وزارة التعليم العالي والبحث العلمي

الجامعة التقنية الشمالية

الكلية التقنية الهندسية / الموصل

قسم هندسة تقنيات ميكانيك القوى

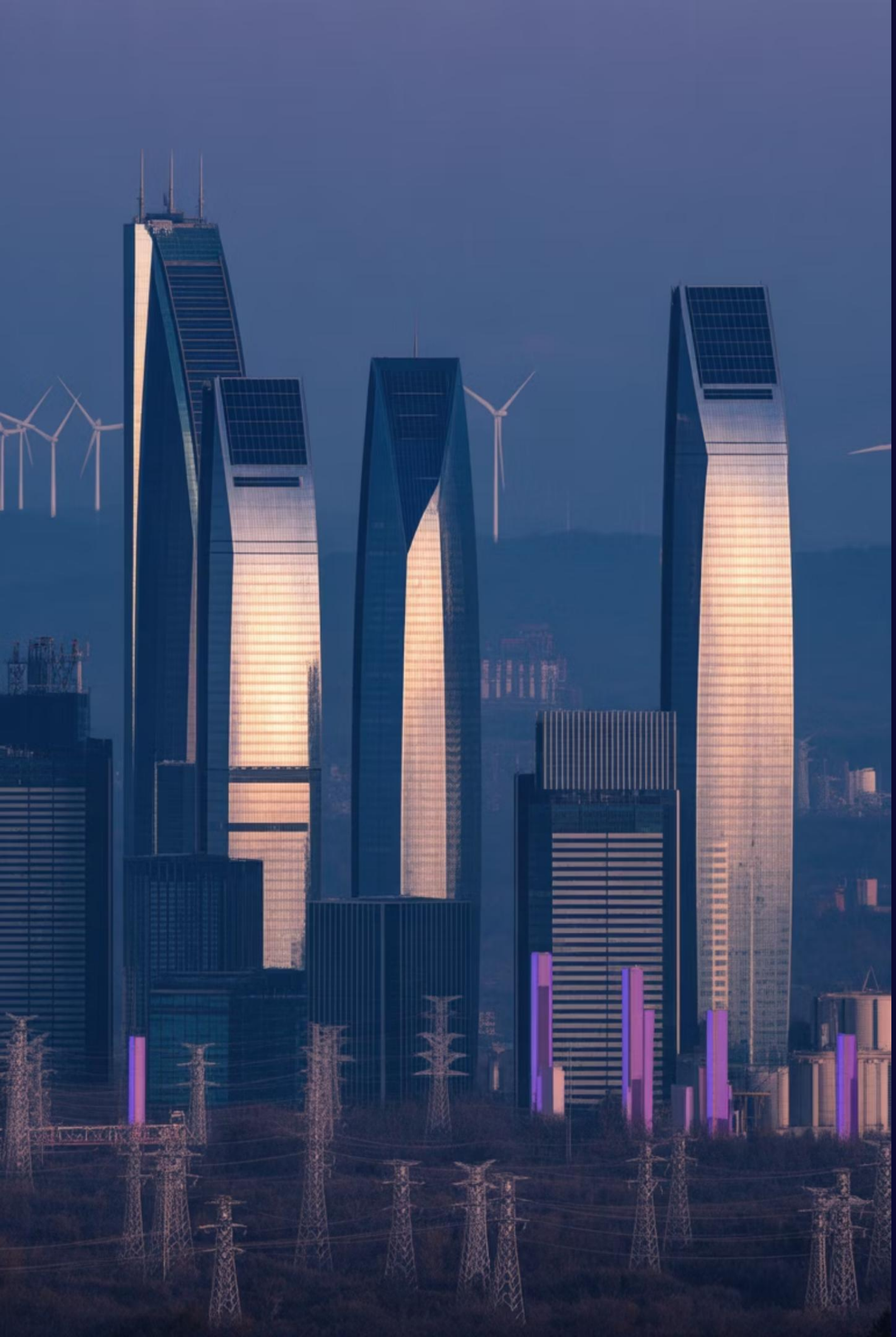
اسم المادة : الطاقة المتجددة

محاضرة بعنوان

Introduction to Energy Resources

مدرس المادة:

م.م محمد طه محمد



Introduction to Energy Resources

Energy resources power modern life and are categorized into traditional (non-renewable) and renewable sources. Traditional energy, like fossil fuels and nuclear, is finite but highly efficient. Renewable energy, such as solar and wind, is sustainable but faces intermittency challenges. Both have unique advantages and drawbacks, shaping global energy policies for a balanced, eco-friendly future.

General Objective of the Lecture:

To give students a basic understanding of traditional and renewable energy resources, their advantages, disadvantages, and role in the future of energy.

