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Chapter 2: Thermal conversion: low temperature application

II.1 Introduction:

Low-temperature thermal conversion is a process that converts solar radiation energy into usable heat, generally for domestic, agricultural, or light industrial applications. It is referred to as **low-temperature** when the operating temperature is below **100 °C**, and in some cases, up to **150 °C**.

This form of conversion is the simplest and most widespread because it does not require radiation concentration or complex devices. It mainly relies on the use of **flat-plate or air solar collectors**, **solar distillers**, **solar pumps**, etc., which absorb solar radiation and transfer it to a **heat-transfer fluid** (water, air, oil, etc.). Typical applications of Low-temperature thermal conversion include:

- ➢ domestic hot water heating,
- ➢ space heating for buildings,
- ➢ solar drying of agricultural products,
- ➢ preheating of industrial fluids.

This technology offers several advantages:

- ✓ it is environmentally friendly, silent, and renewable;
- ✓ it helps reduce fossil fuel consumption;
- ✓ it is economically affordable and easy to maintain.

Thus, **low-temperature solar thermal conversion** represents a **sustainable and efficient solution** for harnessing solar energy in many everyday applications.

II.2 Flat-Plate Thermal Collectors

I.2.1 Definition

A **flat-plate solar thermal collector** is a device that converts **solar radiation into heat** and transfers it to a **heat-transfer fluid** (water, air, oil, etc.). It is the most widely used type of solar collector for:

- domestic hot water heating,
- space heating of buildings,
- solar drying,
- swimming pool heating.

A. Water Solar Collector

The water solar collector is illustrated in Figure II.1, it is composed by the following components (Table 1):

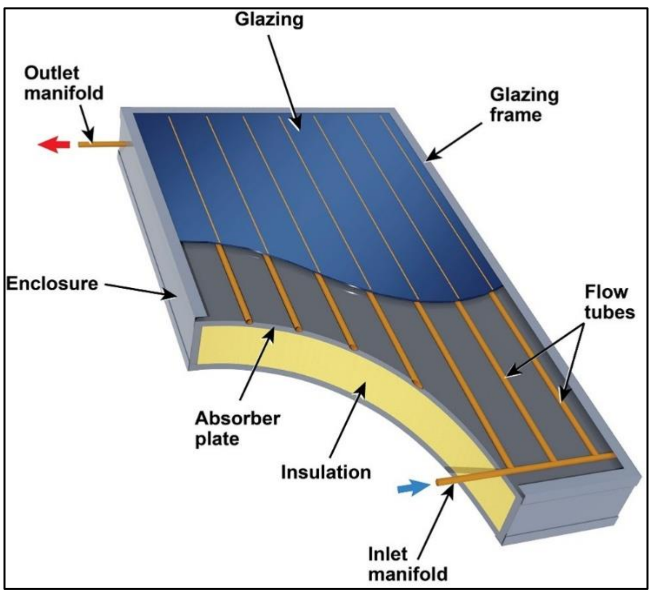

Figure II.1 : Water solar collector.

Table1. Component of water solar collector.

Component	Function	Common Materials
Transparent cover (glazing)	Allows solar radiation to pass through and reduces thermal losses	Tempered glass, Plexiglas
Absorber plate	Absorbs radiation and heats the fluid	Copper, aluminum with selective black coating

Component	Function	Common Materials
Heat-transfer tubes	Transport the working fluid	Copper or steel
Thermal insulation	Reduces conduction losses	Glass wool, polyurethane
Casing	Provides mechanical protection	Galvanized steel, aluminum

Principle: The heat-transfer fluid is **water** (or a **water–antifreeze mixture**). Solar radiation is absorbed by a **black metallic plate**, which transfers the heat to **tubes containing the fluid**.

This type of collector has many applications as;

- Domestic hot water heating
- Swimming pool heating
- Space heating (via underfloor systems or radiators)

It has also many advantages:

- ✓ High thermal efficiency (60–75%)
- ✓ Good thermal stability of the fluid
- ✓ Possibility of heat storage in tanks

The disadvantages of this collector:

- Risk of freezing in winter
- More expensive and complex system (requires sealing and corrosion protection)

B. Air Solar Collector

The air solar collector is noted in Figure II.2, the same components are noted as the water solar collector (Table 1), in this case we have not tubes.

Principle:

The heat-transfer fluid is **air**. The air flows between the **absorber** and a **transparent plate**, becomes heated, and is then directed toward the application (drying chamber, building, etc.).

Applications:

• Solar drying of agricultural products

• Space heating (ambient air)

• Preheating of ventilation air

Advantages:

• No risk of freezing or leakage

• Simple construction and easy maintenance

• Ideal for rural and agricultural environments

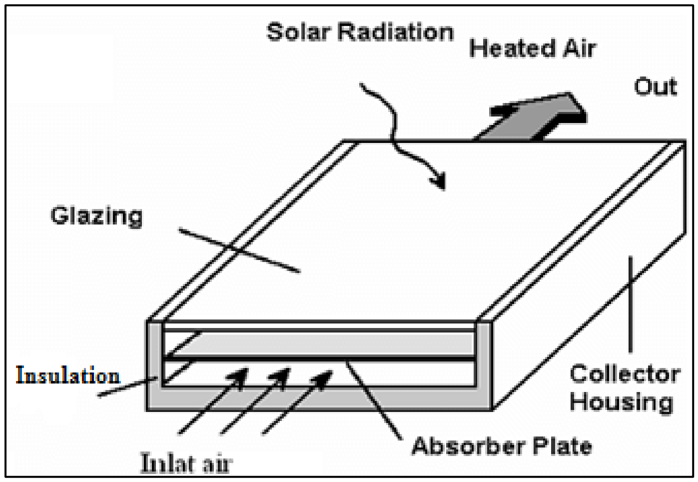

Figure II.2 : Air solar collector.

