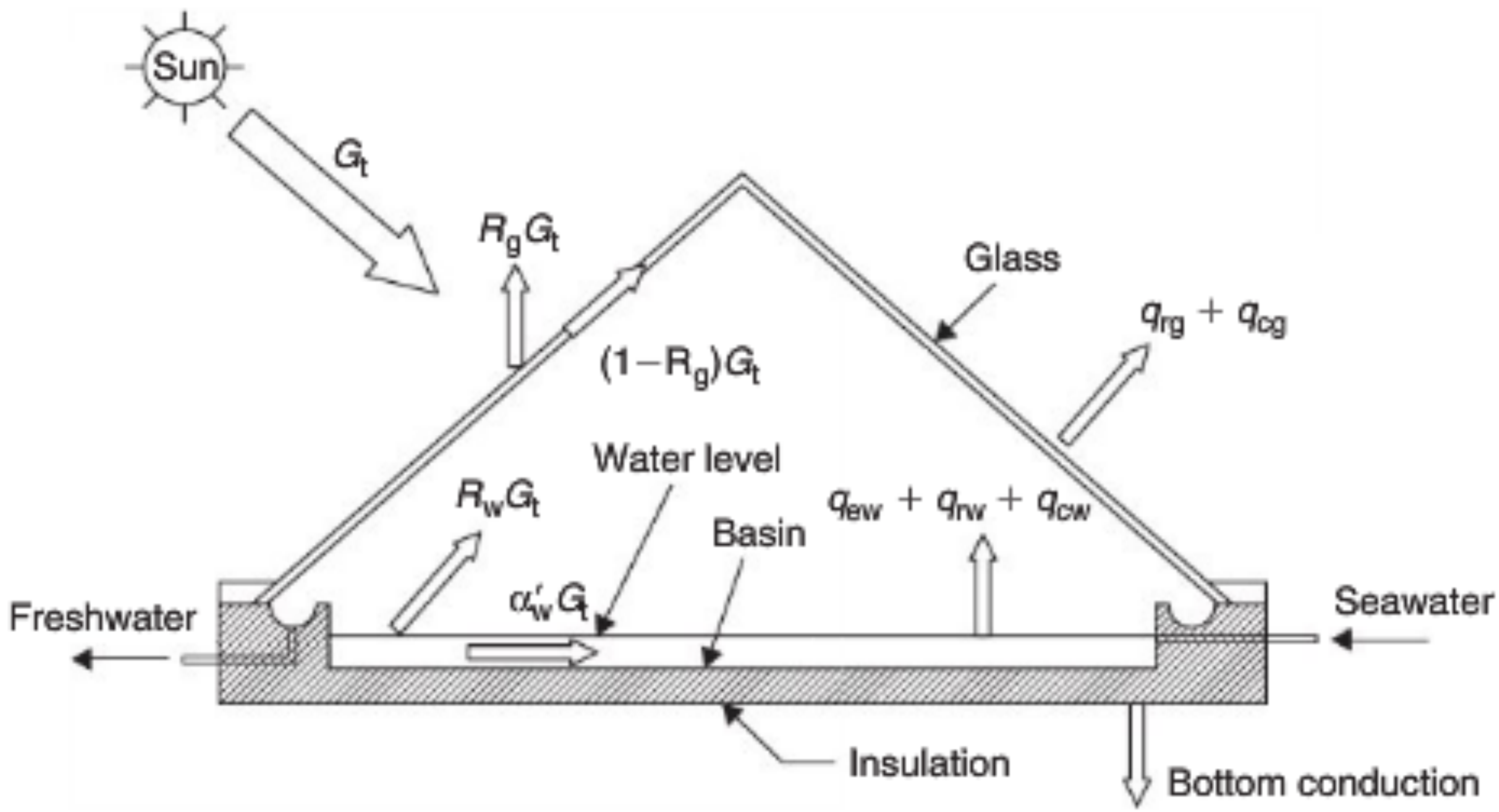


FIGURE 8.1 Schematic of a solar still.

Solar Desalination/Water Purification

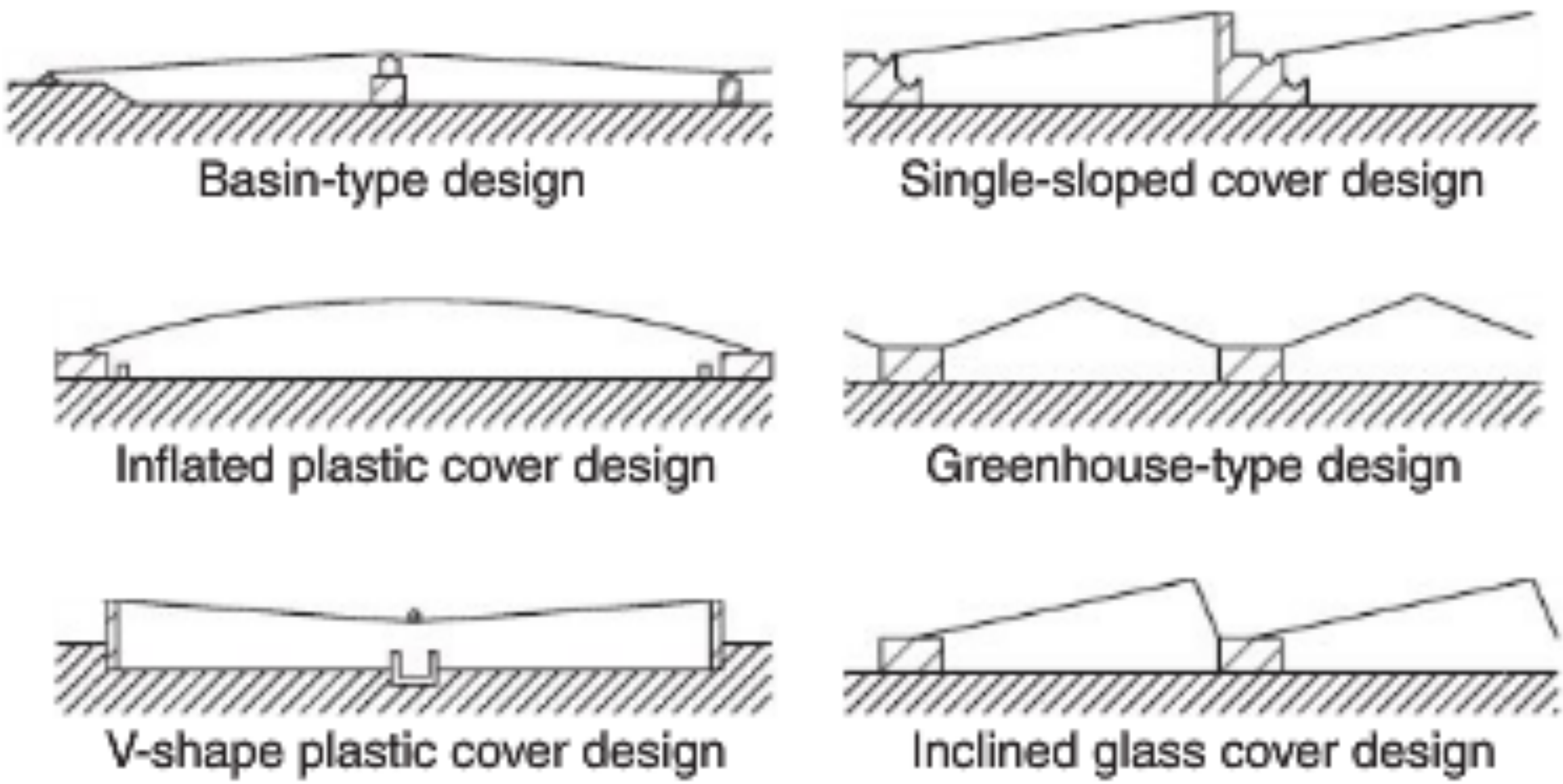


FIGURE 8.2 Common designs of solar stills.

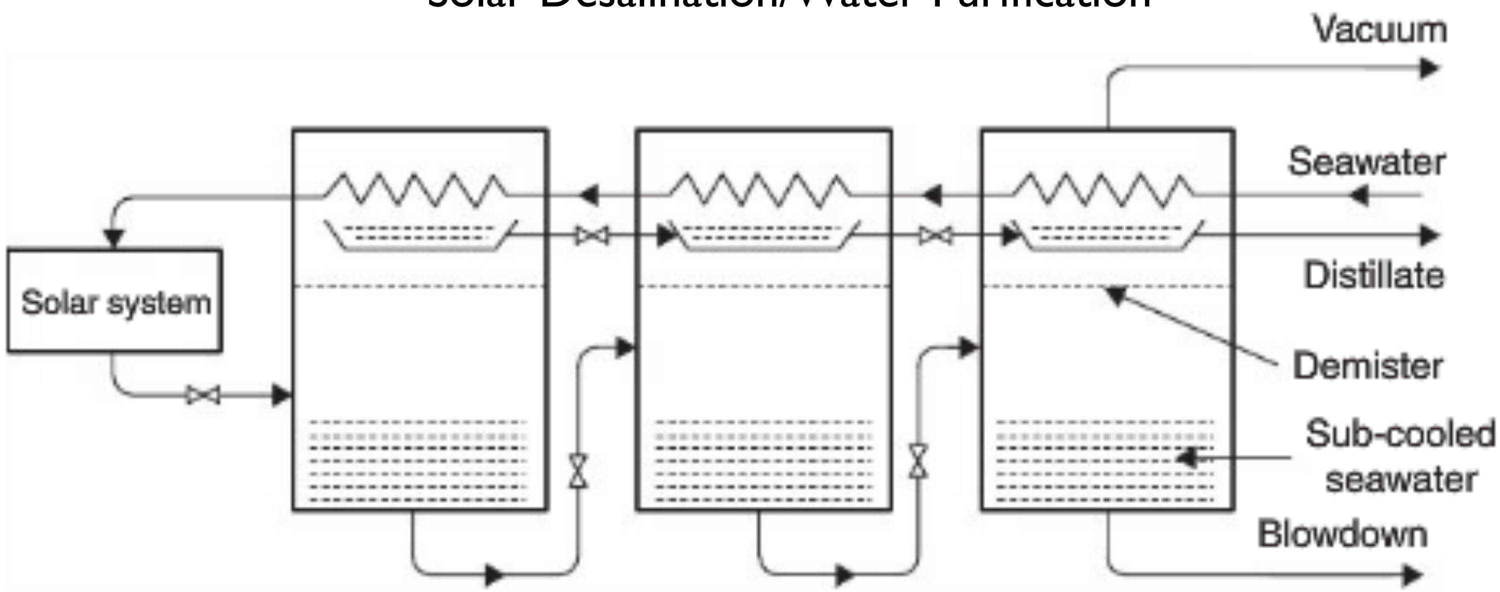


FIGURE 8.4 Principle of operation of the multi-stage flash (MSF) system.

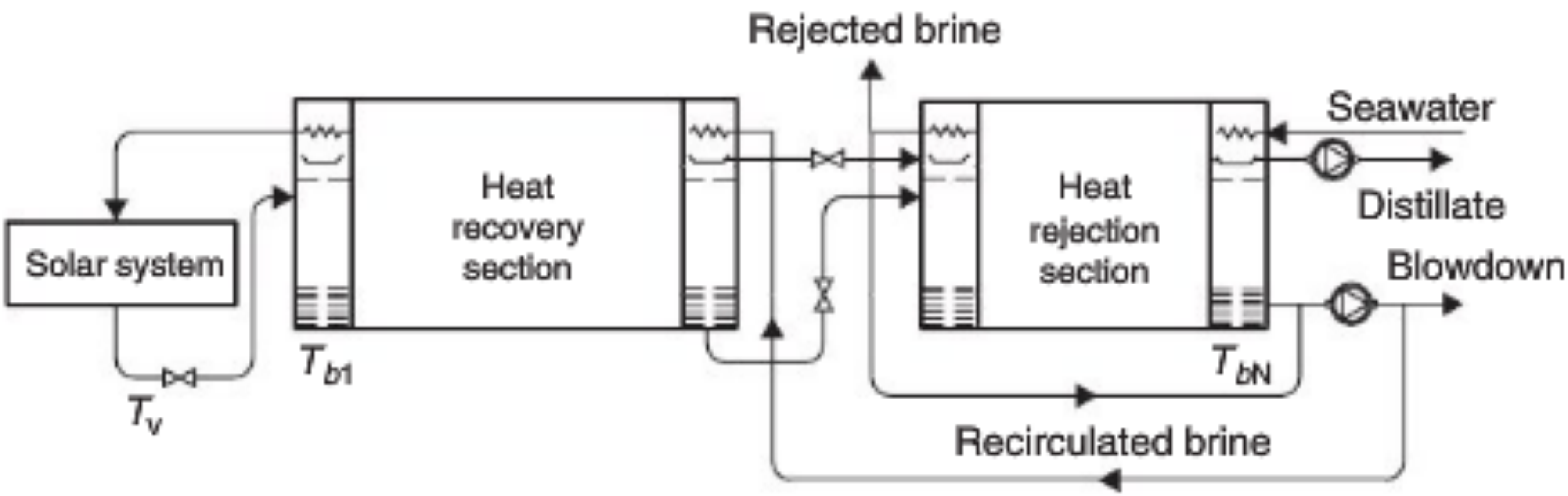


FIGURE 8.5 A multi-stage flash (MSF) process plant.

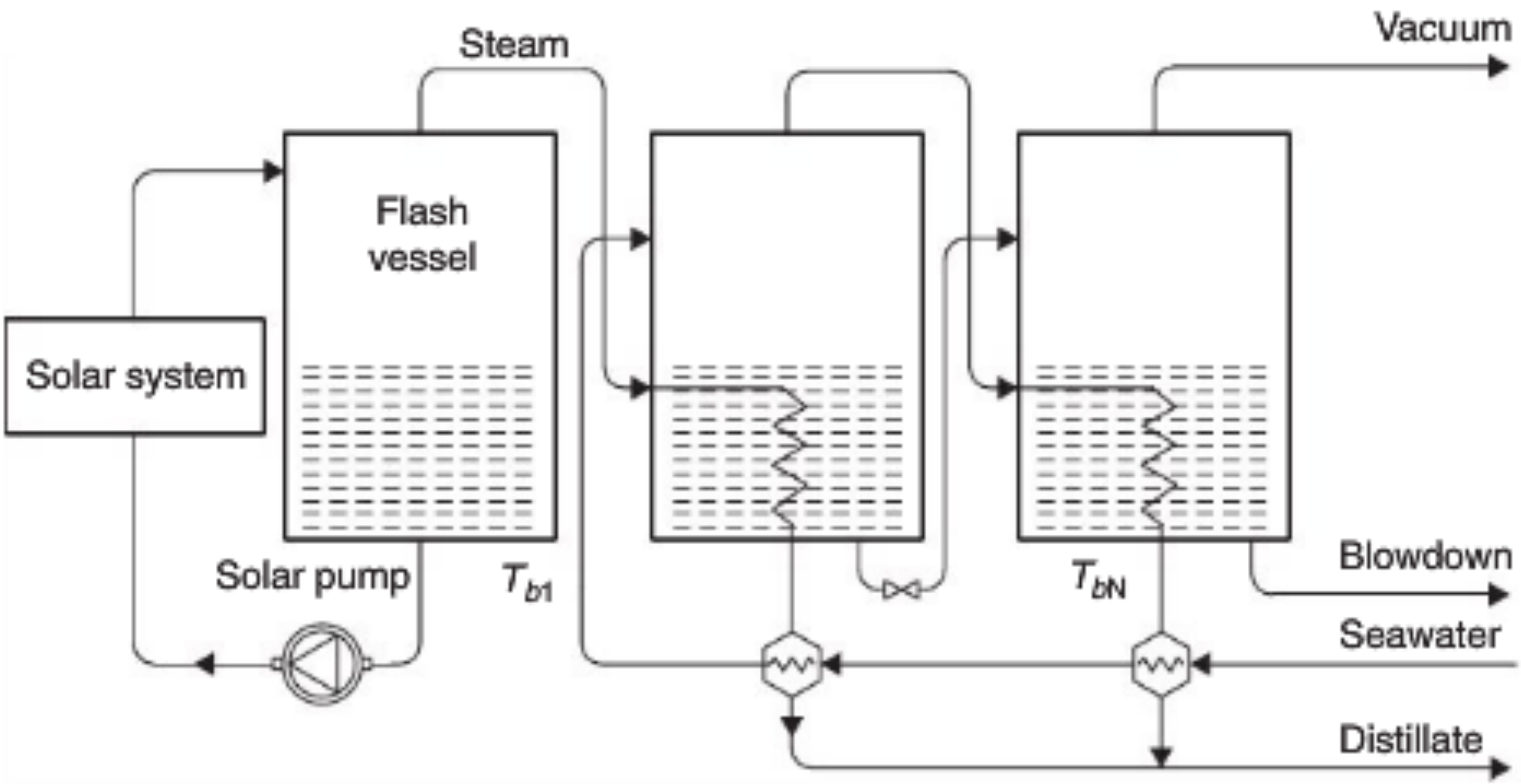


FIGURE 8.6 Principle of operation of a multiple-effect boiling (MEB) system.

