

Solar Thermal Systems: Overview and Key Technologies

1. Introduction to Solar Thermal Systems

Solar thermal systems harness the sun's energy to generate heat, which is then used directly for applications like water and space heating, power generation, refrigeration, and more. These systems typically use collectors or concentrators to absorb and transfer solar energy to a working fluid (water, air, oil). Key advantages include high energy efficiency, reduced greenhouse gas emissions, and the ability to be integrated with thermal storage for continuous availability.

2. Basics of Thermodynamics and Heat Transfer

Thermodynamics governs energy conversion in solar thermal systems:

- **First Law:** Energy conservation. Input solar energy equals the sum of useful output and losses.
- **Second Law:** Maximum efficiency is always less than 100% due to inevitable losses.
- **Energy Conversions:** Solar (radiative) energy is converted into sensible or latent heat.

Heat Transfer Mechanisms:

- **Radiation:** Sun's energy absorbed by a collector's surface.
- **Conduction:** Heat flows through the collector material to the working fluid.
- **Convection:** Fluid movement transfers heat away from the collector into storage or application.

Efficiency depends on maximizing absorption and minimizing conduction and convection losses.

3. Flat Plate Collector (FPC)

Working Principle

- A flat, dark-coated absorber plate collects solar radiation, increasing its temperature.
- Metal tubes bonded to the plate carry a working fluid (water/glycol solution) which absorbs the transferred heat.
- Covers (glass/plastic) reduce convective/radiative loss; insulation minimizes heat escape from back and sides.

Features

- Operate efficiently up to ~80–100°C.
- Simple, robust, low-maintenance.
- Widely used for residential and commercial hot water, solar space heating, and pool heating.

4. Evacuated Tubular Collector (ETC)

Working Principle

- Rows of parallel glass tubes contain an absorber surface (sometimes with a heat pipe).
- The space between the inner and outer tubes is evacuated (vacuum), drastically reducing heat losses by conduction and convection.
- More efficient in cold or cloudy climates and can achieve higher temperatures—up to 150°C or more.

Use Cases

- Domestic/large-scale hot water, process steam, space heating.

5. Solar Air Collector

Principle

- Similar to water systems, but air is the working fluid.
- Sun heats an absorber plate; air is blown or drawn across or through it.
- Used for space heating, crop drying, and ventilation preheating in buildings.

Key Points

- Simple and freeze-proof since no liquid is used.
- Typically lower thermal capacity than water-based systems.

6. Solar Concentrator

Types & Function

- Mirrors or lenses focus sunlight onto a small receiver area, increasing heat intensity.
- Types: Parabolic troughs, dishes, Fresnel reflectors, central towers.
- Achieves temperatures up to 400–1,000°C, suitable for power generation (steam turbines), industrial process heat, or high-efficiency solar cookers.

Advantages

- Higher temperatures than flat plate or tubular collectors.
- Can be coupled with thermal storage for grid power.

7. Solar Distillation

Principle

- Used for water purification via solar stills.
- Water is evaporated using solar heat and condensed on a glass cover, collecting as distilled water.
- Simple, reliable, with minimal maintenance, suited for small-scale desalination or potable water provision.

8. Solar Cooker

Types

- **Box Cookers:** Insulated box with transparent lid traps heat.
- **Parabolic Dish Cookers:** Use mirrors to focus sunlight to a cooking vessel.
- **Panel Cookers:** Simple reflective panels focus sunlight.

Features

- Eco-friendly, no fuel required.
- Ideal for slow cooking and places with abundant sunlight.

Limitations

- Dependent on weather and sunlight availability.
- Cooking time longer than conventional stoves.

9. Solar Refrigeration and Air Conditioning

Main Methods

- **Absorption Refrigeration:** Uses solar-heated fluid to drive a cooling cycle (ammonia-water or lithium bromide systems).
- **Adsorption Chillers:** Leverage heat-driven adsorption cycles using special materials.
- **Desiccant Cooling:** Air is passed through solar-regenerated desiccants.
- **Photovoltaic-Driven Systems:** PV panels generate electricity that powers conventional refrigeration.

Benefits

- Efficient use of solar for cooling, especially in off-grid or remote areas.
- Reduces grid demand and overall emissions.

10. Thermal Energy Storage Systems

Purpose

- Store solar heat for use during cloudy periods or nighttime.
- Extends usability and reliability of all solar thermal systems.

Types

- **Sensible Heat Storage:** Using water, sand, rocks, or molten salts to store heat based on temperature change.
- **Latent Heat Storage:** Uses phase change materials (e.g., paraffin wax, salt hydrates) for higher energy density.
- **Thermochemical Storage:** Involves reversible chemical reactions for high-capacity storage.

Applications

- Solar water heating, district heating, industrial processes, and electricity production in combined solar-thermal power plants.

Summary Table: Key Features of Solar Thermal Components

Technology	Working Principle	Key Applications	Typical Temps (°C)
Flat Plate Collector	Absorption, conduction	Water heating, space heating	30–100
Evacuated Tubular Collector	Absorption, vacuum	Hot water, process heat	up to 150
Solar Air Collector	Heating air, convection	Space heating, crop drying	30–80
Solar Concentrator	Focused radiation	Steam, power generation, cooking	100–1,000
Solar Distillation	Evaporation, condensation	Water purification	Ambient–70
Solar Cooker	Concentration/conversion	Cooking food	up to 200
Solar Refrigeration & AC	Sorption/electrical	Cooling and air conditioning	Variable
Thermal Energy Storage	Sensible/latent/chem.	All of the above systems	Variable

Solar thermal technologies form a versatile family of engineering solutions that provide sustainable heating, cooling, cooking, and power—promoting energy independence and environmental stewardship.