Disadvantages:

• Low heat capacity of air → lower efficiency (30–55%)

• Difficulty in storing heat

II.2.3 Simplified energy balance

The useful energy recovered (by air or water) is expressed as:

$$Q_u = m \times \dot{C_p} \times (T_s - T_e) \qquad (2.1)$$

where:

• Qu: useful power (W)

• m˙: mass flow rate of the fluid (kg/s)

• Cp: specific heat capacity of the fluid (J/kg·K)

• Ts and Te ; outlet and inlet temperatures (°C or K)

II.2.4 Thermal Collector Efficiency

The **instantaneous efficiency** (η) of a flat-plate solar collector is defined as the ratio between the **useful energy** actually recovered by the heat-transfer fluid and the **incident solar energy** received on the collector surface:

$$\eta = \frac{Q_u}{A_c \times G} \qquad (2.2)$$

where:

- Qu = useful power transferred to the fluid (W),
- Ac= effective area of the collector (m²),
- G = incident solar radiation on the plane of the collector (W/m²).

II.2.5 Theoretical Efficiency (Experimental Formula)

In practice, the efficiency varies with:

- the mean temperature of the collector,
- the ambient temperature,
- the level of solar irradiance.

The experimental (linearized) relationship is:

$$\eta = \eta_0 - \alpha_1 \frac{(T_m - T_0)}{G} \qquad (2.3)$$

or, more precisely:

$$\eta = \eta_0 - \alpha_1 \frac{(T_m - T_0)}{G} - \alpha_2 (\frac{(T_m - T_0)}{G})^2 \qquad (2.3)$$

where:

- **η_0** : optical efficiency (without losses, typically between 0.7 and 0.8),
- **α_1** : linear heat loss coefficient (W/m²·K),
- **α_2** : quadratic heat loss coefficient (W/m²·K²),
- **$T_m = (T_s + T_e)/2$** : mean temperature of the heat transfer fluid,
- **T_a** : ambient air temperature.

Interpretation of Parameters

Term	Meaning
η_0	Maximum efficiency when the collector is not yet hot
α_1	Losses due to convection and conduction
α_2	Radiative losses, significant at high temperature
$(T_m - T_a)$	Temperature difference between the collector and the air — the greater it is, the higher the losses
G	Solar irradiance — the higher it is, the greater the efficiency

Typical Efficiency According to Collector Type

Collector Type	Optical Efficiency η0	Typical Overall Efficiency	Remarks
Water collector	0.70 – 0.80	**60 – 75%**	Very good heat transfer, limited losses
Air collector	0.50 – 0.65	**30 – 55%**	Higher losses, low heat capacity of air

In summary, **water collectors** show higher efficiency due to the better heat capacity and conductivity of water, while **air collectors**, simpler and more robust, are better suited for agricultural applications such as **solar drying**.

II.3 Solar distillers

II.3.1 Definition: A solar distiller is a device that uses solar energy to evaporate contaminated or salty water and then condenses the resulting vapor into pure water. Its purpose is to produce drinking water with low energy cost and without the use of fossil fuels. It operates on a simple principle: solar energy heats the water until it evaporates, the vapor then condenses on a cooler surface, allowing the collection of distilled water.

Main Components of the Solar Distiller (Figure3)

• **Transparent cover (glass or polycarbonate):** allows solar radiation to pass through and enables condensation.

• **Absorbing basin (usually black):** captures heat.

• **Thermal insulation:** minimizes heat losses.

• **Collection system:** channel used to collect the distilled water

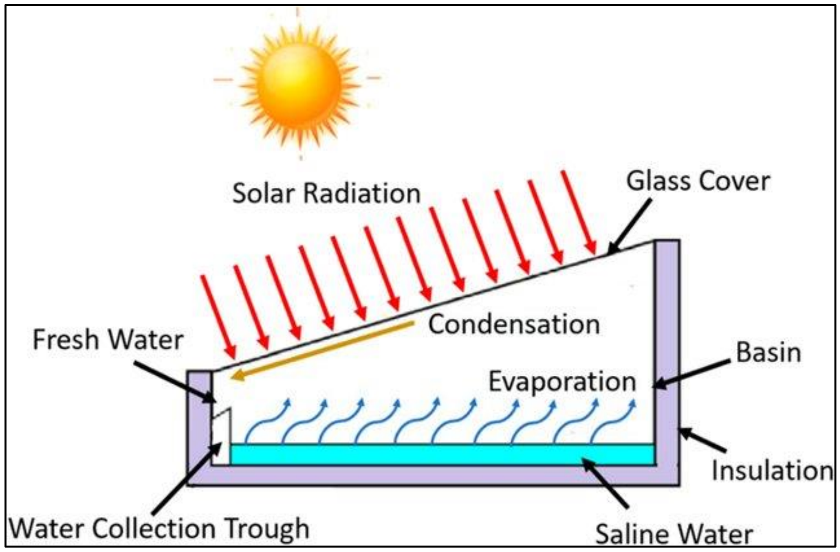

Figure 3 : Principle of operation of a solar distiller [web1].