Solar Desalination/Water Purification

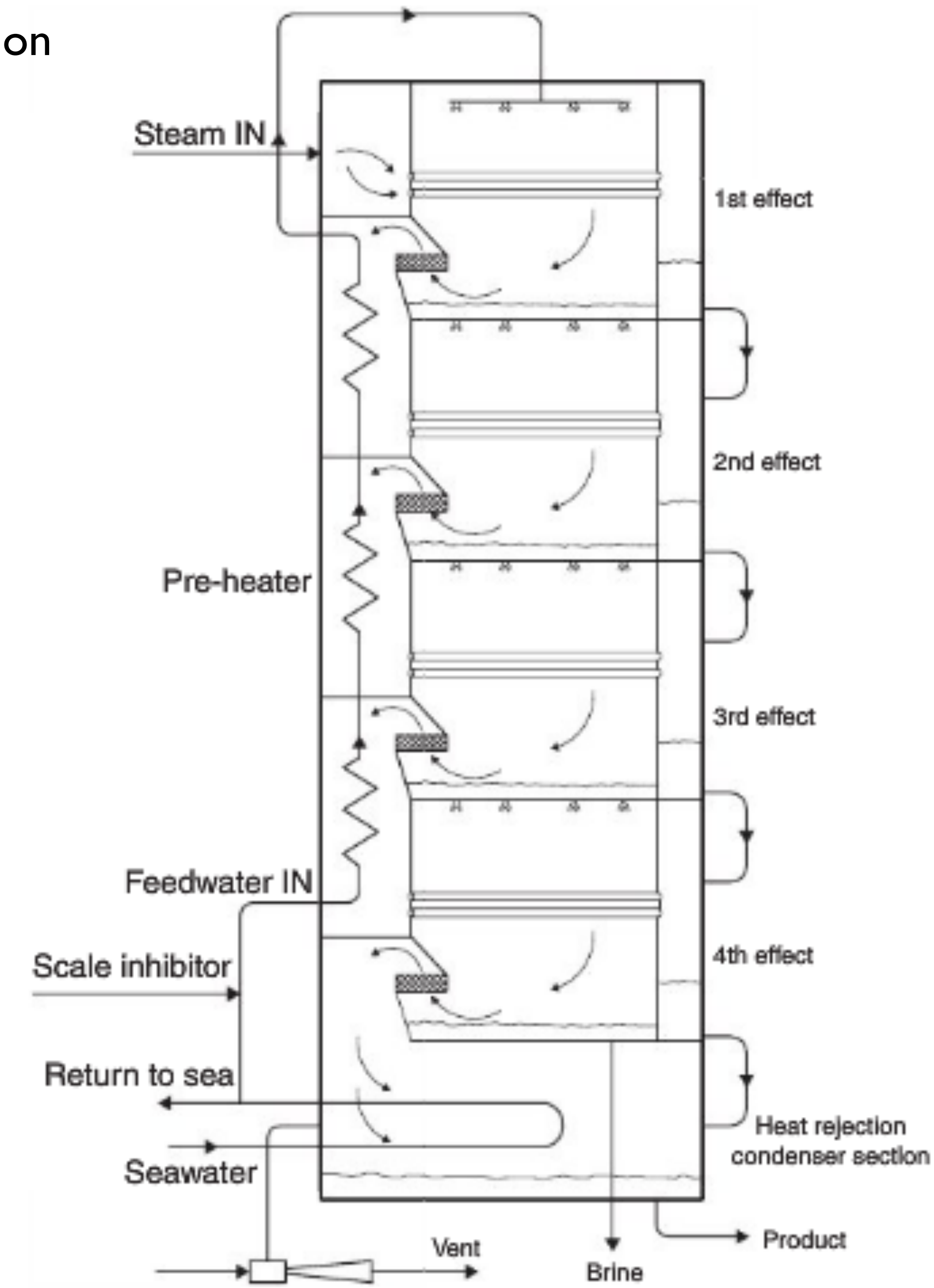


FIGURE 8.8 Schematic of the MES evaporator.

Solar Heat Collectors

Solar Heat Collectors

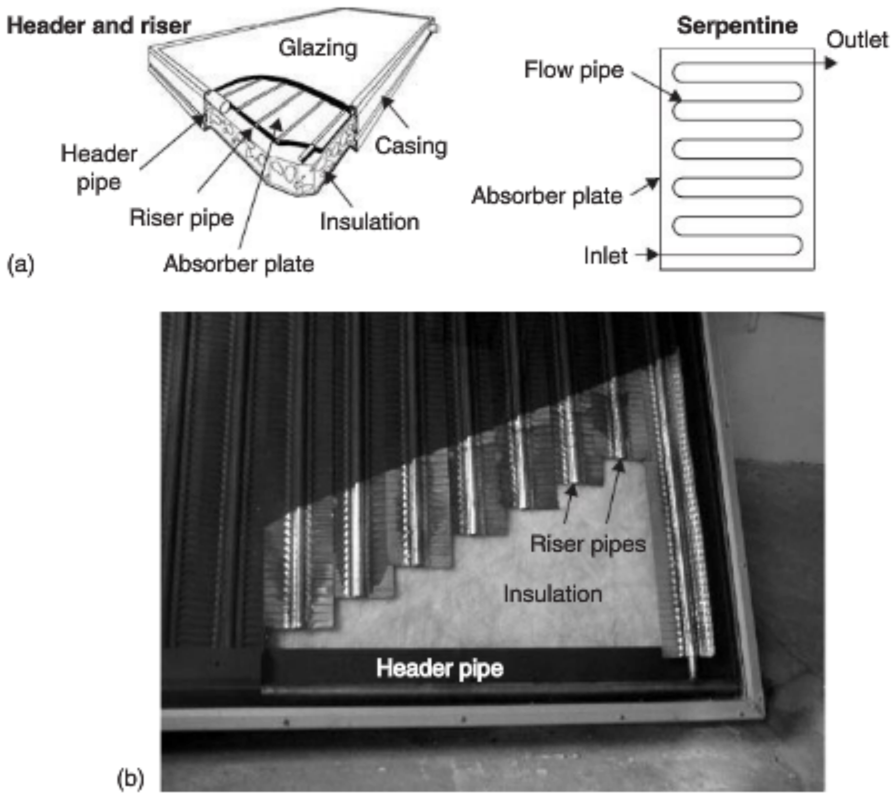


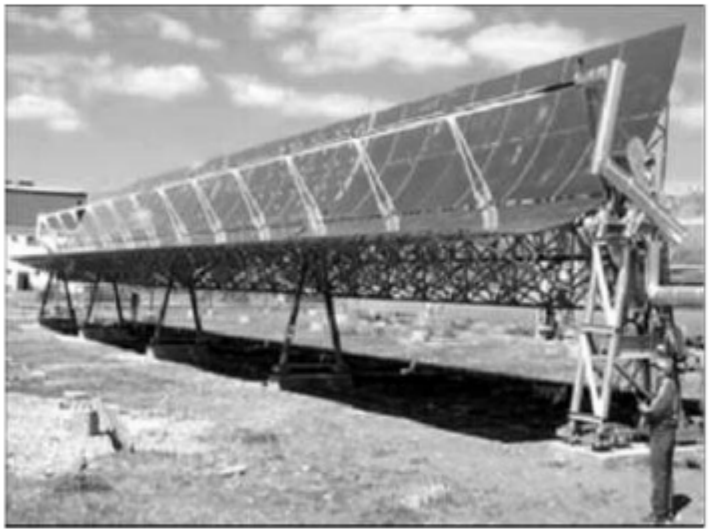
FIGURE 3.1 Typical flat-plate collector. (a) Pictorial view of a flat-plate collector. (b) Photograph of a cut header and riser flat-plate collector.

Table 3.1 Solar Energy Collectors

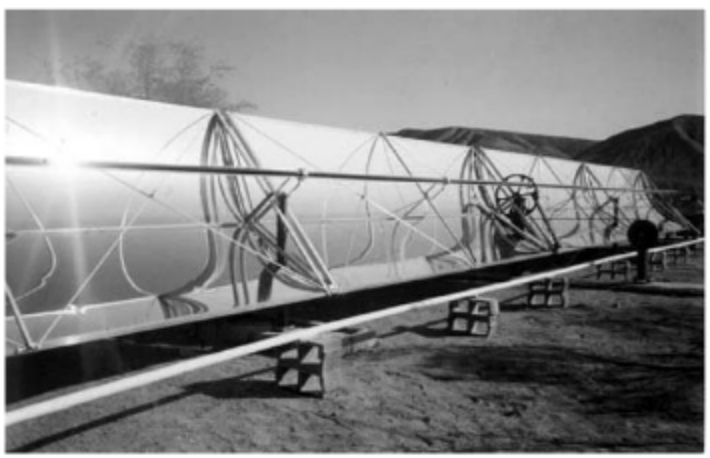
Motion	Collector type	Absorber type	Concentration ratio	Indicative temperature range (°C)
Stationary	Flat-plate collector (FPC)	Flat	1	30–80
	Evacuated tube collector (ETC)	Flat	1	50–200
	Compound parabolic collector (CPC)	Tubular	1–5	60–240
Single-axis tracking			5–15	60–300
	Linear Fresnel reflector (LFR)	Tubular	10–40	60–250
	Cylindrical trough collector (CTC)	Tubular	15–50	60–300
	Parabolic trough collector (PTC)	Tubular	10–85	60–400
Two-axis tracking	Parabolic dish reflector (PDR)	Point	600–2000	100–1500
	Heliostat field collector (HFC)	Point	300–1500	150–2000

Note: Concentration ratio is defined as the aperture area divided by the receiver/absorber area of the collector.

Solar Heat Collectors

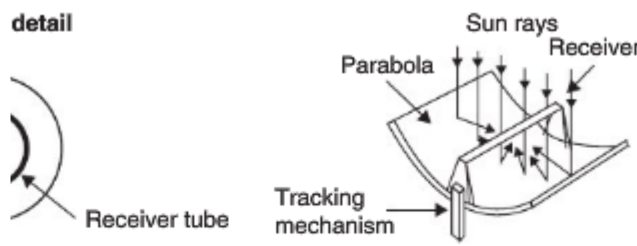


(a)



(b)

FIGURE 3.14 Photos of actual parabolic trough collectors. (a) The EuroTrough (from www.sbp.de/en/html/projects/detail.html?id=1043). (b) An Industrial Solar Technology collector.



tic of a parabolic trough collector.

Solar Heat Collectors

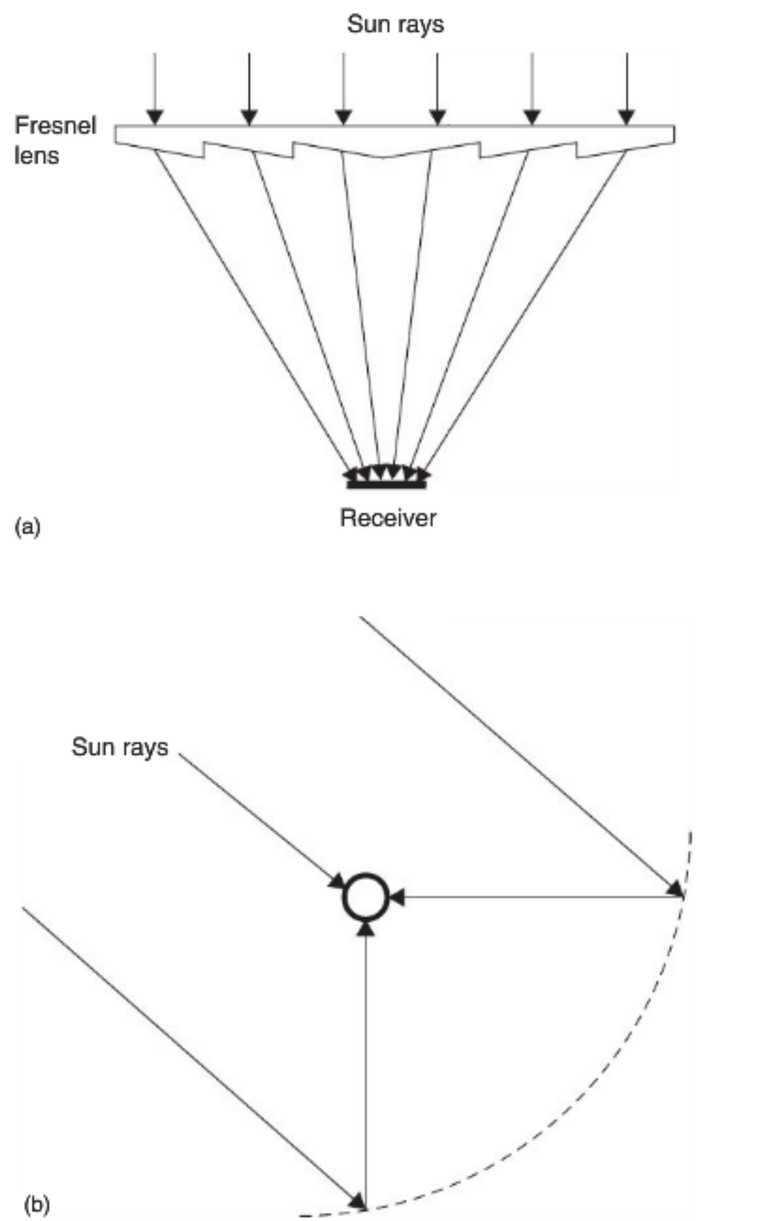


FIGURE 3.17 Fresnel collectors. (a) Fresnel lens collector (FLC). (b) Linear Fresnel-type parabolic trough collector.

Solar Heat Collectors

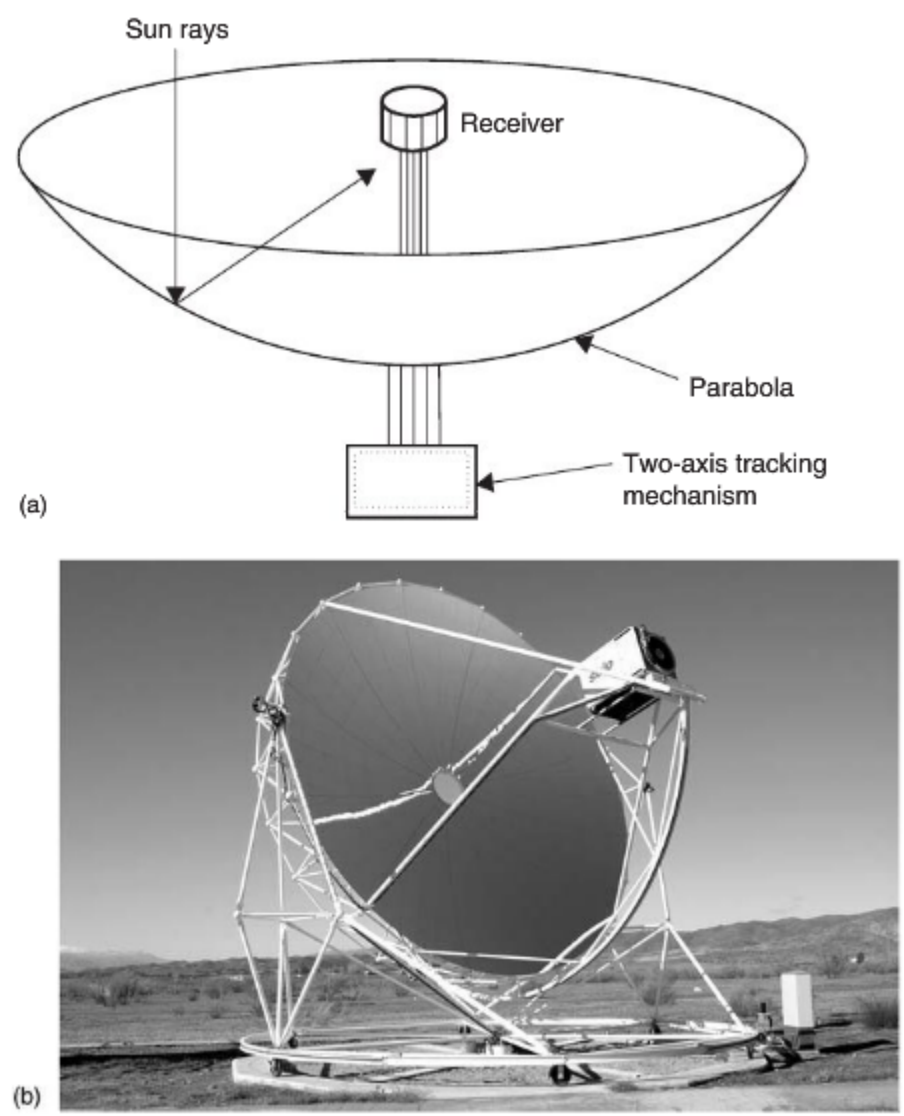


FIGURE 3.20 Parabolic dish collector. (a) Schematic diagram. (b) Photo of a Eurodish collector (from www.psa.es/webeng/instalaciones/discos.html).

Solar Heat Collectors

FIGURE 10.7 Heliostat detail of the Solar Two plant (source: www.energylan.sandia.gov/sunlab/overview.htm).

FIGURE 10.8 Photograph of a dish concentrator with Stirling engine (source: www.energylan.sandia.gov/sunlab/pdfs/dishen.pdf).

Sterling Engine Wiki (http://en.wikipedia.org/wiki/Stirling_engine)

Sterling Engine Water Pump (Large)
(http://www.youtube.com/watch?v=CEBuzq5iIqk)

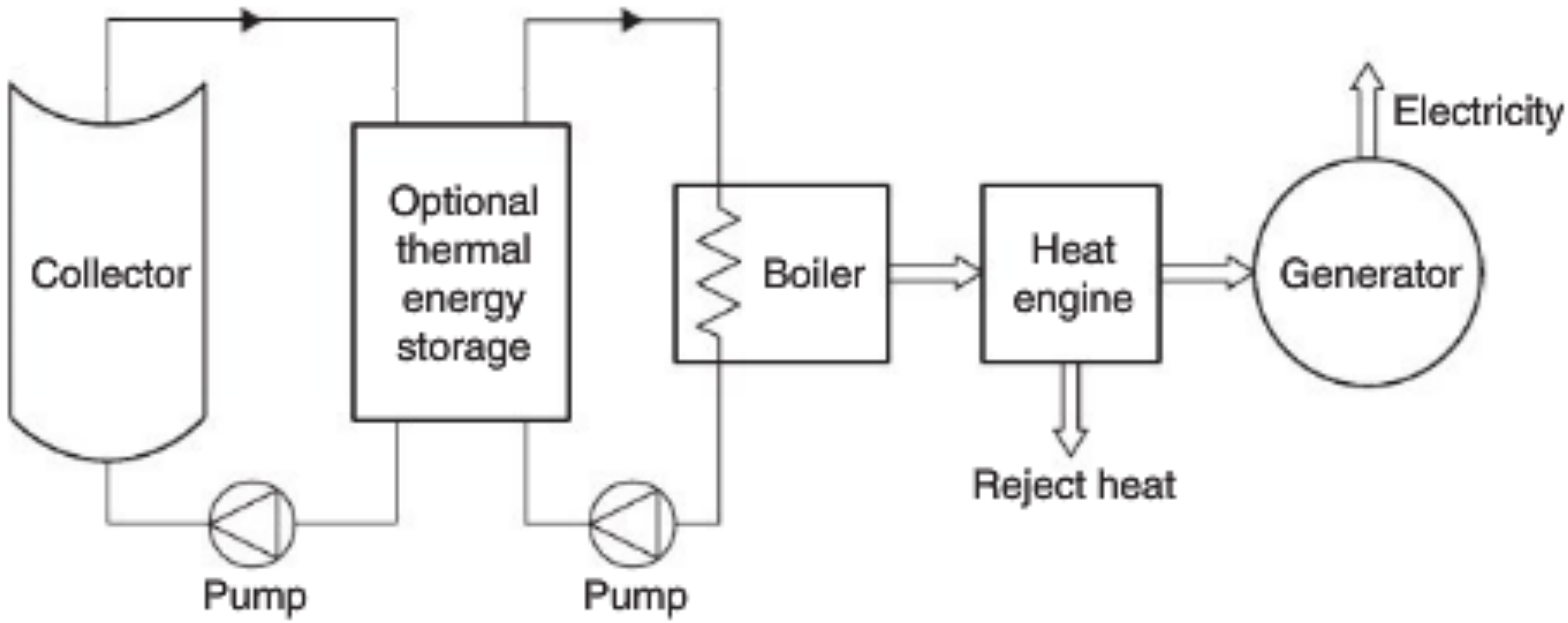


FIGURE 10.1 Schematic diagram of a solar-thermal energy conversion system.