II.3.2 Types of Solar distillers

All types of solar distillers operate based on the same principle; they differ only in terms of performance, design, and construction materials. The main types are distinguished as follows:

II.3.2.1 Simple Distiller (Conventional or Single-Slope Type)

The single-slope solar distiller, illustrated in Figure 4, is the simplest and most widely used type in the world. It consists of a shallow basin horizontally filled with saline, slightly impure, or brackish water, covered with a transparent glass surface inclined at a certain angle to maximize solar exposure. The condensed water droplets then flow into a gutter located at the bottom of the glass surface, where the distilled water is collected and stored. To minimize energy losses, the unit is equipped with thermal insulation at the bottom and on both sides.

II.3.2.2 Double-Slope Distiller

The double-slope distiller operates on the same principle as the single-slope type but consists of two glass covers, each inclined at an angle (Figure 5). The advantage of this design is that one cover is exposed to sunlight while the other remains in the shade, which helps to accelerate the condensation process.

II.3.2.3 Spherical Solar Distiller

The spherical solar distiller consists of a transparent dome (made of glass or plastic) covering a hemispherical or circular basin. The dome acts as an omnidirectional greenhouse, capturing sunlight from all angles. Condensation occurs on the inner surface of the dome, and the distilled water flows down into a circular collector.

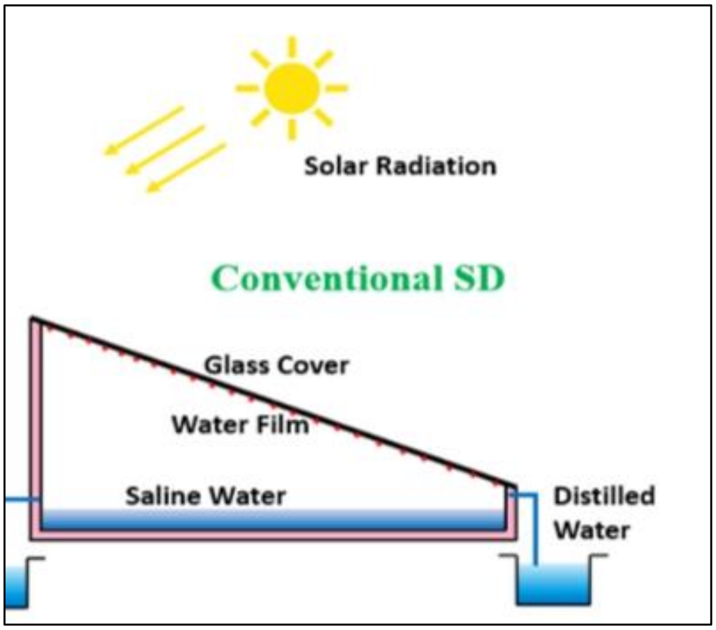

Figure : A simple Solar distiller [web2]

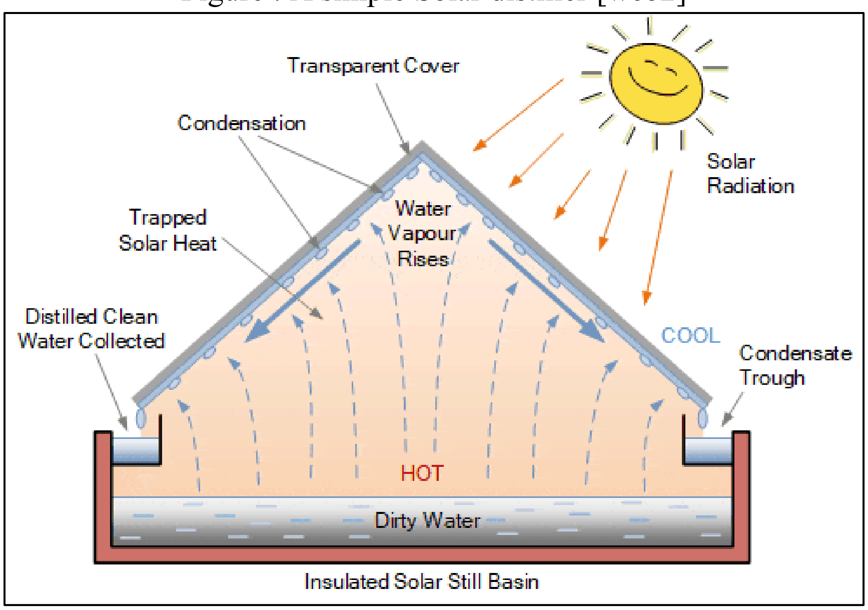

Figure5 : A double slope distiller [web3].