Solar Heat Collectors

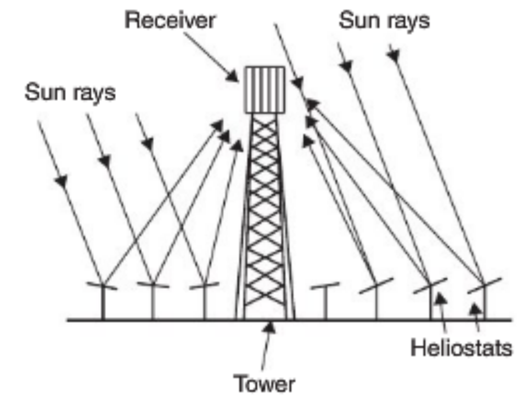


FIGURE 3.21 Schematic of central receiver system.

FIGURE 3.22 Detail of a heliostat.

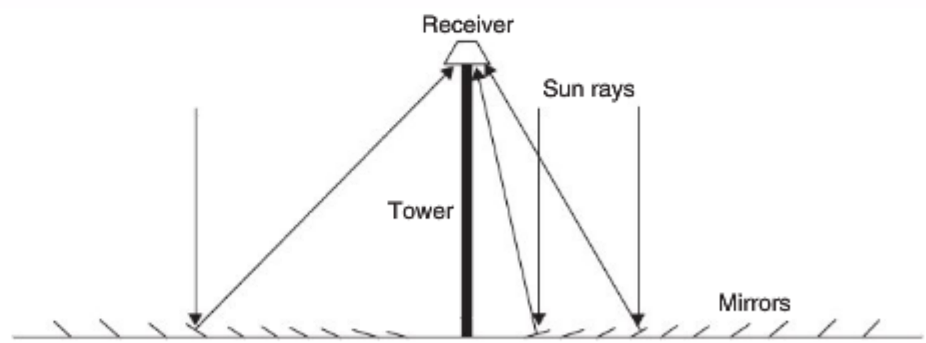


FIGURE 3.18 Schematic diagram of a downward-facing receiver illuminated from an LFR field.

Solar Heat Collectors

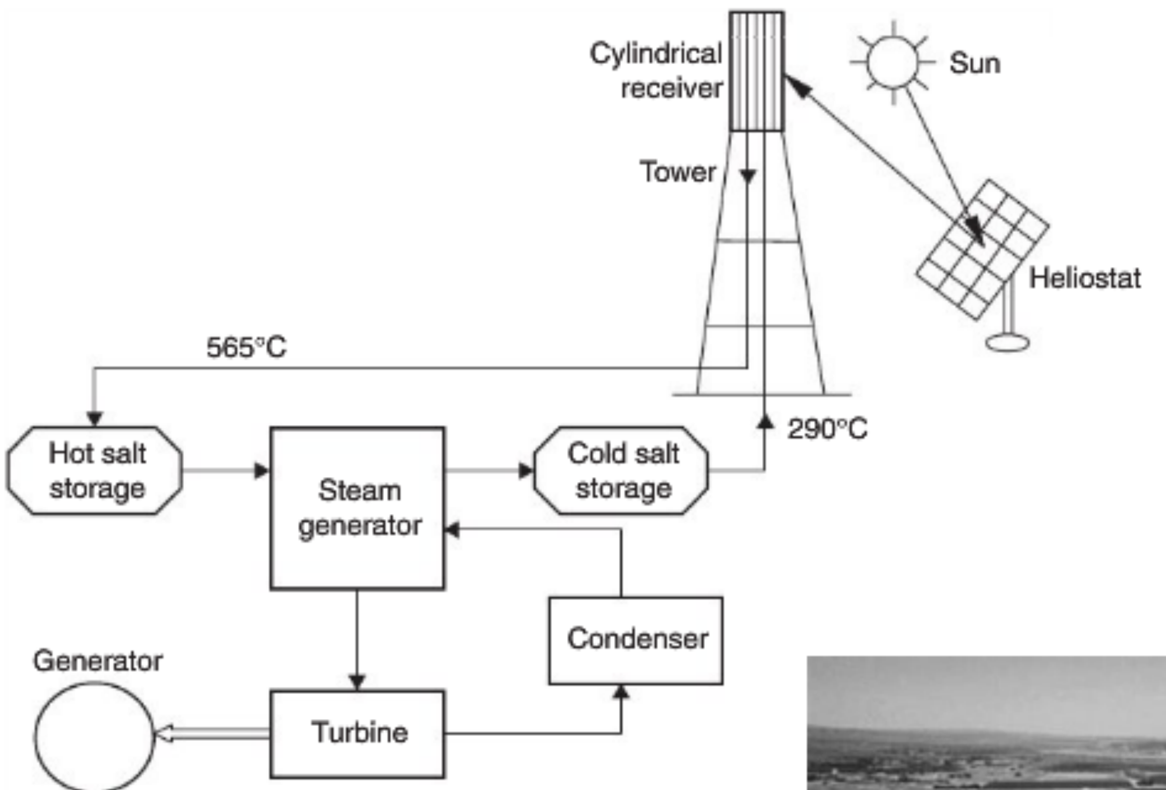


FIGURE 10.5 Schematic of the Solar Two plant.

FIGURE 10.6 Photograph of the Solar Two central receiver plant (source: www.energylan.sandia.gov/sunlab/Snapshot/STFUTURE.HTM).

Solar Heat Collectors

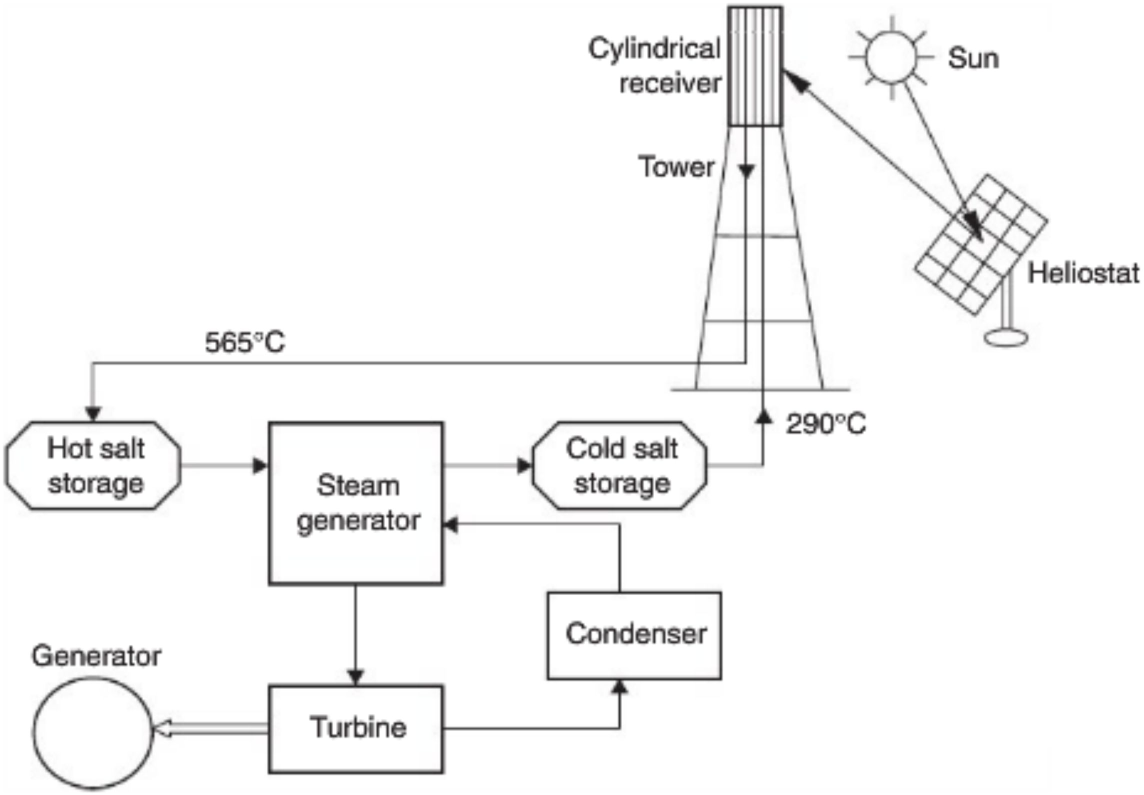


FIGURE 10.5 Schematic of the Solar Two plant.

[Solar Tres (Gemasolar)]

[How it works]

Gemasolar

Gemasolar

Location of Gemasolar

Country	Spain
Location	Fuentes de Andalucía, Sevilla
Coordinates	37°33′29.11″N 5°19′44.6″W
Status	Operational
Commission date	May 2011
Owner(s)	Torresol Energy
Solar farm	
Type	CSP
CSP technology	Solar power tower
Heliostats	2,650
Power generation	
Installed capacity	19.9 MW
Annual generation	110 GW·h

Photo 3.1 **The Gemasolar power tower near Sevilla (Spain)**

Source: Torresol Energy.

Key point

Molten-salts solar towers can generate electricity round the clock.

Table 10.1 Performance Characteristics of Various CSP Technologies

Technology	Capacity range (MW)	Concentration	Peak solar efficiency (%)	Solar-electric efficiency (%)	Land use (m^2/MWh-a)
Parabolic trough	10–200	70–80	21	10–15	6–8
Fresnel reflector	10–200	25–100	20	9–11	4–6
Power tower	10–150	300–1000	20	8–10	8–12
Dish-Stirling	0.01–0.4	1000–3000	29	16–18	8–12

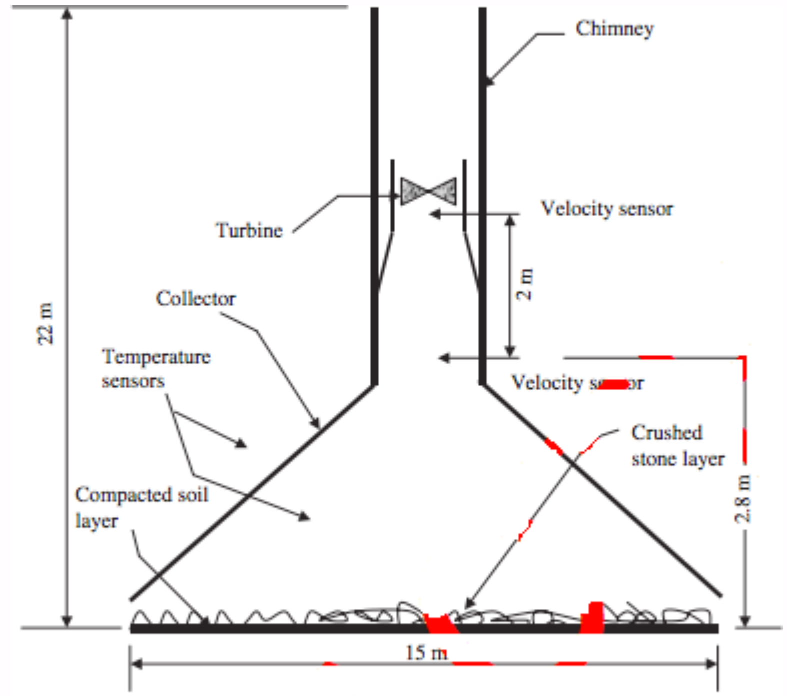
Images for **dish stirling** - Report images

Solar Chimney's

[Enviromission (Australia)]

[Solar Chimney Spain (Madrid)]

Solar Chimney's



Gaborone, Botswana

Hot Water Systems

Hot Water Systems

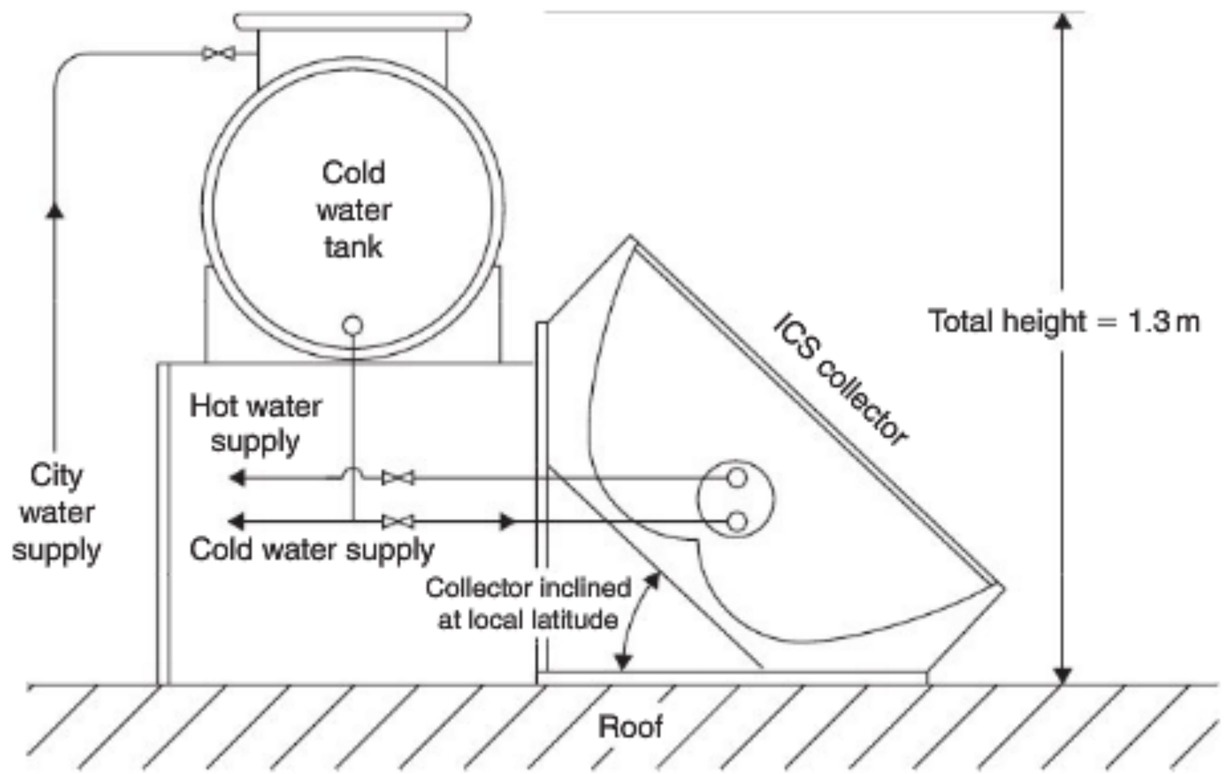
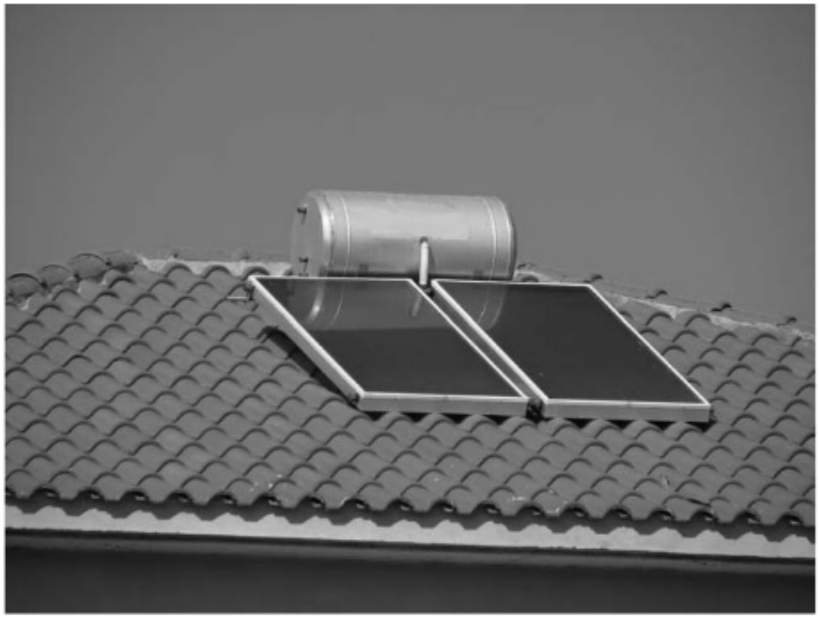


FIGURE 5.8 The complete solar ICS hot water system.

Hot Water Systems



(a)

(b)

FIGURE 5.2 Thermosiphon system configurations. (a) Flat-plate collector configuration. (b) Evacuated tube collector configuration.

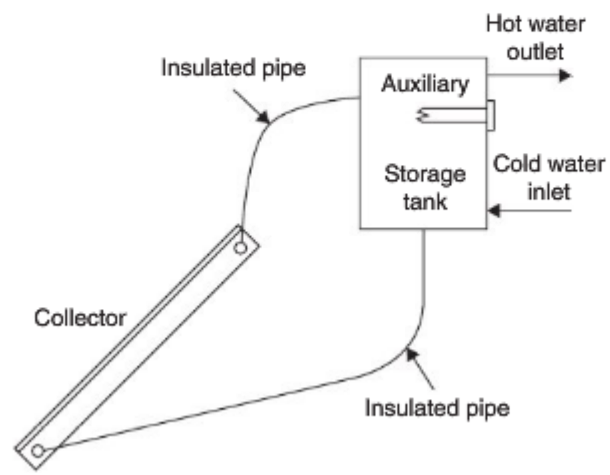


FIGURE 5.1 Schematic diagram of a thermosiphon solar water heater.

Hot Water Systems

Direct vs Indirect Systems

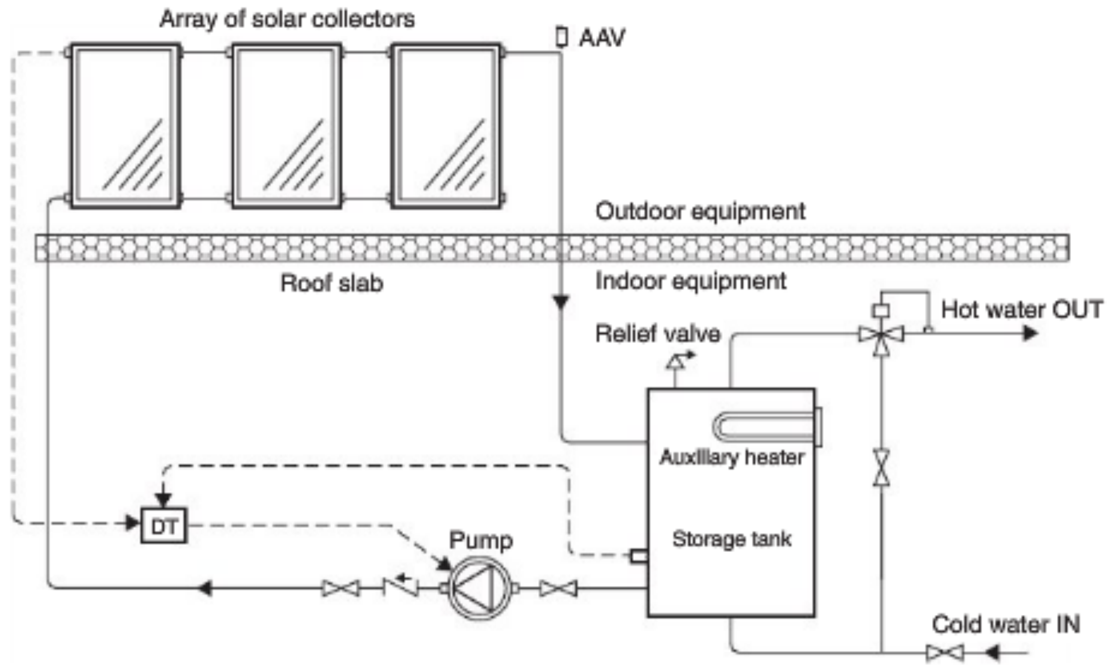


FIGURE 5.9 Direct circulation system.

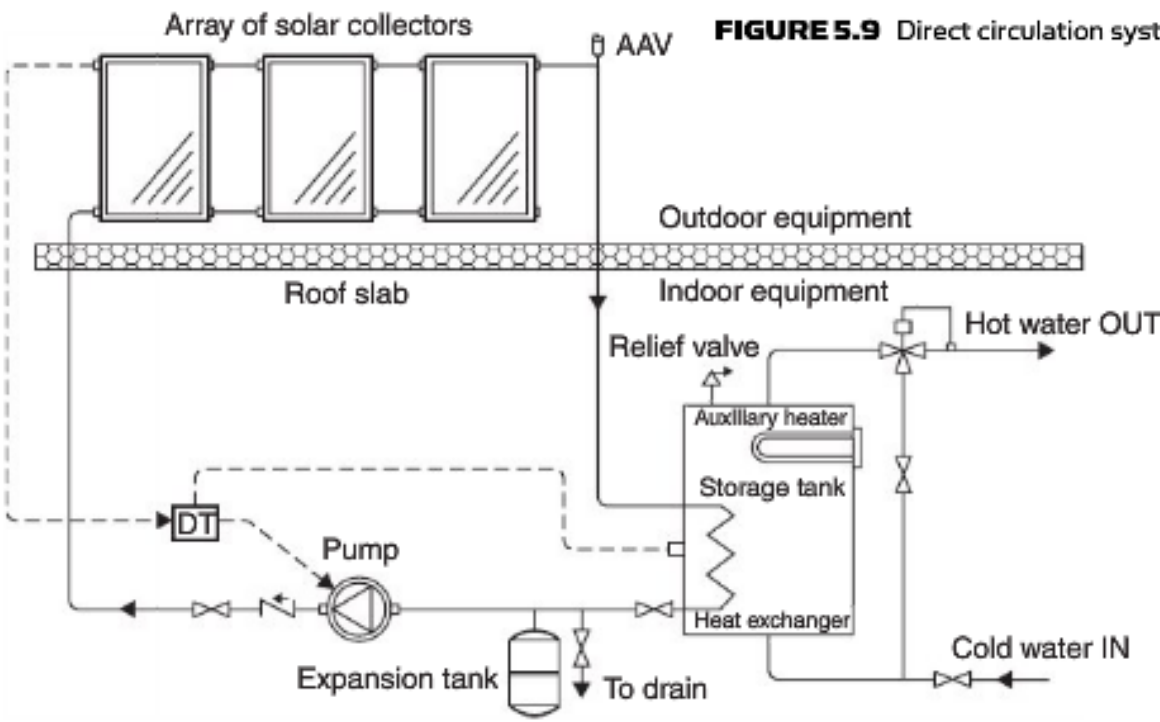


FIGURE 5.11 Indirect water heating system.

Hot Water Systems

Figure 4-7 *A home-made clip fin collector.*

that faces away from the sun. We need to try to eliminate thermal bridges as far as we possibly can.

Aluminum clip fins are one of the easiest ways of assembling a solar collector quickly, as they essentially clip onto a matrix of copper pipe.

Another way of constructing a solar collector is to use an old radiator painted black inside an insulated box—crude but effective! (Figure 4-9). This system contains more water, and as a result has a slower response time. This is because it takes more time to heat up the thermal mass of the radiator.

Warning

One of the problems that solar collectors suffer from is freezing in the winter. When temperatures drop too low, the water in the pipes of the collectors expands—this runs the risk of *severely* damaging the collectors.

Figure 4-8 *Aluminum clip fins.*

Figure 4-9 *A recycled radiator collector.*

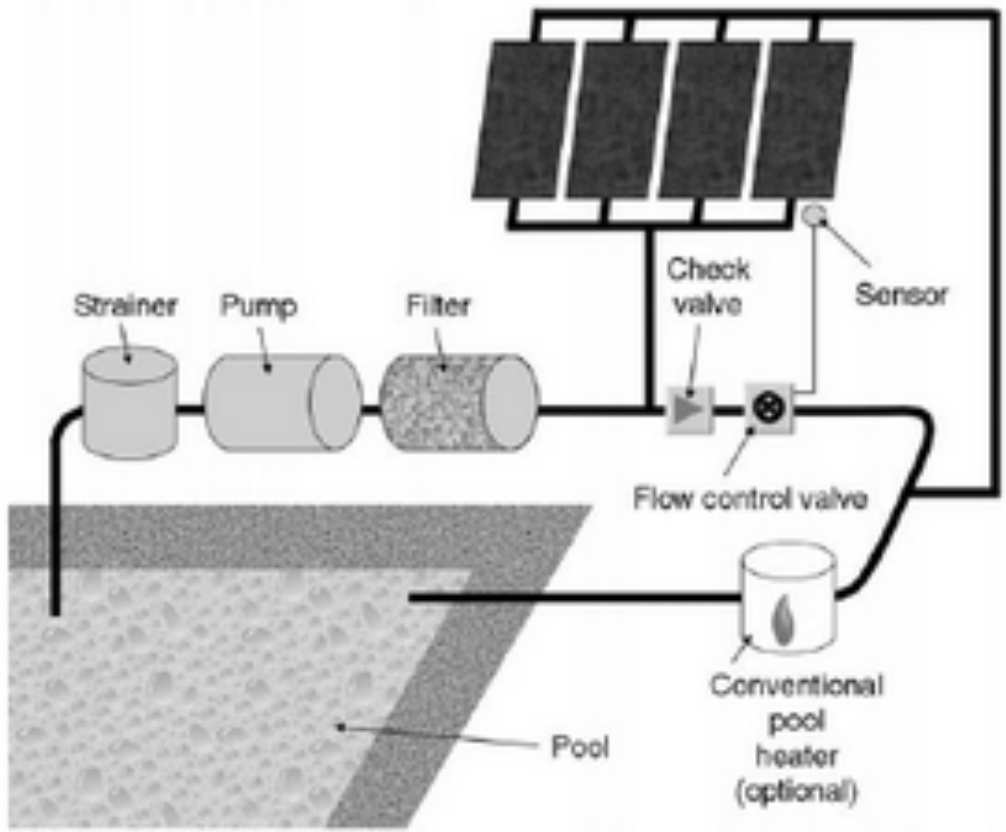


Figure 4-10 *Solar pool heating.*

Tip

Enerpool is a free program that can be used to simulate your swimming pool being heated with solar collectors. By inputting information such as your location, and how the pool is covered. The program can predict what temperature your pool will be at, at any given time!

www.powermat.com/enerpool.html

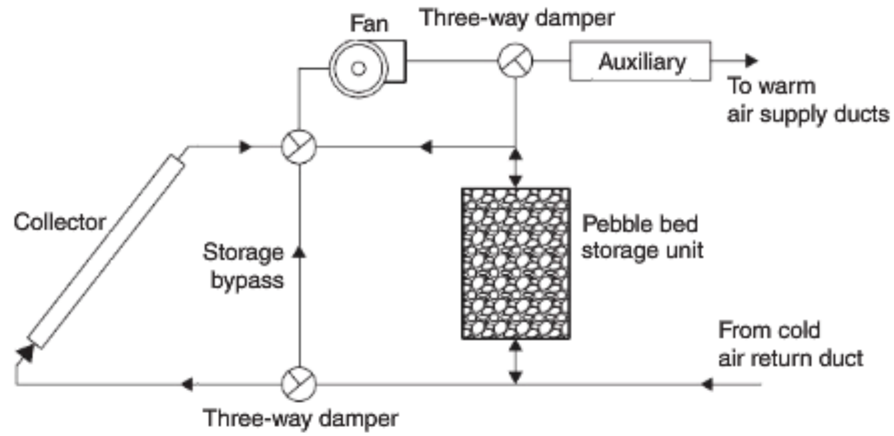


FIGURE 6.11 Schematic of basic hot air system.

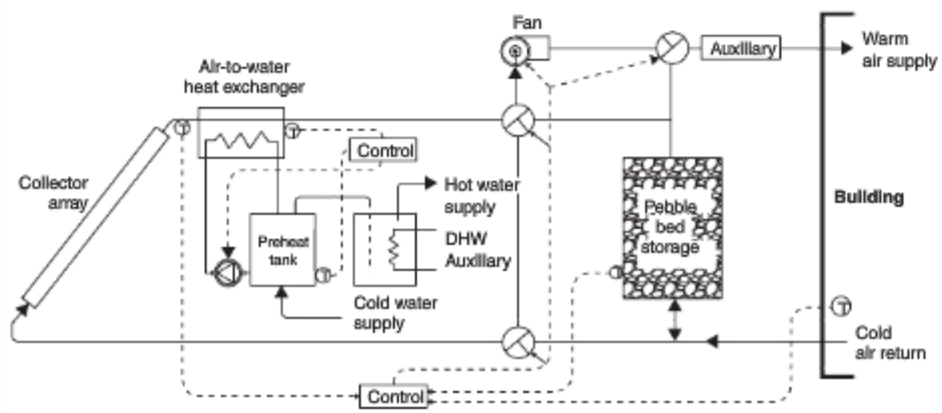


FIGURE 6.12 Detailed schematic of a solar air heating system.

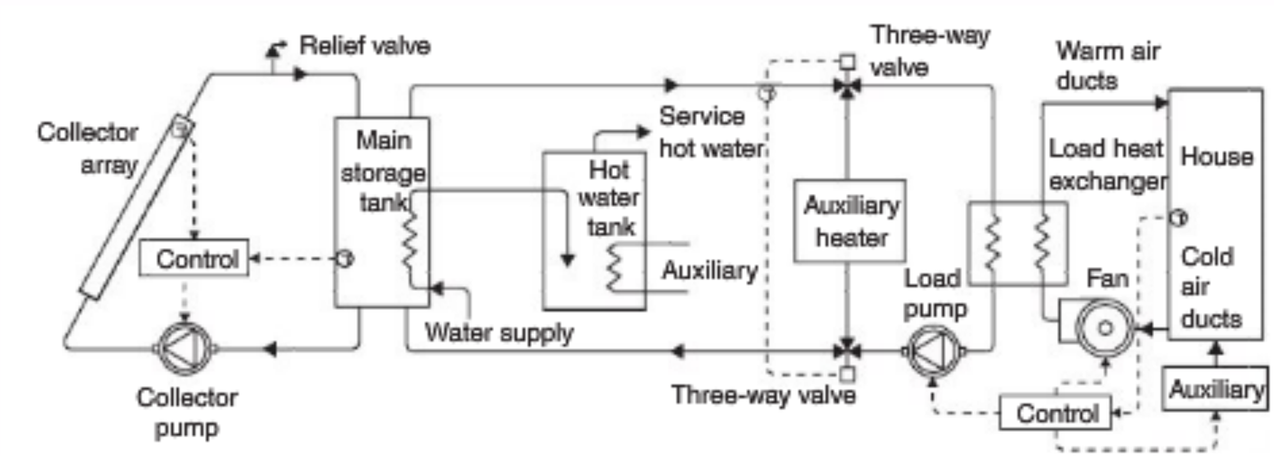


FIGURE 6.13 Schematic diagram of a solar space heating and hot water system.

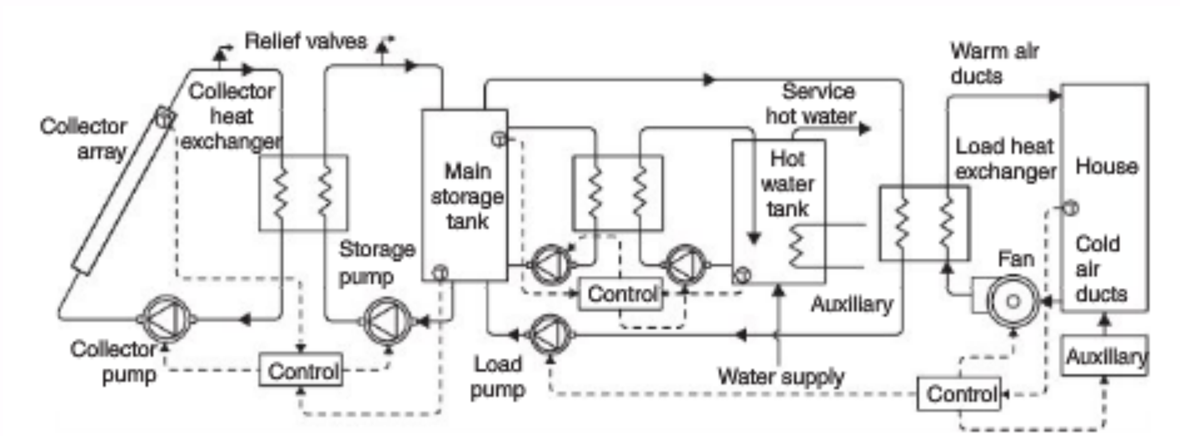


FIGURE 6.14 Detailed schematic diagram of a solar space heating and hot water system with antifreeze solution.

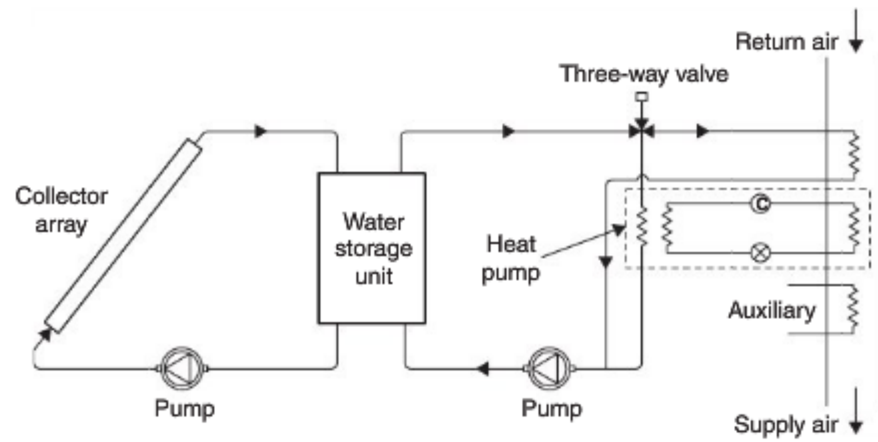


FIGURE 6.16 Schematic diagram of a domestic water-to-air heat pump system (series arrangement).

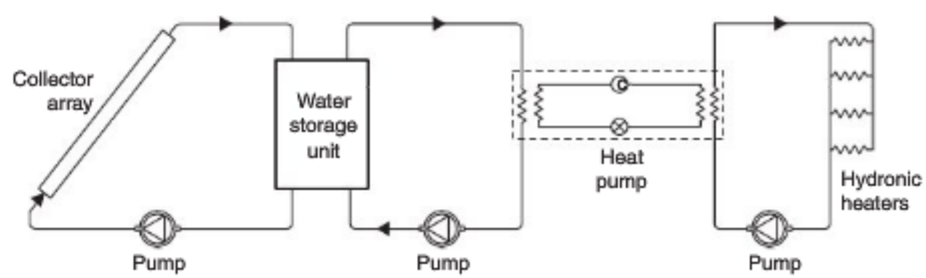


FIGURE 6.17 Schematic diagram of a domestic water-to-water heat pump system (parallel arrangement).

Passive Solar

Passive Solar: Trombe Walls

Trombe walls

As with many of the themes in this book, this idea is not a new one, in fact it was patented in 1881 (U.S. Patent 246626). However, the idea never really gained much of a following until 1964, when the engineer Felix Trombe and architect Jacques Michel began to adopt the idea in their buildings. As such, this type of design is largely referred to as a "Trombe wall."

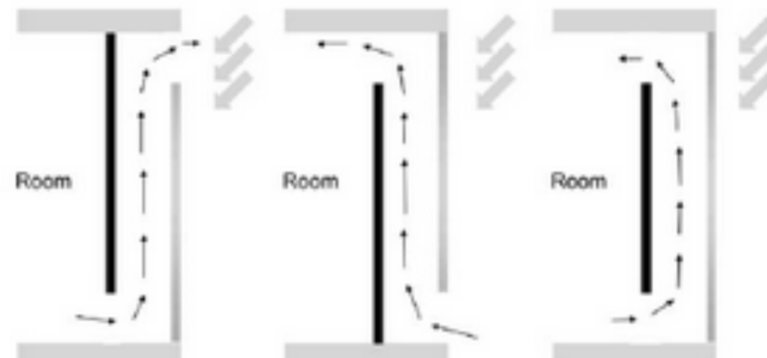


Figure 5-2 *Trombe wall modes of operation.*

Passive Solar: Trombe Walls

Ice Fishing Shack

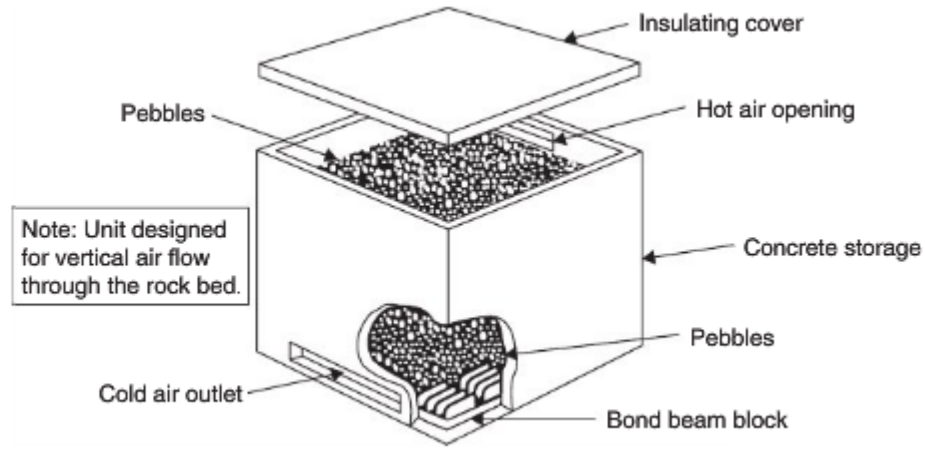


FIGURE 5.15 Vertical flow packed rock bed.