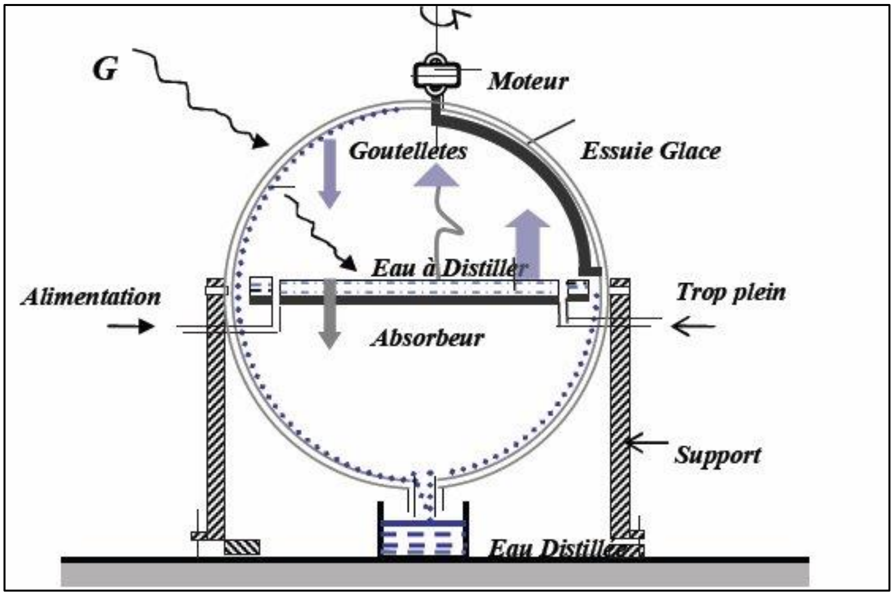

Figure 6: Spherical Solar Distiller [web 4].

II.3.3 Parameters Affecting the Operation of the Distiller

These factors were considered in our research based on the conventional solar distiller.

II.3.3.1 Geometric Parameters

➢ **Solar Radiation Intensity:**

The intensity of solar radiation is the most important factor influencing water production, as it directly affects the temperature of the water to be distilled [32].

➢ **Wind Speed:**

Wind speed affects the operation of the still; when it is strong, it causes a decrease in temperature, which can reduce efficiency.

➢ **Ambient Temperature:**

This temperature influences heat exchanges between the internal and external parts of the system. It has been observed that the distillate productivity slightly increases with higher ambient temperature.

II.3.3.2 Construction Parameters

➢ **Cover:**

The cover serves as the condensation surface. It must be wettable, safe, and resistant to wind shocks and solid particles. The cover is selected based on:

- Its nature (glass),
- Its wettability by water,
- Its transparency to solar radiation.

➢ **Inclination:**

The inclination of the cover with respect to the horizontal determines the amount of solar energy entering the distiller and helps reduce the distance between the saline water and the glass. The inclination angle must be carefully chosen. It also influences the energy balance equations of the various components of the distiller.

➢ **Absorber:**

Studies conducted by several researchers have shown that the absorbing surface can be made of different materials (wood, metal, concrete, synthetic material, or ordinary glass). The choice of material and construction method has a significant impact on the performance of the distiller.

II.3.4 Energy Balance for the Simplified Distiller

The thermal efficiency of the distiller is given by:

$$\eta = \frac{m_{evap} \times Lv}{Gt \times A}$$

Where:

m_{evapm} = mass of evaporated water (kg),

Lv= latent heat of vaporization (≈ 2.26×10^6 J/kg),

Gt = solar energy received (J/m^2),

A= surface area of the distiller (m^2).

Typical efficiency: **30–45%** for a simple distiller.

To characterize a distiller in a more absolute way, **gross performance factor (G.P.F)** and **hourly performance factor (H.P.F)** have been developed:

Gross Performance Factor (G.P.F)

This is a global indicator that evaluates the daily efficiency of the solar distiller. It relates the total amount of distilled water produced during a day to the total solar energy received on the surface of the distiller.

$$FPB = \frac{m_d \times L}{A \times \int_0^t G(t)dt}$$

Where:

• mdm_dmd: total mass of distilled water (kg/day)

• LLL: latent heat of vaporization of water (J/kg)

• AAA: surface area of the distiller basin (m²)

• ∫0tG(t) dt: solar energy received (J/m²) during the day

Hourly Performance Factor (H.P.F)

It represents the instantaneous or hourly efficiency of the distiller. This is a more detailed measure that allows studying the system's performance according to the climatic conditions throughout the day.

$$FPH = \frac{\dot{m}_d(t) \times L}{A \times G(t)}$$

Where:

• $\dot{m}_d(t)$: hourly flow rate of distilled water (kg/h)

• G(t) : instantaneous solar flux (W/m²)

Interpretation:

The **H.P.F** allows monitoring the variations in efficiency throughout the day (often reaching its maximum between 12:00 p.m. and 2:00 p.m.).

Possible Improvements:

- Use of **phase change materials (PCM)** for heat storage.
- **Coupling** with **flat-plate solar collectors**.
- Use of **reflective mirrors** to increase solar flux.
- **Multi-effect distillation** or **hybrid PV–thermal systems**.