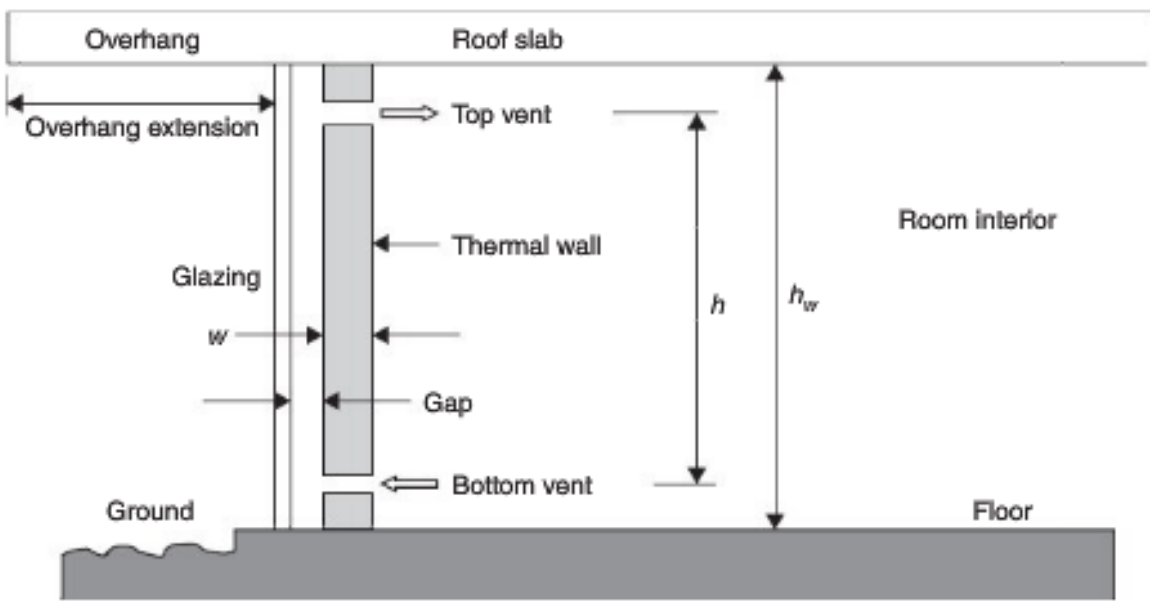


FIGURE 6.4 Schematic of the thermal storage wall.

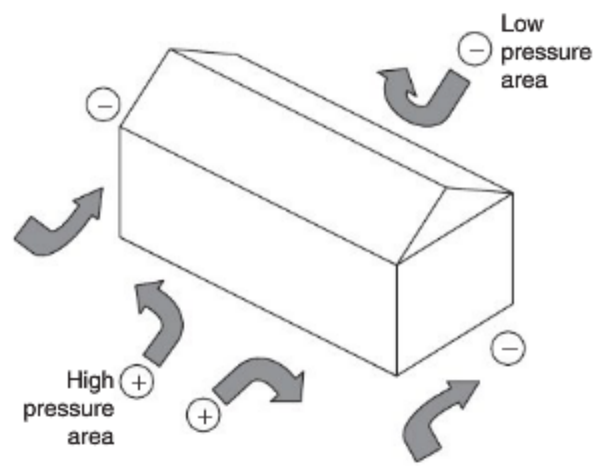


FIGURE 6.8 Pressure created because of the wind flow around a building.

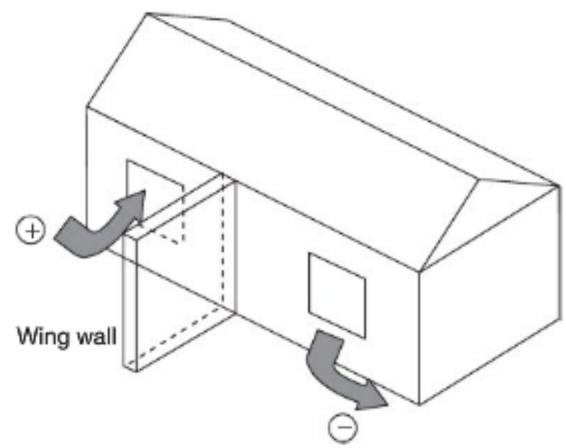


FIGURE 6.9 Use of a wing wall to help natural ventilation of windows located on the same side of the wall.

Solar Power Cooling

Swamp Cooler (http://www.youtube.com/watch?v=6ooAAcsbf_0)

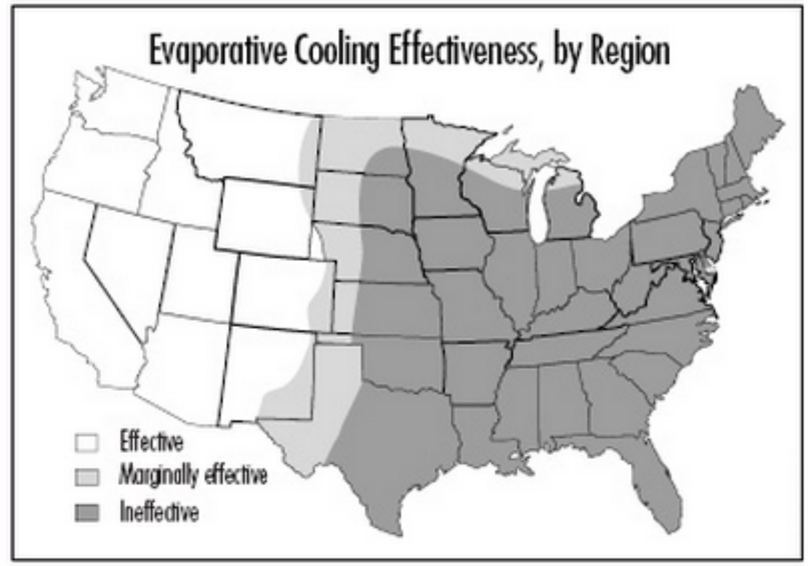
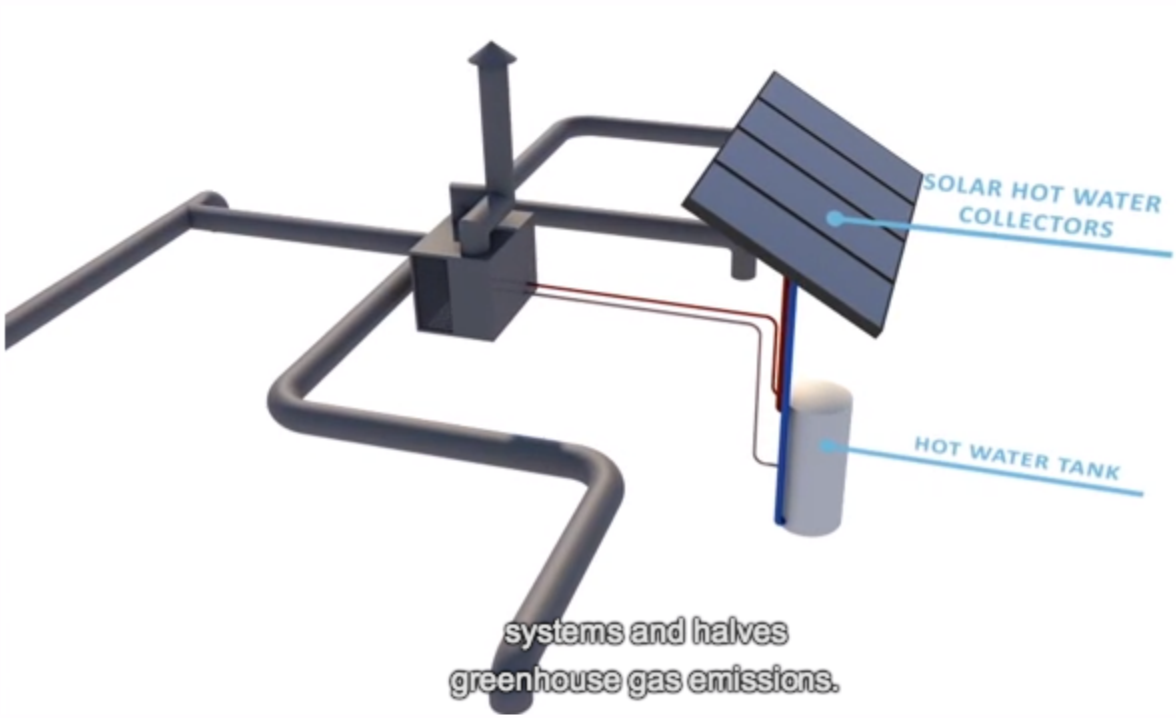


Figure 2. In areas of the United States where humidity tends to run high in the summertime, evaporative cooling is not the best way to stay cool; in the West, it's a very good choice.

A simple system (http://www.youtube.com/watch?v=cz-kquRmvqk)



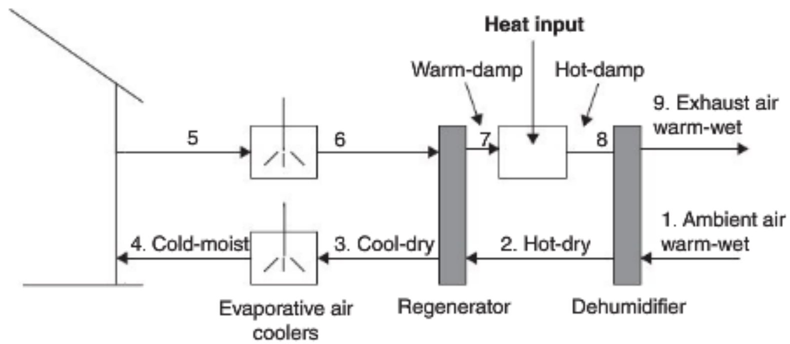


FIGURE 6.19 Schematic of a solar adsorption system.

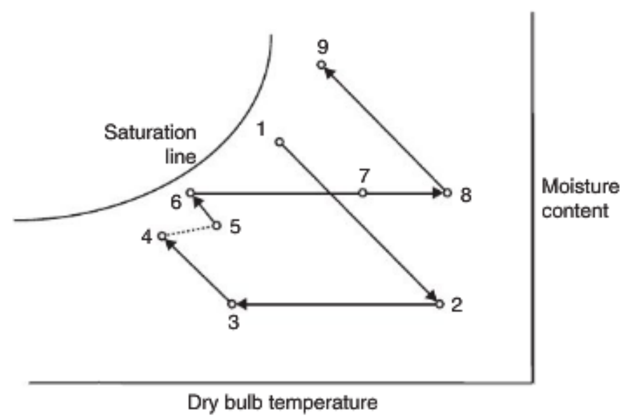


FIGURE 6.20 Psychrometric diagram of a solar adsorption process.

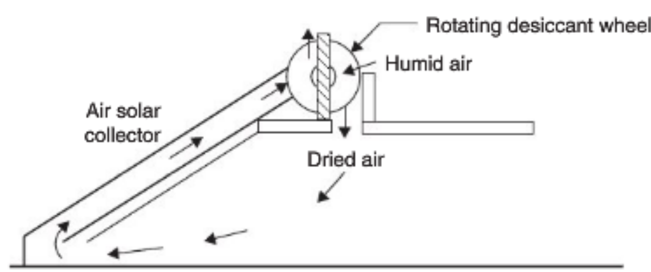
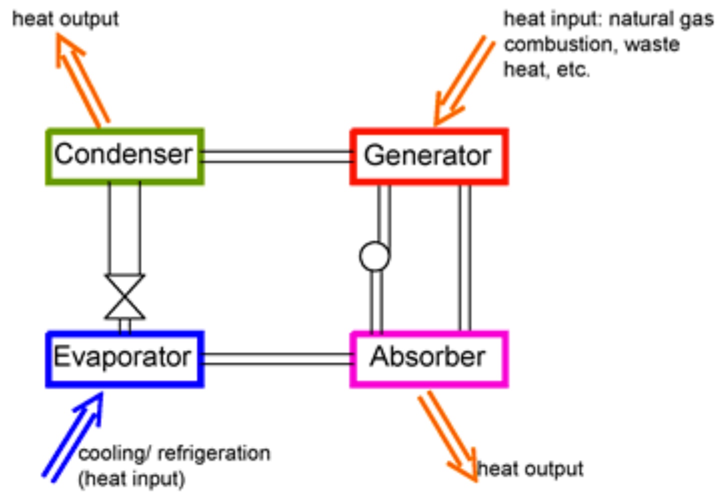


FIGURE 6.21 Solar adsorption cooling system.



The basic operation of an ammonia-water absorption cycle is as follows. Heat is applied to the generator, which contains a solution of ammonia water, rich in ammonia. The heat causes high pressure ammonia vapor to desorb the solution. Heat can either be from combustion of a fuel such as clean-burning natural gas, or waste heat from engine exhaust, other industrial processes, solar heat, or any other heat source. The high pressure ammonia vapor flows to a condenser, typically cooled by outdoor air. The ammonia vapor condenses into a high pressure liquid, releasing heat which can be used for product heat, such as space heating.

The high pressure ammonia liquid goes through a restriction, to the low pressure side of the cycle. This liquid, at low pressures, boils or evaporates in the evaporator. This provides the cooling or refrigeration product. The low pressure vapor flows to the absorber, which contains a water-rich solution obtained from the generator. This solution absorbs the ammonia while releasing the heat of absorption. This heat can be used as product heat, or for internal heat recovery in other parts of the cycle, thus unloading the burner and increasing cycle efficiency. The solution in the absorber, now once again rich in ammonia, is pumped to the generator, where it is ready to repeat the cycle.

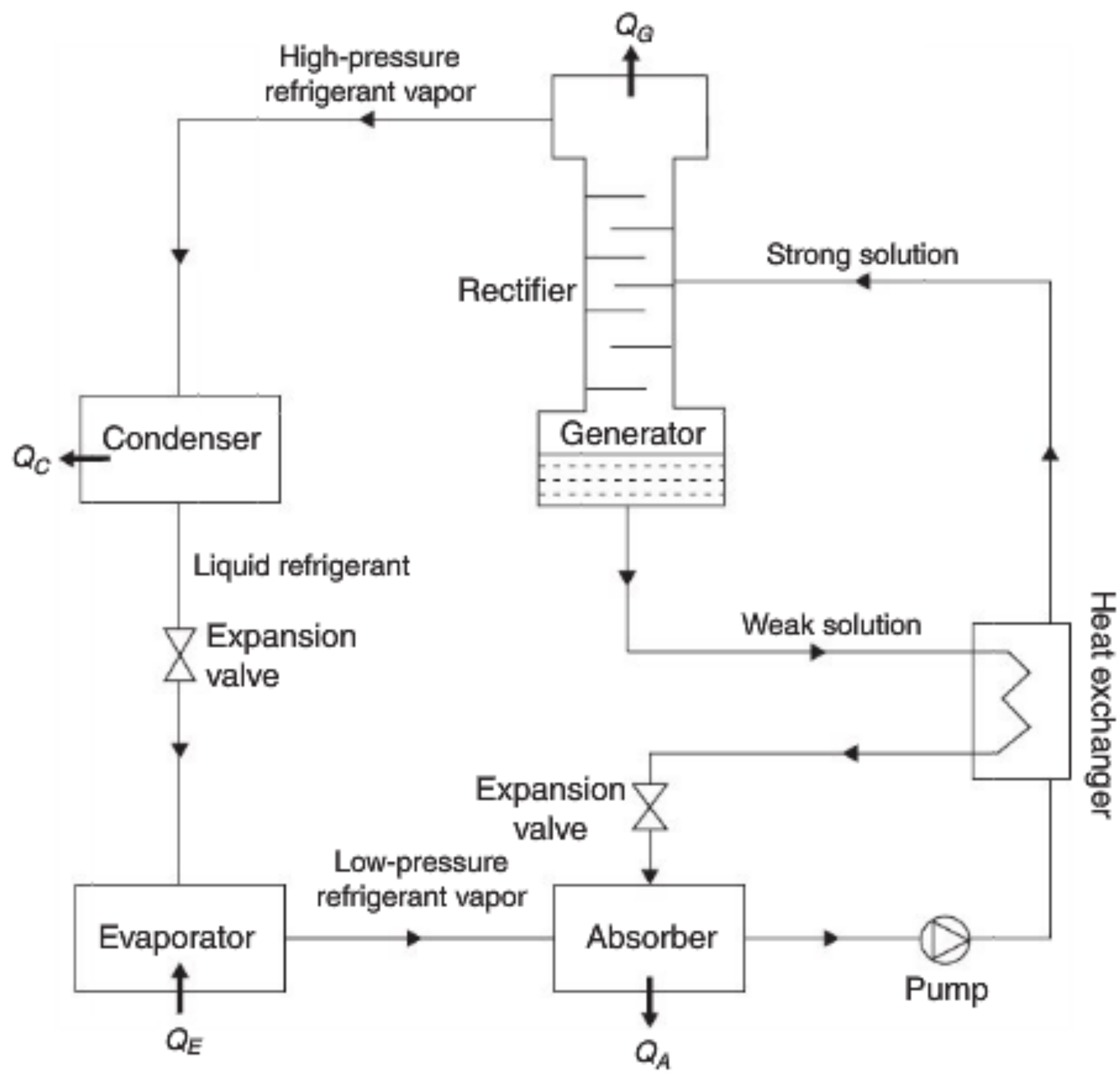


FIGURE 6.27 Schematic of the ammonia-water refrigeration system cycle.

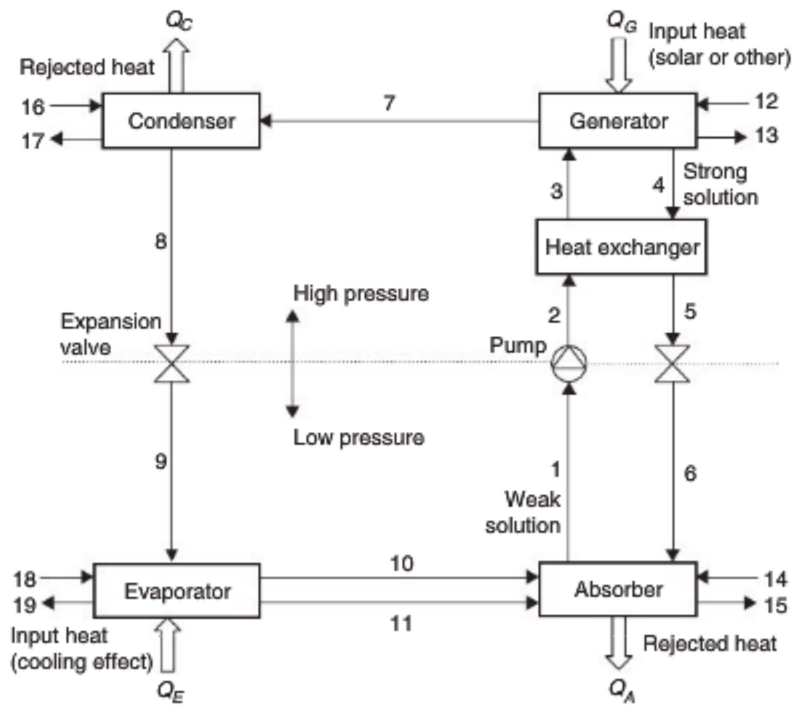


FIGURE 6.23 Schematic diagram of an absorption refrigeration system.