II.3.5 Importance of Solar Distillers

II.3.5.1. Low-Cost Production of Drinking Water

- Solar distillers make it possible to produce fresh water from salty, brackish, or polluted water using only solar energy.
- Ideal for rural, isolated, or arid areas where drinking water networks are unavailable.
- Requires no fossil fuels or grid electricity.

II.3.5.2. Simple, Clean, and Sustainable Technology

- Operates based on the natural principle of evaporation and condensation.
- Produces no pollutants or toxic waste.
- Easy to maintain and manufacture using local materials (glass, aluminum, plastic).
- Long service life and low maintenance cost.

II.3.5.3. Energy Independence

- Utilizes a free, renewable, and inexhaustible source: solar radiation.
- Independent of energy infrastructure — useful in non-electrified regions.
- Suitable for decentralized drinking water production.

II.3.6.4 Educational and Scientific Approach

- ✓ Solar distillers also serve as educational tools:
- ✓ Study of thermal phenomena (evaporation, condensation, heat transfer).
- ✓ Practical application of concepts related to solar energy and thermal efficiency.
- ✓ University or research projects focused on improving performance (multi-effect, wick-type, double-slope distillers, etc.).

II.4 Solar thermal pump

It is important not to confuse **solar thermal pumps** with **solar photovoltaic pumps**, as both use solar energy but rely on different physical principles. Solar thermal pumps use solar energy to **heat a working fluid** and drive a **thermodynamic cycle** that enables water pumping. They represent an **eco-friendly alternative** to electrically powered pumps, particularly suitable for **rural areas without access to the electrical grid**.

- A **solar thermal pump** uses the **heat from the sun** to produce **mechanical motion**.
- A **photovoltaic pump** converts **sunlight into electricity**, which powers an **electric motor** that drives the pump.

II.4.1 Operating principal of a Solar thermal pump

Solar thermal pumps are devices that use **solar thermal energy (heat from the sun)** to circulate a fluid within a **closed-loop system**, without the need for any external electrical power supply. They play a key role in solar thermal systems for:

- Domestic hot water heating (solar water heaters),

- Building heating,
- Agricultural applications, such as solar drying.

There are two main types:

A. Natural Thermal Pump (Thermosiphon Circulation)

No mechanical pump is used. The movement of the fluid occurs due to the **density difference** between the hot and cold fluid(Figure 7).

- The fluid **heated in the solar collector** becomes lighter and naturally rises toward the storage tank.
- The **cooled fluid** in the tank descends back into the collector.

This phenomenon is called **natural circulation** or the **thermosiphon effect**.

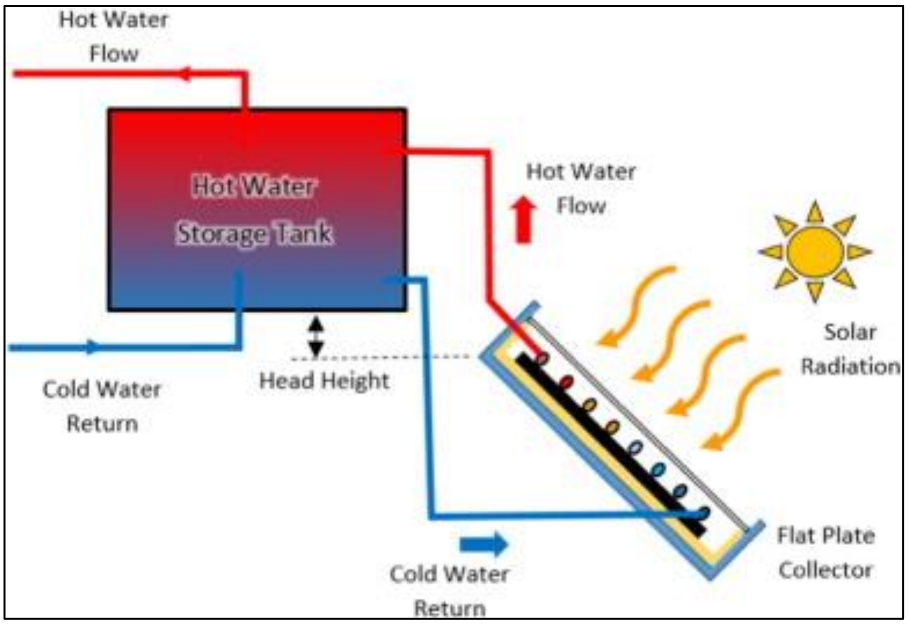

Figure 7: Natural thermal pump.

Advantages:

- No need for electricity.
- Simple, reliable, and requires little maintenance.

Disadvantages:

- Requires the **storage tank to be positioned above** the collector.
- **Limited flow rate** and **high pressure losses**.
- Not suitable for **large-scale installations**.

B. Solar thermal absorption pump

A **solar heat pump** uses the **sun's thermal energy** to drive a **thermodynamic cycle**—most commonly an **absorption** or **adsorption** cycle (Figure 8).

Principle of the Absorption Cycle:

The system consists of the following components:

1. **Solar thermal collector** – heats a heat transfer fluid using solar energy.
2. **Generator** – where solar heat boils a working solution (typically *water–lithium bromide* or *ammonia–water*).
3. **Condenser** – the vapor condenses, releasing useful heat.
4. **Evaporator** – the fluid evaporates at low pressure, absorbing heat from the cold source.
5. **Absorber** – the vapor is reabsorbed into the absorbent solution.

Solar heat acts as the **driving energy source** that circulates the working fluid through the different components.

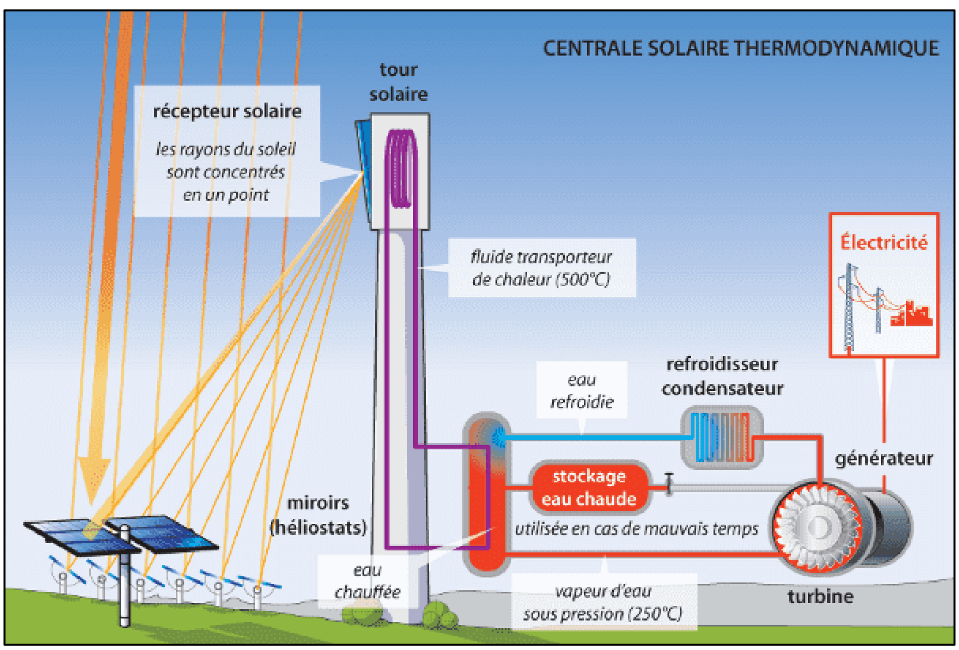

Figure 7: Thermodynamic solar power plan.

Advantages:

- Saves electrical energy.

- Can be combined with **solar air conditioning systems**.
- Environmentally friendly (low CO_2 emissions).

Disadvantages:

- System complexity.
- Efficiency depends on solar temperature levels.
- High initial cost.

The types of Solar Collectors Used (depending on temperature):

1. **Flat-plate glazed collectors:** medium temperatures (40–80 °C)
2. **Evacuated tube collectors:** higher temperatures (up to 150 °C)
3. **Parabolic or concentrating collectors:** high temperatures (150–400 °C), suitable for absorption pumps.

Performance and Efficiency

The **thermal efficiency (η)** of a **solar thermal pump** is given by this equation:

$$\eta=\eta 0-a1(Tm-Ta)/G-a2(Tm-Ta)^2/G$$

where:

- η_0 = optical efficiency (efficiency at ambient temperature)
- a_1, a_2 = thermal loss coefficients ($W/m^2 \cdot K$)
- T_m = mean fluid temperature
- T_a = ambient temperature
- **G** = solar radiation (W/m^2)

This efficiency depends on:

- The **type and efficiency of the solar collector** (flat-plate, evacuated tube, or concentrating).
- The **temperature difference** between the heat source (solar collector) and the sink (working fluid or water).
- The **quality of thermal insulation** and **heat losses** in the system.
- The **type of thermodynamic cycle** used (absorption, adsorption, or other).
- The **solar irradiance** and **climatic conditions** (ambient temperature, wind speed, etc.).
- The **operating conditions**, such as flow rate and pressure of the working fluid.

In general, the overall thermal efficiency of solar thermal pumps ranges between **30% and 60%**, depending on the design and operating parameters.

II.5 Solar urban planning and solar heating of buildings

Solar urban planning aims to design and develop cities in a way that optimizes the use of solar energy — whether for natural lighting, passive heating, photovoltaic electricity generation, or solar thermal heating.

Solar heating of buildings is one of the main applications of this approach: it helps reduce fossil fuel consumption, improve thermal comfort, **and** limit CO_2 emissions.

II.5.1. Objectives of Solar Urban Planning

1. Maximize the capture of **solar radiation** on buildings.
2. Reduce **energy demand** through appropriate orientation and architectural design.
3. Integrate **active and passive solar systems** into housing.
4. Create **positive-energy neighborhoods (PEN)** or **low-energy buildings (LEB)**.