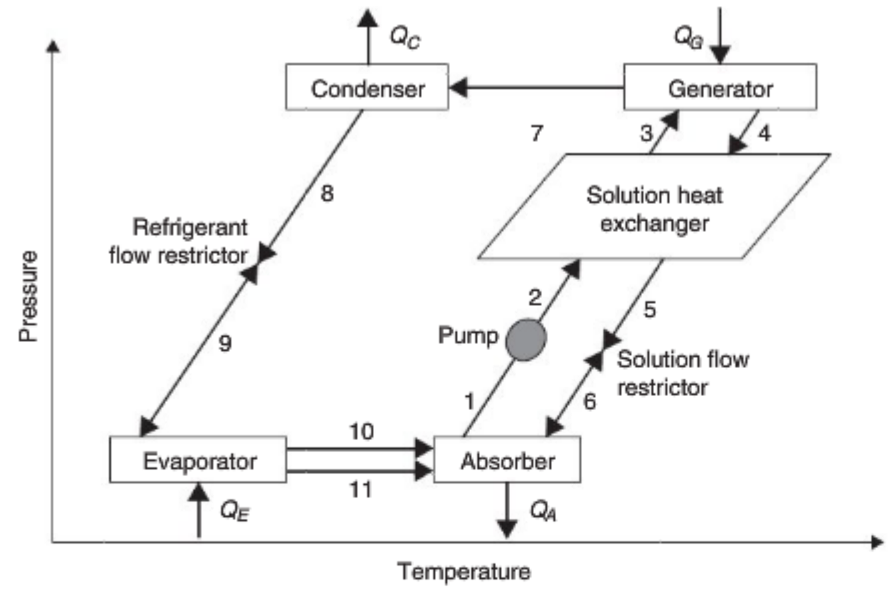
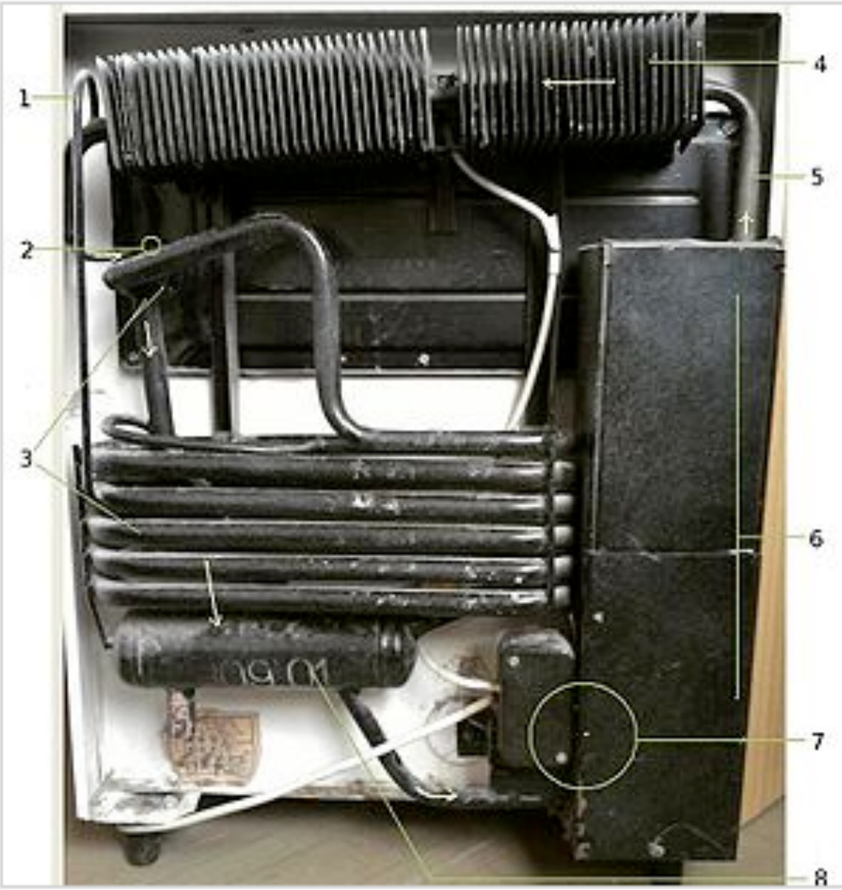


FIGURE 6.24 Pressure-temperature diagram of a single effect, LiBr-water absorption cycle.



Labeled photo of a domestic absorption refrigerator.

1. Hydrogen enters the pipe with liquid ammonia
2. Ammonia+hydrogen enter the inner compartment of the refrigerator. Change in partial pressure causes ammonia to evaporate. Energy is being drawn from the surroundings - this causes the cooling effect. Ammonia+hydrogen return from the inner part, ammonia returns back to absorber and dissolves in water. Hydrogen is free to rise upwards
3. Ammonia gas condensation (passive cooling)
4. Hot ammonia (gas)
5. Heat insulation and separation of water from ammonia gas
6. Heat source (electric)
7. Absorber vessel (water + ammonia solution)

How it works: Absorption Refrigerator

http://www.youtube.com/watch?v=hUNmDQu_fvY

Industrial Solar Refrigerator in Tunisia

http://www.youtube.com/watch?v=EPbjwv-7fWI

[Example of one of these large scale systems](http://www.youtube.com/watch?v=AtMC2MXc_n8) (http://www.youtube.com/watch?v=AtMC2MXc_n8)

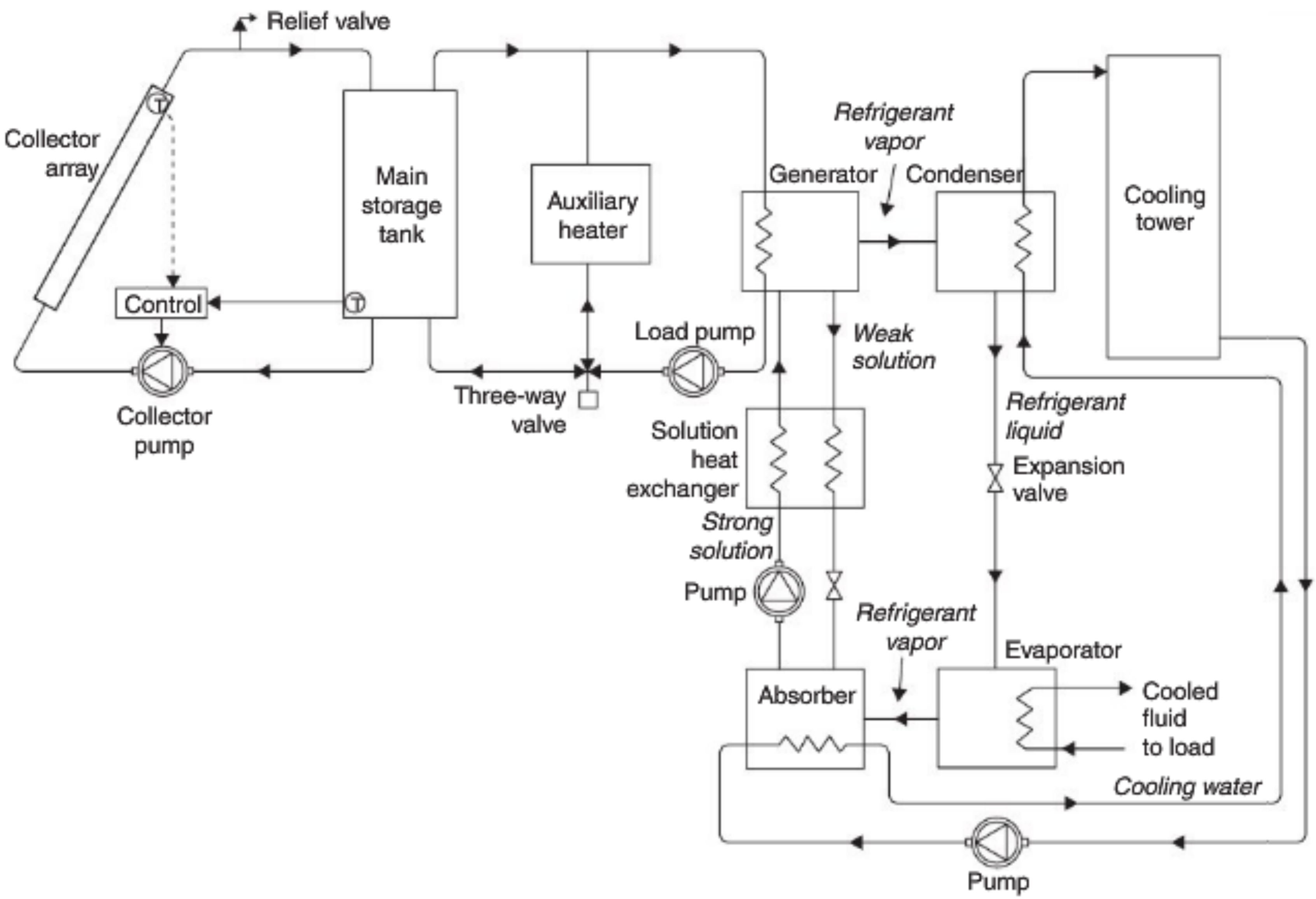
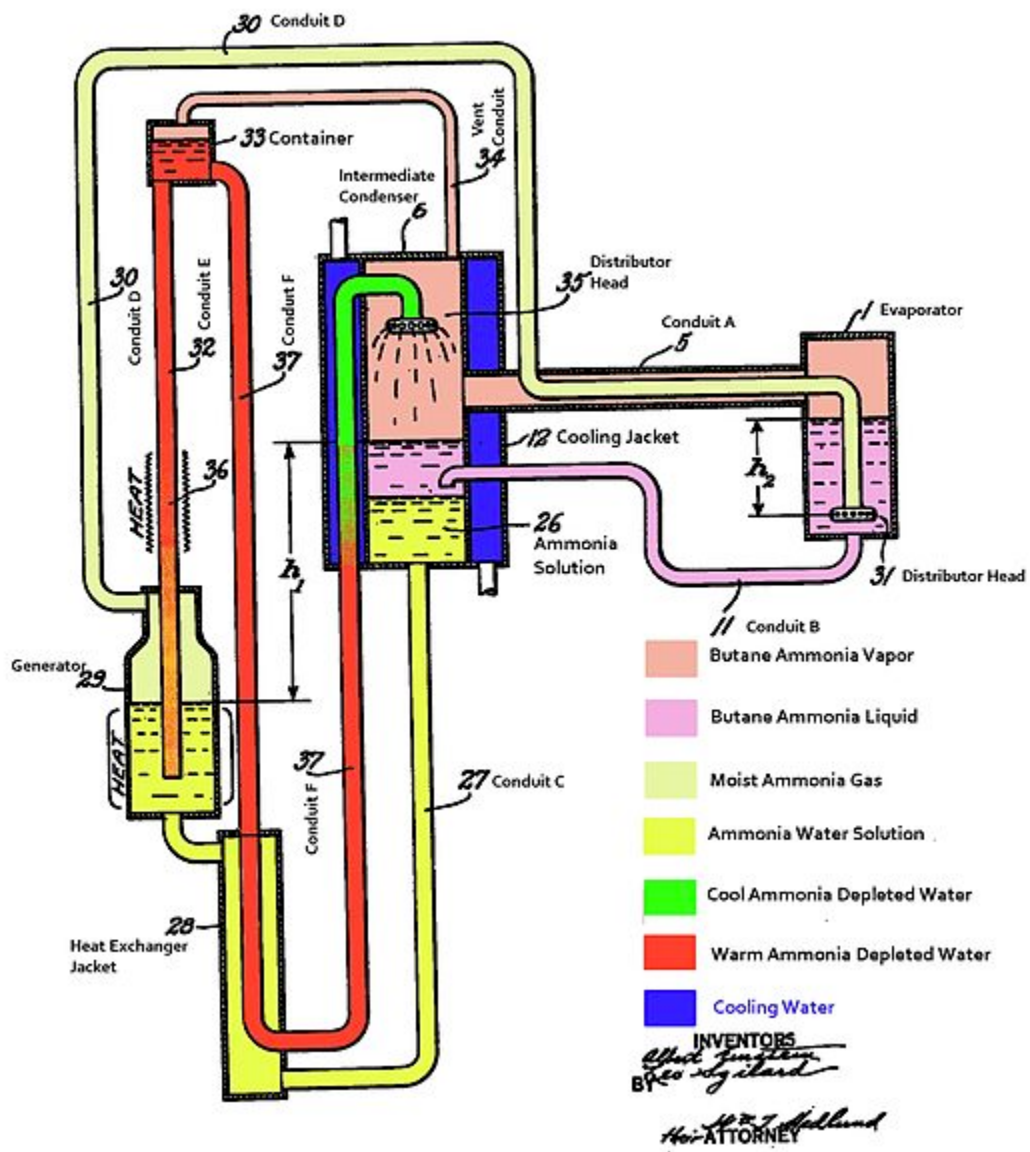


FIGURE 6.28 Schematic diagram of a solar-operated absorption refrigeration system.

Einstein Refrigerator



Project 7: Solar-Powered Ice-Maker

You will need

- Four sheets galvanized metal, 26 ga.
- 3 in. black iron pipe, 21 ft length
- 120 sq ft mirror plastic
- 2¼ in. stainless steel valves
- Evaporator/tank (4 in. pipe)
- Freezer box (free if scavenged)
- 4 ft × 8 ft sheet ¾ in. plywood
- six 2 × 4 timbers, 10 ft long
- Miscellaneous ¼ in. plumbing
- Two 3 in. caps
- 1¼ in. black iron pipe, 21 ft length
- Four 78 in. long 1½ in. angle iron supports
- 15 lb ammonia
- 10 lb calcium chloride

This design is for an ice-maker which will produce about 10 lb of ice in a single cycle. It uses the evaporation and condensation of ammonia as a refrigerant. If you remember in the explanation above, I mentioned that we needed a refrigerant and an absorber for this type of cooler to work. Well, the ammonia is our refrigerant, and we use a salt—calcium chloride—as the absorber. You might have seen small gas fridges often used in caravans and RVs which can be powered by propane—these also generally use ammonia as a

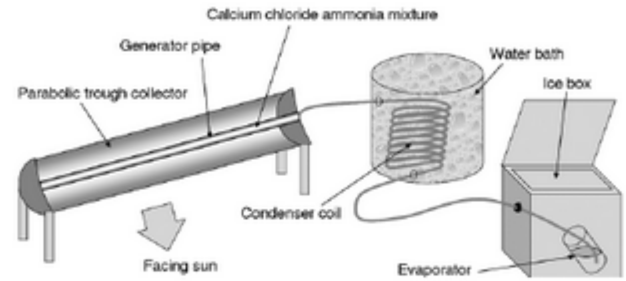


Figure 5-3 *Solar cooler layout.*

Warning

For the system to operate for long periods of time, the materials used should be resistant to corrosion by ammonia. Steel and stainless steel are ideal in this respect as both are immune to corrosion by ammonia. Another consideration is the pressure under which the system will have to operate.

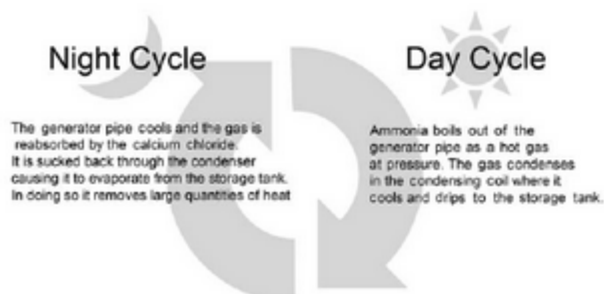


Figure 5-5 *The solar cooler cycle.*

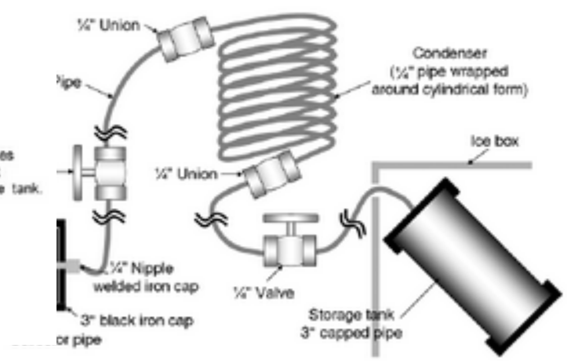


Figure 5-4 *Solar cooler plumbing details.*

How does the ice-maker work?

The ice-maker works on a cycle—during the daytime ammonia is evaporated from the pipe at the focal point of the parabolic mirrors. This is because the sun shines on the collector which is painted black to absorb the solar energy—this collector heats up, driving the ammonia from the salt inside.

At night, the salt cools and absorbs the ammonia, as it does this, it sucks it back through the collector. As it evaporates from the storage vessel, it takes heat with it.

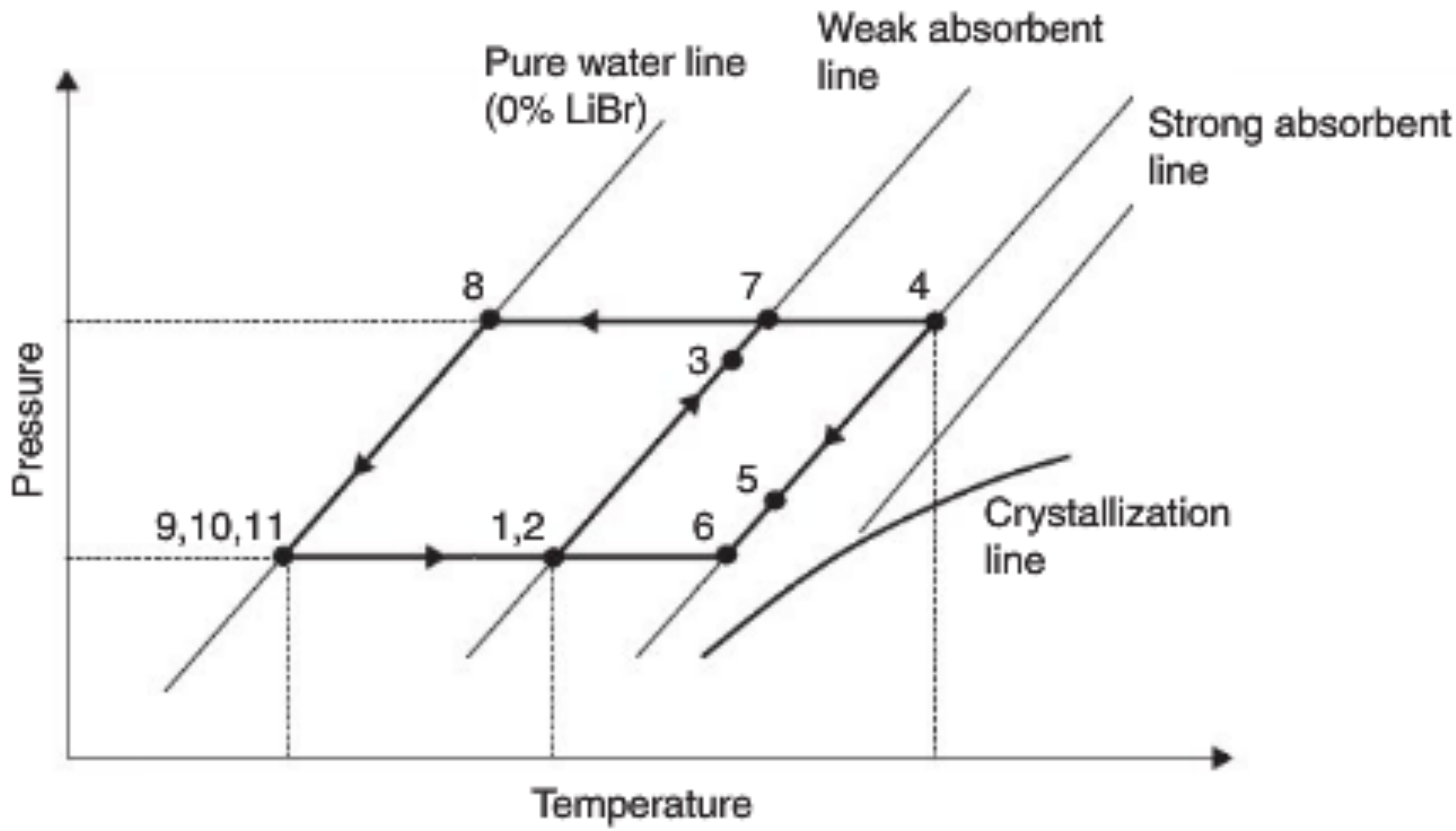
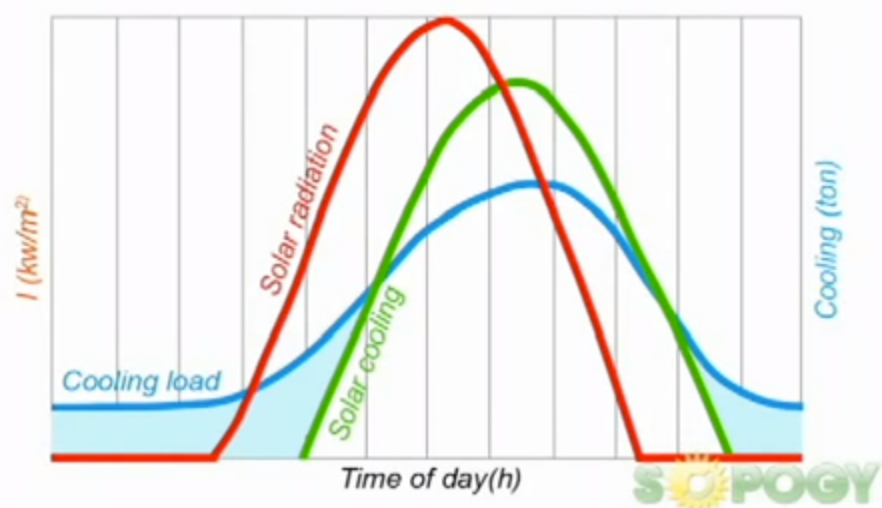
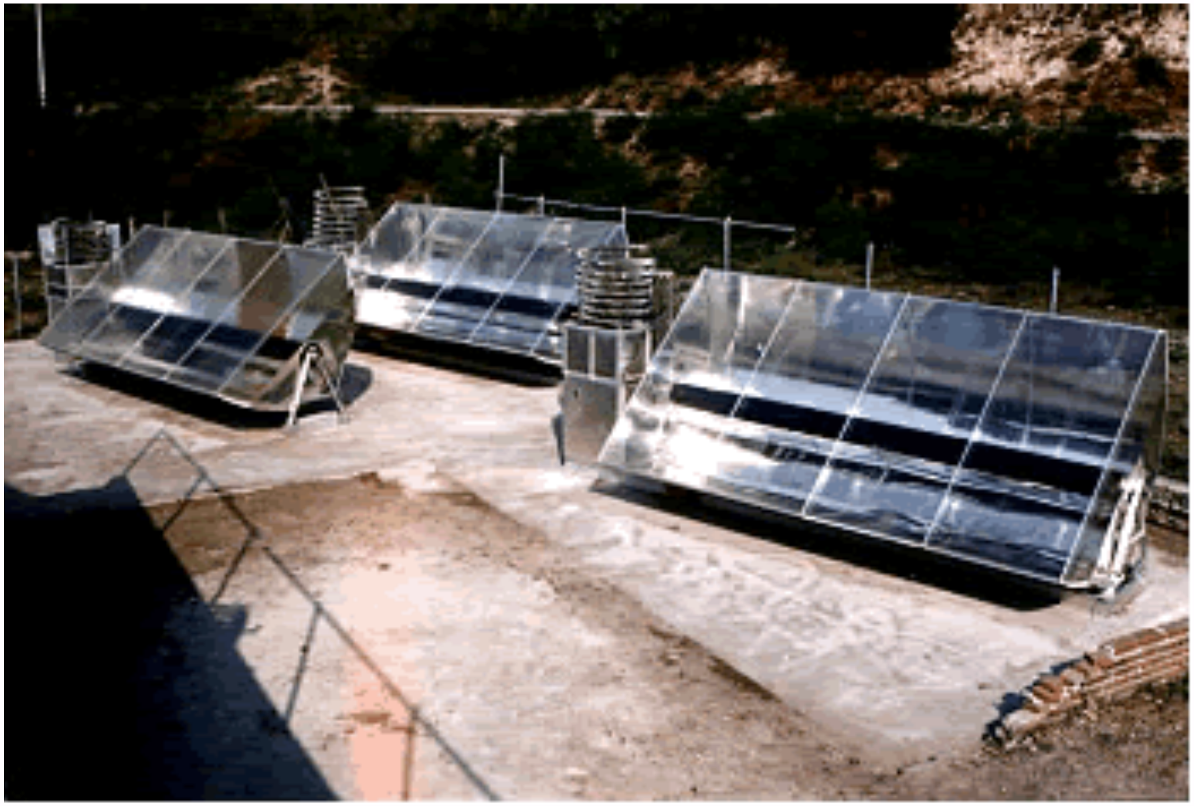


FIGURE 6.25 Duhring chart of the water–lithium bromide absorption cycle.

SOPOGY Solar Air Conditioning LiBr



Issac Ice Maker (http://www.energy-concepts.com/isaac)



Ted Talk on Developing World Refrigerator

Solar Cooking

Figure 6-1 *A solar cooker being used in the developing world.* Image courtesy Tom Sponheim.

Project 11: Build a Solar Cooker

You will need

- Sheet of thin MDF
- Sheet of flexible mirror plastic
- Sheet of thin polystyrene
- Veneer panel pins

Tools

- Bandsaw
- Pin hammer
- Sharp knife/scalpel
- Angle marking gauge

This solar cooker is a very simple project to construct—we will be harnessing the sun's energy from a relatively wide area and concentrating it to a smaller area using mirrors (read more in Chapter 8 about this). The area which we will concentrate it into will be lined with polystyrene to keep in the heat.

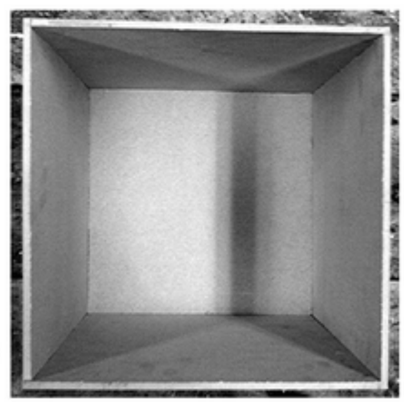


Figure 6-6 *The box constructed from MDF.*

Construct a box for your cooker out of MDF. I find small veneer pins to be very useful as they can be hammered neatly into the end grain of thin MDF without splitting the wood. For this application they are perfectly strong enough. When you have finished the box it should look something like Figure 6-6.

Now you need to line the box with polystyrene, this will prevent the heat from escaping. The lined box will look like Figure 6-7.

Now measure the size of the cube inside the lined polystyrene box. You should cut the mirror plastic to this size, and further line the box with it. Duck Tape is more than ideal for making good all of the joints and securing things into place.

We now need to cut the mirrored reflectors. Cut a strip of mirror plastic about two feet wide on the bandsaw. Now, using an angle marking gauge, mark from the long side of the mirror to the very corner of the mirror, a line which makes an angle of 67°, forming a right-angled triangle in the scrap piece of plastic. You now need to mark out a series of trapeziums along this length of mirror, where

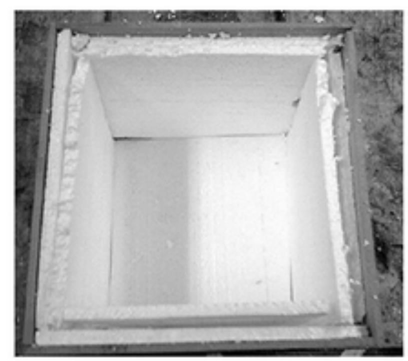


Figure 6-7 *The box lined with polystyrene.*

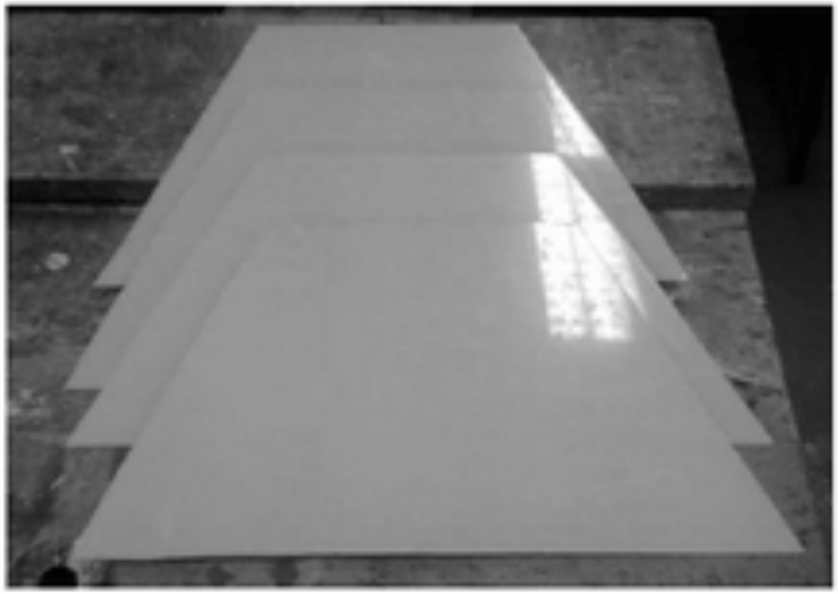


Figure 6-8 *The mirrored reflectors cut ready.*

the shortest side is equal to the length of the inside of the box cooker (Figure 6-8).

Now take the mirrored reflectors, and on the nonreflective side, use Duck Tape to join them together to form the reflector which will sit on the top. Using Duck Tape allows you to make flexible hinges, which allow the reflector to be folded and stored out of the way.

Figure 6-9 *The solar cooker ready and complete.*

When the cooker is finished it will look like Figure 6-9. It is now ready for cooking!

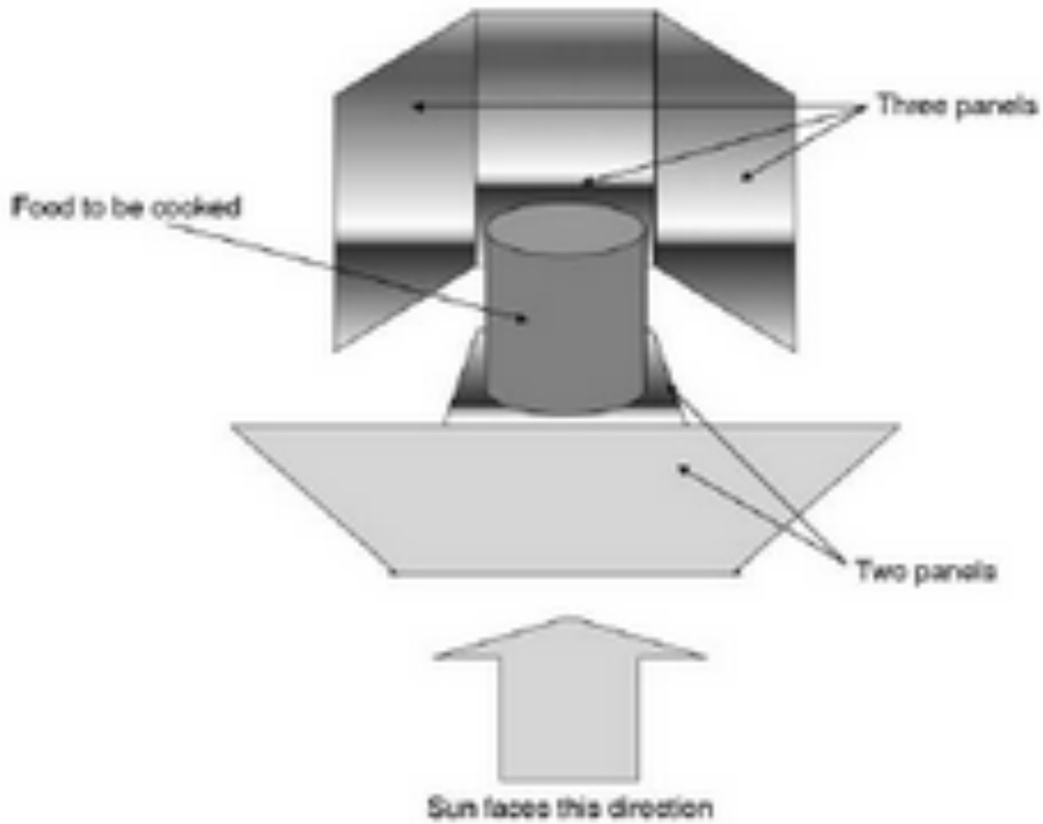


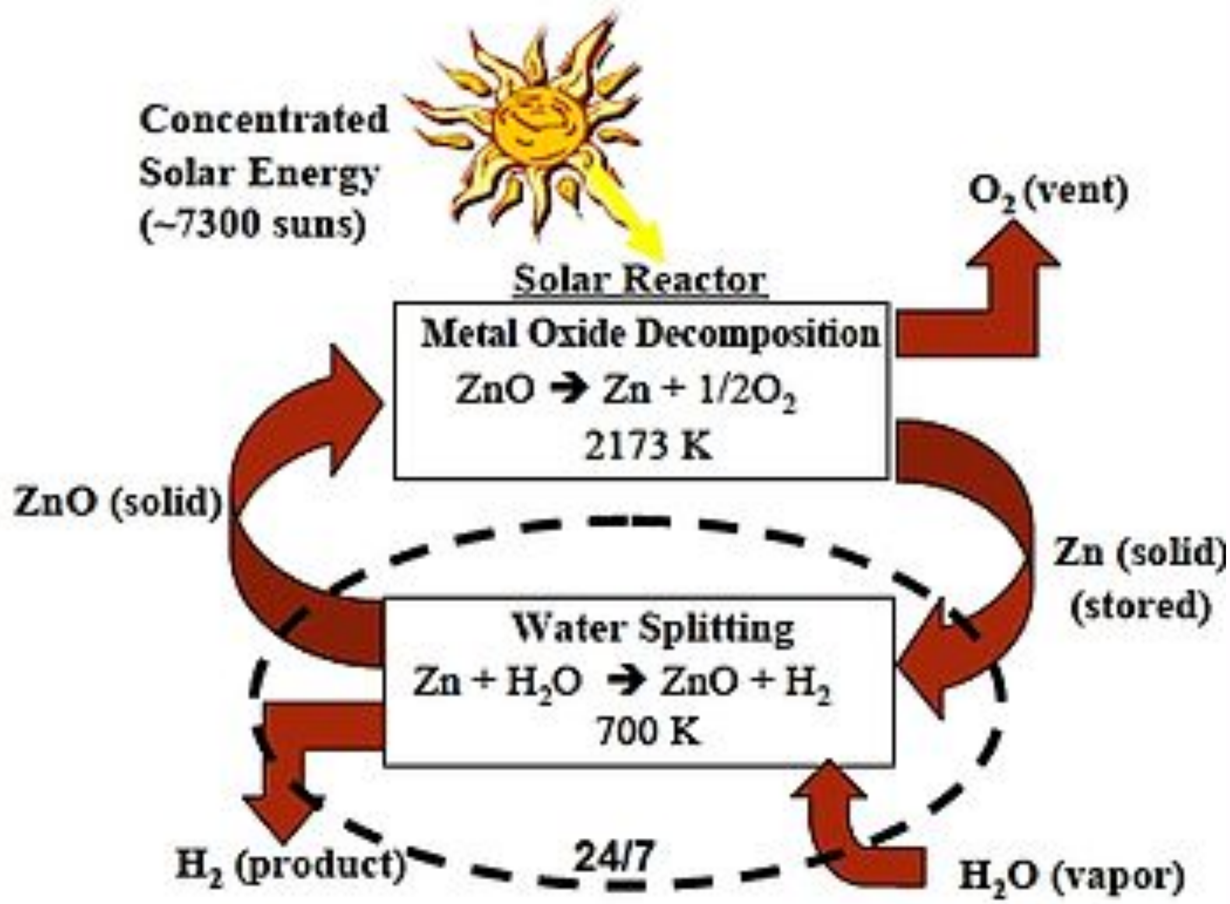
Figure 6-10 *The set-up solar stove.*

Go Sun Stove (http://www.kickstarter.com/projects/707808908/gosun-stove-portable-high-efficiency-solar-cooker)

Solar Cookers International (http://video.nationalgeographic.com/video/environment/energy-environment/solar-cooking/)

Zn => ZnO Cycle
(Solar Driven Redox Reactions)

Zn => ZnO Cycle (http://en.wikipedia.org/wiki/Zinc%E2%80%93zinc_oxide_cycle)



UNLV (http://www.hydrogen.energy.gov/pdfs/review06/pd_10_weimer.pdf)