II.5.2. Basic Principles of Solar Urban Planning

a) Orientation and Layout

- Buildings are oriented **due south (±15°)** to capture maximum solar radiation in winter.
- Streets and open spaces are designed to **avoid mutual shading** between buildings.
- **Roof slopes** are optimized (between **30° and 45°**) for the installation of solar collectors.

b) Urban Form and Density

- The **compactness of the built environment** affects energy performance:
  - Overly dense buildings → **mutual shading**.
  - Overly dispersed buildings → **increased heat losses**.
- **Solar urban planning** seeks a **balance between sunlight exposure and urban density**.

c) Materials and Albedo

- Use of **high thermal inertia materials** (such as concrete or stone) to store heat.
- **Reflective surfaces (high albedo)** are used to reduce **summer overheating**.

II.5.3. Solar Heating of Buildings

Solar heating can be achieved through two complementary approaches:

A. Passive Solar Heating

No mechanical systems are required — the **building itself captures and retains heat**.

Principles:

1. **South-facing orientation** → large glazed openings on the south façade.
2. **Trombe walls** → a thick, dark wall placed behind glazing to absorb and slowly release heat.
3. **Solar greenhouses** → glazed spaces that trap warm air.
4. **Thermal inertia** → floors and walls store heat during the day and release it at night.
5. **Efficient insulation** → minimizes thermal losses.

Example:

- A **bioclimatic house** in southern France can meet **60–70% of its heating needs** through **passive solar energy**.

B. Active Solar Heating

Uses **thermal equipment** to **collect, store, and distribute** heat as noted in Table1.

Table 1: Thermal equipment.

Component	Function
Solar thermal collectors	Absorb heat from solar radiation.
Heat transfer fluid	Carries the heat (water or antifreeze).
Heat exchanger	Transfers heat to the building's heating water circuit.
Storage tank	Stores thermal energy for later use.
Backup system	Provides additional heat when needed (boiler, heat pump, etc.).

Types of collectors depending on the operating temperature range:

1. **Flat-plate collectors** – the most common for residential applications.
2. **Evacuated tube collectors** – more efficient during winter.
3. **Concentrating collectors** – used for large-scale or industrial installations.

II.5.4. Architectural and Urban Integration

The integration of solar technologies must take into account:

- The **aesthetics of the building** (panels integrated into roofs or façades).
- **Local urban planning regulations.**
- **Sunlight conditions** and **shading obstacles.**

Solar analysis software (e.g., **Heliodon**, **SketchUp with Sefaira plug-in**, **PVsyst**) can be used to assess:

- **Shaded areas**,
- **Angles of solar incidence**,
- **Solar potential** for each façade or roof.

II.5.4. Benefits of Solar Heating

The benefits of solar heating are regrouped in Table 2.

Table 2: Benefits of Solar Heating

Type of Benefit	Details
Energy	Reduction of 40–80% in heating energy consumption.
Economic	System payback period of 5 to 10 years, depending on the region.
Environmental	Reduction in CO_2 emissions and local pollutants.
Comfort	Stable and well-distributed indoor temperature.

II.5.5 Case Studies

1.Vauban Solar District (Freiburg, Germany) (Figure 8)

Bioclimatic design, photovoltaic and solar thermal roofs, and energy self-sufficiency.

2. Masdar City (United Arab Emirates) (Figure 9)

Urban planning oriented according to **prevailing winds** and **solar radiation** to optimize natural ventilation and solar energy use.

Figure 8: Vauban Solar District (Freiburg, Germany)

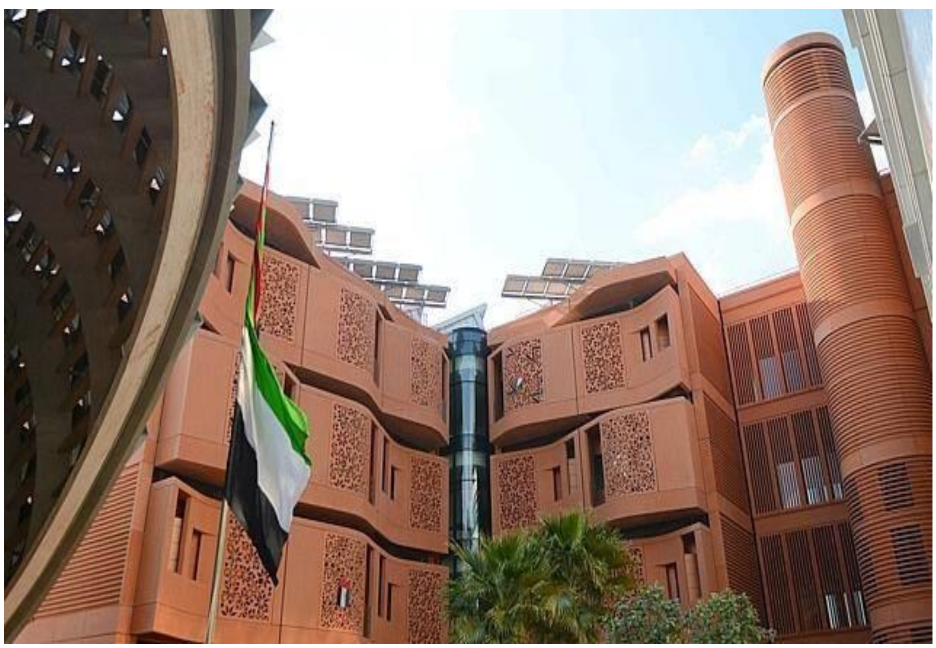

Figure 9: Masdar City (United Arab Emirates)

II.5.6 Solar Urban Planning and Public Policies

Regulations Promoting Solar Urbanism

Although there is currently strong momentum for **solar electricity**, less attention is given to **urban aspects** such as **building orientation**, **integration of solar thermal collectors**, or the **planning of solar neighborhoods**.