PSI/ETHZ (http://www.psi.ch/lst/)

Biomass/Syngas

Biomass/Syngas

Single House Biogas (http://www.youtube.com/watch?v=3th2bcqHbsk)

Moderate Scale Plant (http://www.dailymotion.com/video/xit4aj_xylowatt-biomass-gasification-renewable-syngas_tech)

Biogas in Kenya (http://www.youtube.com/watch?v=qh3mmgiybTw)

Solar Thermolysis

Extreme House (http://www.youtube.com/watch?v=xEdQRVQtffw)

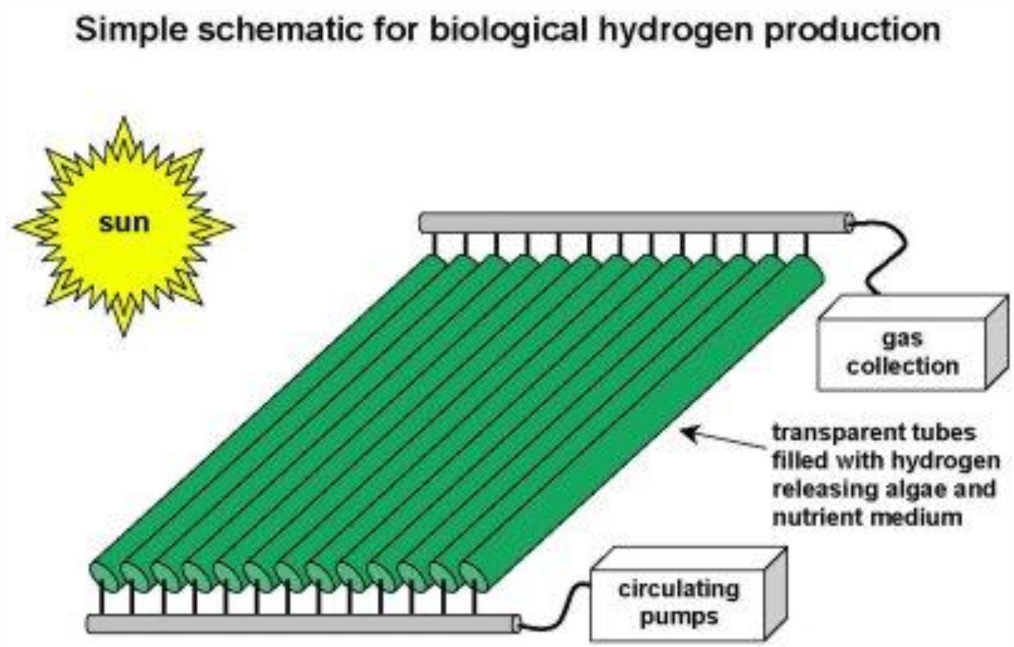
Direct solar theromlysis (http://www.youtube.com/watch?v=fBLGIVm-B2A)

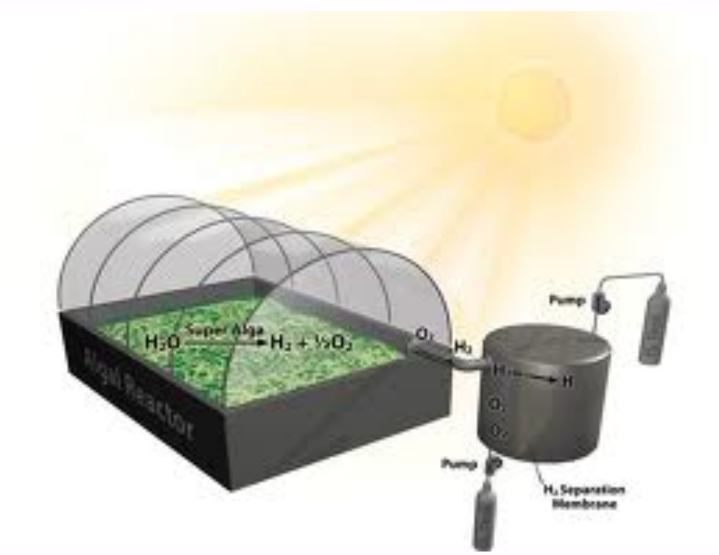
Titania Catalyst (http://www.youtube.com/watch?v=8kJqsDh8cs0)

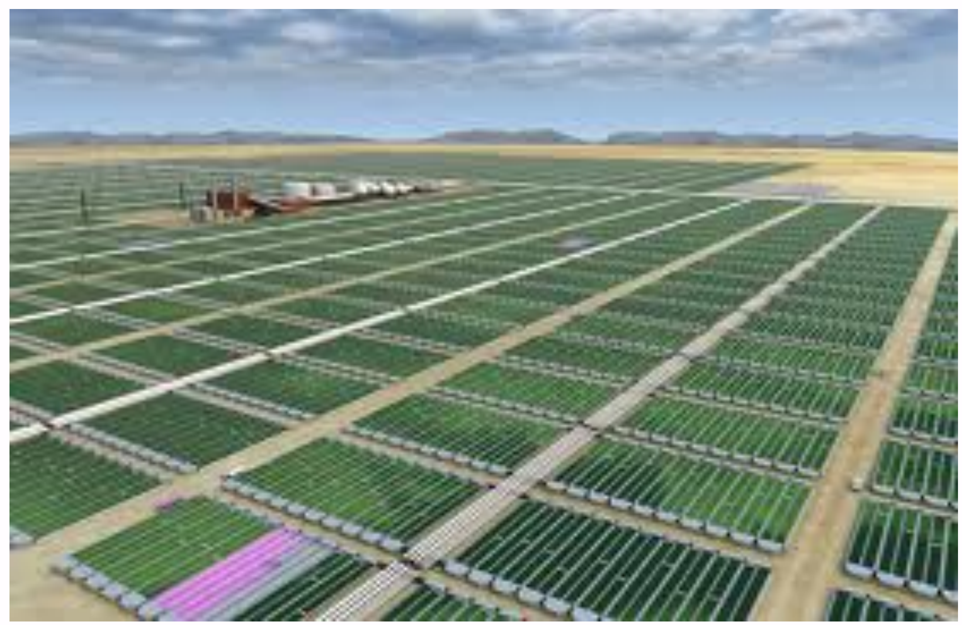
Algae Tower

[CNET Algae Tower](http://www.youtube.com/watch?v=DXLy6E9iEnI) (http://
www.youtube.com/watch?v=DXLy6E9iEnI)

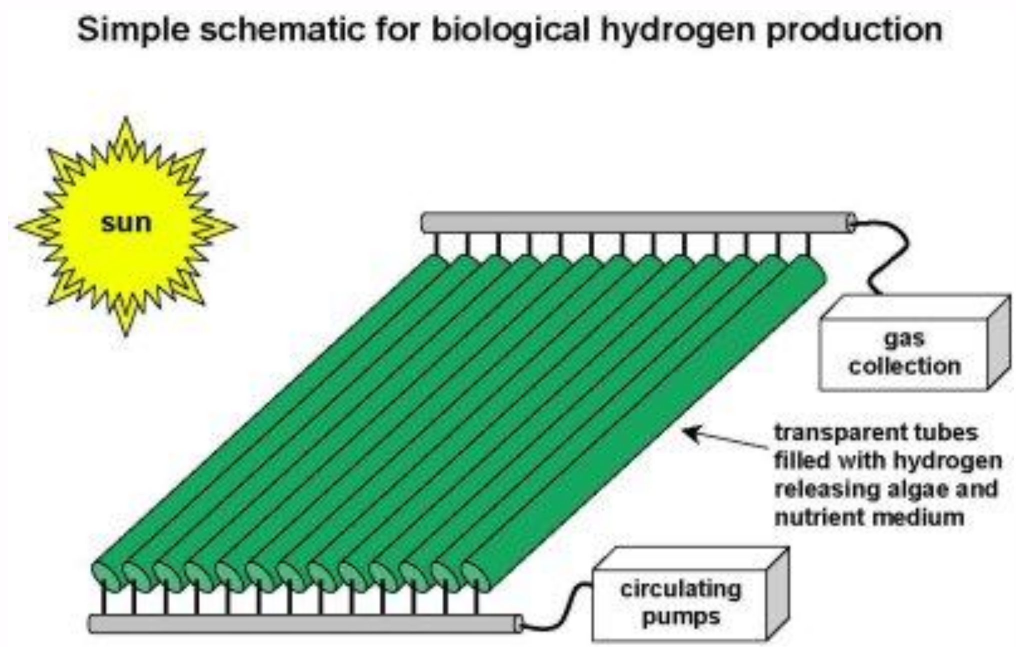
[NASA Algae Project](http://www.youtube.com/watch?v=c7Goyg12Reg) (http://
www.youtube.com/watch?v=c7Goyg12Reg)







Algae Tower



[Hydrogen from Algae](http://www.youtube.com/watch?v=Or_F6qC0sK4)
(http://www.youtube.com/watch?v=Or_F6qC0sK4)

[Hydrogen from Algae Imperial College](https://www.youtube.com/watch?v=OFByDMRbucs)
(https://www.youtube.com/watch?v=OFByDMRbucs)

FIGURE 10.2 Photograph of a SEGS plant (source: www.energylan.sandia.gov/sunlab/Snapshot/TROUGHS.HTM).

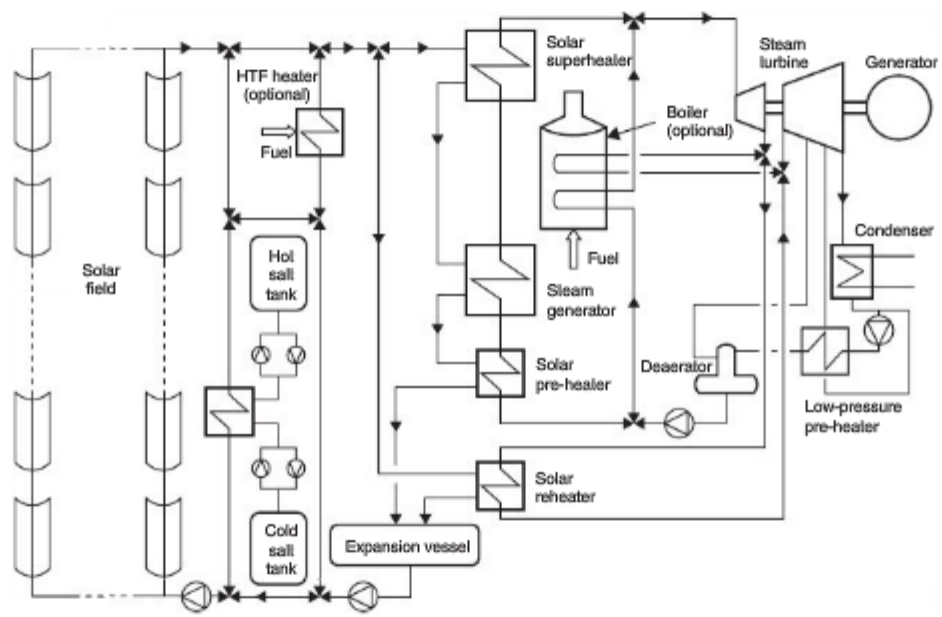


FIGURE 10.3 Schematic diagram of a solar Rankine parabolic trough system.

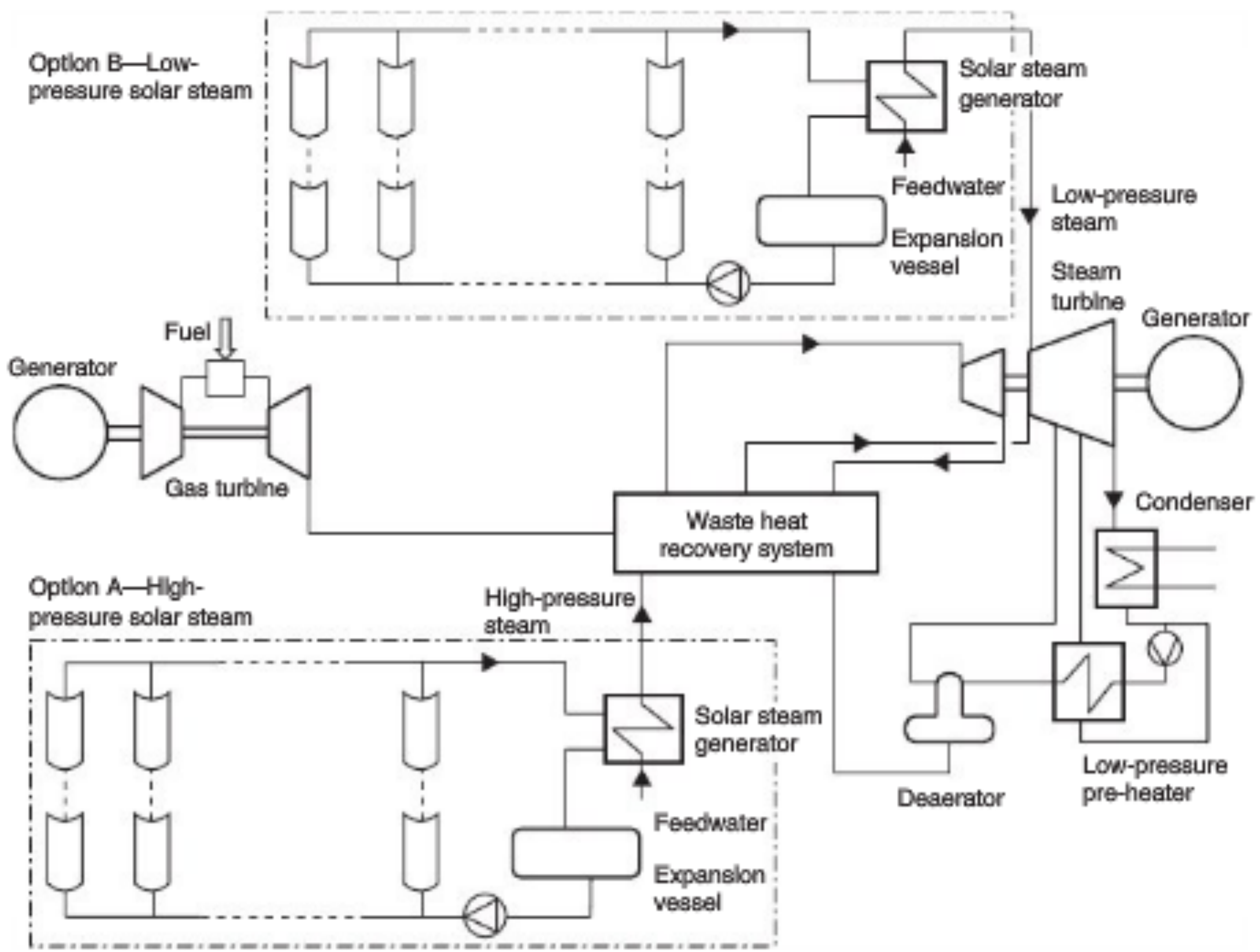


FIGURE 10.4 Schematic diagram of the integrated solar combined-cycle plant.

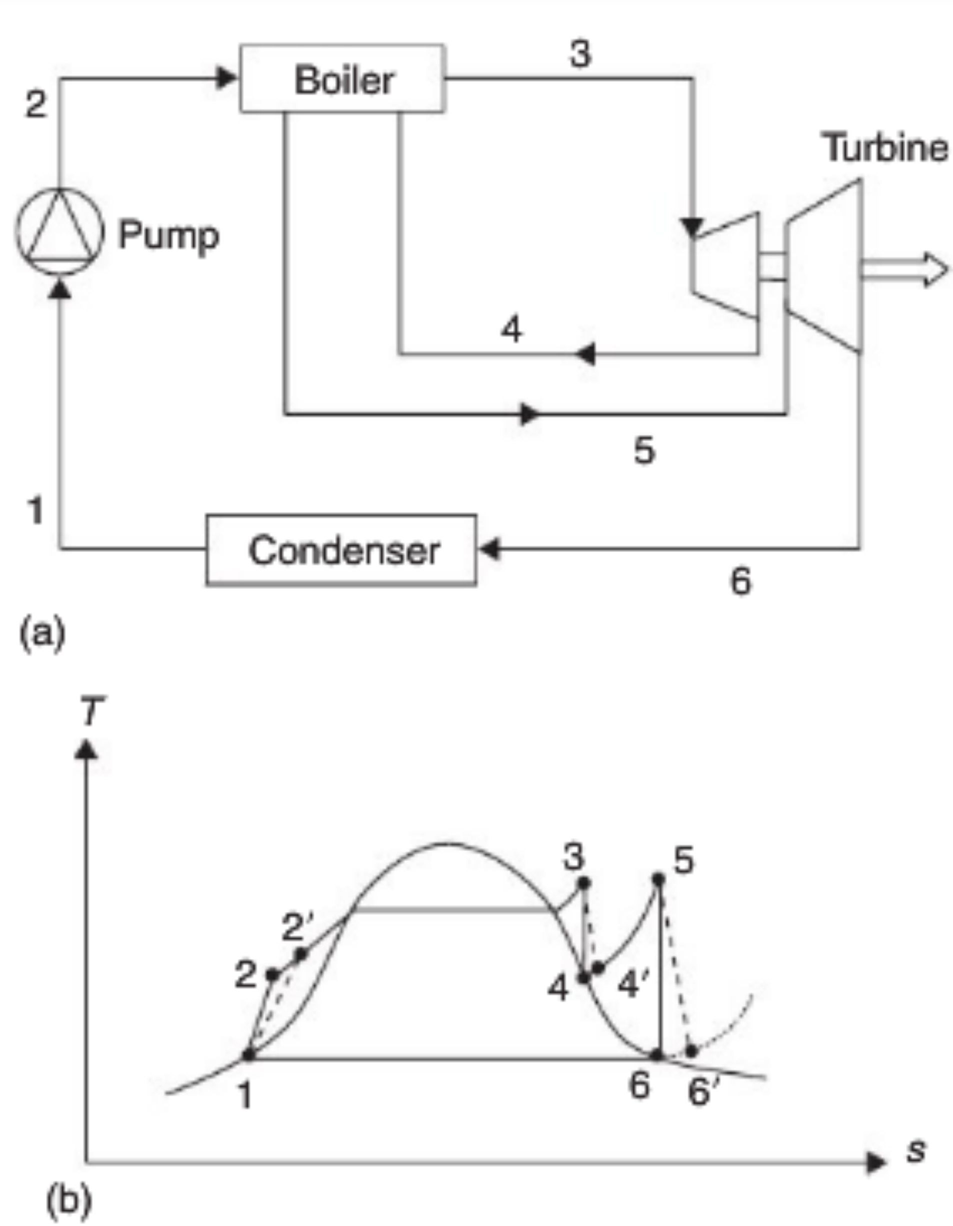


FIGURE 10.10 Reheat Rankine power plant cycle. (a) Reheat Rankine cycle schematic.