However, solar-oriented urban design can optimize natural energy inputs — **light, heat, and ventilation** — and reduce dependence on fossil fuels. Several countries have already introduced **thermal and urban regulations** encouraging the **consideration of solar radiation** in building design (for example: southern orientation, terraced layouts, limitation of shading).

Public policies promoting solar urbanism could include:

- **Tax incentives** for bioclimatic building design;
- **Requirements for solar integration** in new developments;
- **Training programs** for urban planners and architects in urban energy planning;
- **Certification labels** for high solar performance districts.

Thus, solar urbanism is not merely a technical issue but a **matter of territorial governance** and **sustainable energy policy**.

II.6 Coupling of Solar Collectors with Thermal Machines

Solar thermal energy can be used **directly for heating** or **indirectly** to power **thermal machines** such as **heat engines** or **heat pumps**. Solar–thermal machine coupling involves converting the **heat collected by solar collectors** into **mechanical work** or **cooling**, depending on the system configuration.

II.6.1 Types of Solar-Coupled Thermal Machines

A. **Heat Engine Cycles**

These systems convert solar heat into **mechanical or electrical energy**:

- **Rankine cycle** (water vapor or organic fluid)
- **Stirling cycle**
- **Brayton cycle** (air or gas)

Such systems form the basis of **solar thermodynamic power plants**.

B. **Cooling (Receiver) Cycles**

These systems use solar heat to **produce cooling**:

- **Absorption machines** (LiBr–H_2O, NH_3–H_2O)
- **Adsorption machines** (silica gel–water, zeolite–water)
- **Thermal ejector cycles** (steam ejector systems)

These systems are applied in **solar cooling**, **air conditioning**, and **food preservation**.

II.6.2 Solar Thermal Collectors Used

Depending on the **temperature required** by the thermal machine, a suitable type of solar collector is selected:

Type of Collector	Useful Temperature (°C)	Typical Application
Flat-plate collector	40–90	Heating, water preheating
Evacuated tube collector	60–150	Single-effect absorption
Parabolic trough concentrator	150–350	Organic Rankine Cycle (ORC)
Paraboloid / Solar tower concentrator	400–1000	Stirling, steam Rankine, or Brayton cycle

II.6.3 Examples of Possible Couplings

1. Collector + Rankine Cycle

- Solar collectors concentrate radiation to produce steam.
- The steam powers a steam engine or a microturbine.
- The mechanical energy is converted into electricity by an alternator.

- **Example:** Concentrated Solar Power (CSP) plant.

$$\eta_{overall} = \eta_{collector} \times \eta_{cycle} \times \eta_{generator}$$

2. Collector + Absorption Machine

- Solar heat drives the generator of the absorption chiller.
- The system then provides cooling (chilled water or fresh air).

- **Example:** Solar air conditioning for buildings.

$$COP = Q_{cold} / Q_{solar}$$

3. Collector + Stirling Engine

- A parabolic collector focuses solar radiation onto the hot head of the Stirling engine.
- The engine directly converts solar heat into mechanical energy.
- **Efficiency:** high (~30%).

4. Study of Overall Coupling Efficiency

Efficiency of the Complete System

$$\eta_{global} = \eta_{collector} \times \eta_{conversion} \times \eta_{utilization}$$

Numerical Example

$\eta_{collector} = 0.6$, $\eta_{Rankine\ cycle} = 0.25$, $\eta_{generator} = 0.9$

$\eta_{global} = 0.6 \times 0.25 \times 0.9 = 0.135 \Rightarrow 13.5\%$

This means that **13.5% of the incident solar radiation** is converted into electricity.

II.6.4 Advantages and Limitations of Solar Coupling

Advantages	Limitations
Free renewable energy	Intermittent solar resource
Reduction of CO_2 emissions	High initial cost
Production of heat, cooling, or electricity	Requires thermal storage
Adaptable to various thermal machines	Needs precise control

II.6.5 Application Areas

- Solar steam power plants (Morocco, Spain)
- Solar cooling for buildings (Middle East, North Africa)
- Micro-ORC plants for remote villages
- **Solar cogeneration:** simultaneous production of heat and electricity

Coupling solar collectors with thermal machines is a **strategic path toward energy transition**:

- It uses solar radiation as a **primary heat source**.
- It provides **clean and decentralized solutions** for producing thermal, mechanical, or cooling energy.

Recent developments focus on:

- **Advanced heat transfer fluids**,
- **Phase Change Materials (PCM)** for thermal storage,
- **Optimized Organic Rankine Cycles (ORC)** for low-temperature operation.