Specific Objectives of the Lecture:

1. By the end of the lecture, students will be able to list at least five renewable energy resources with one example each.
2. Within the session, students will be able to compare two key differences between traditional and renewable energy resources.
3. After the lecture, students will be able to identify one main advantage and one disadvantage of both traditional and renewable energy sources.

1.1 Traditional Energy Resources

Traditional energy resources, also called non-renewable energy, are derived from finite sources that take millions of years to form. These include:

Fossil Fuels

Coal, oil, and natural gas.

Nuclear Energy

Uranium and plutonium (through nuclear fission).

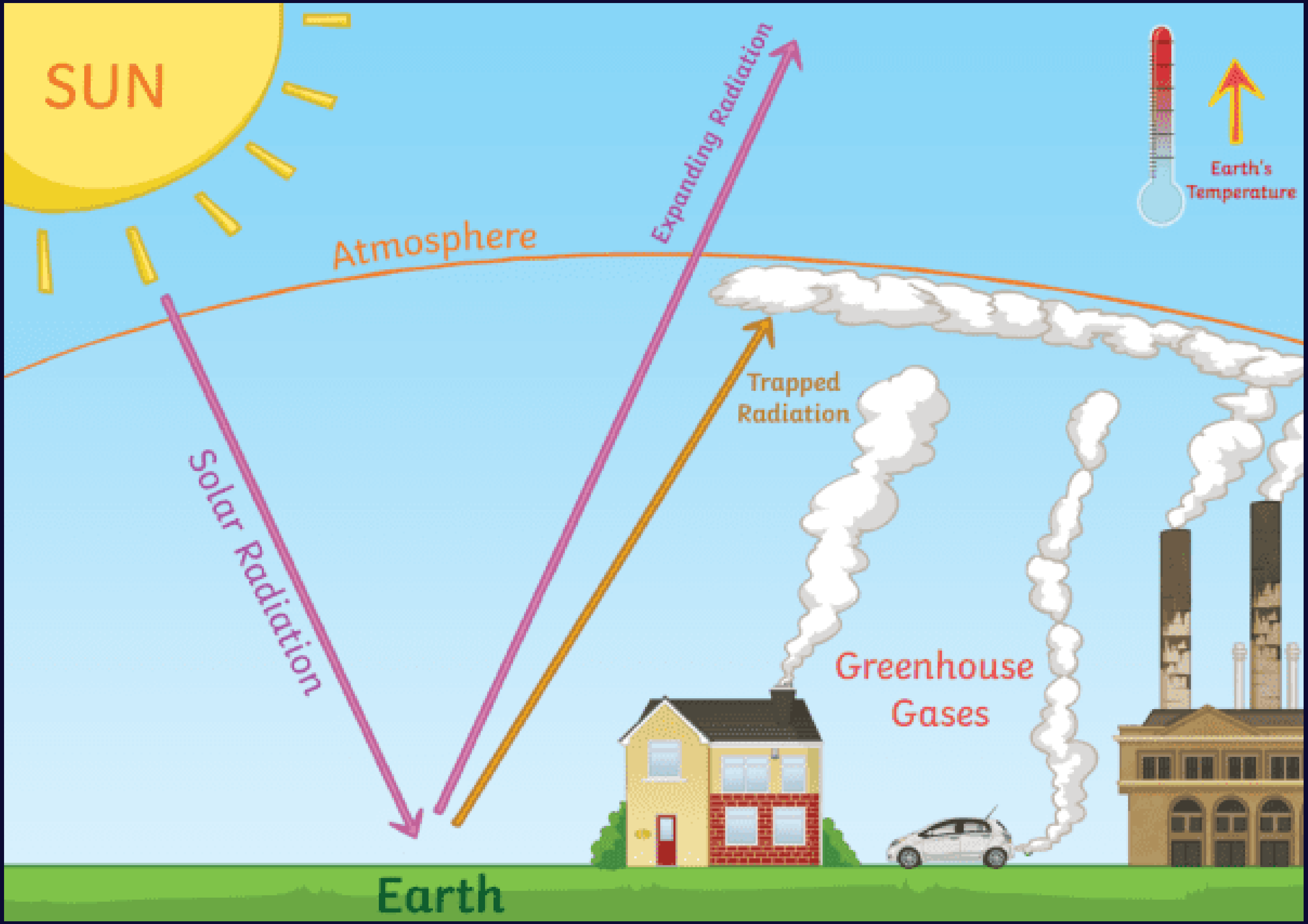
1.1.1 Advantages:

- High energy output.
- Reliable and well-established infrastructure.
- Cost-effective for large-scale energy production.

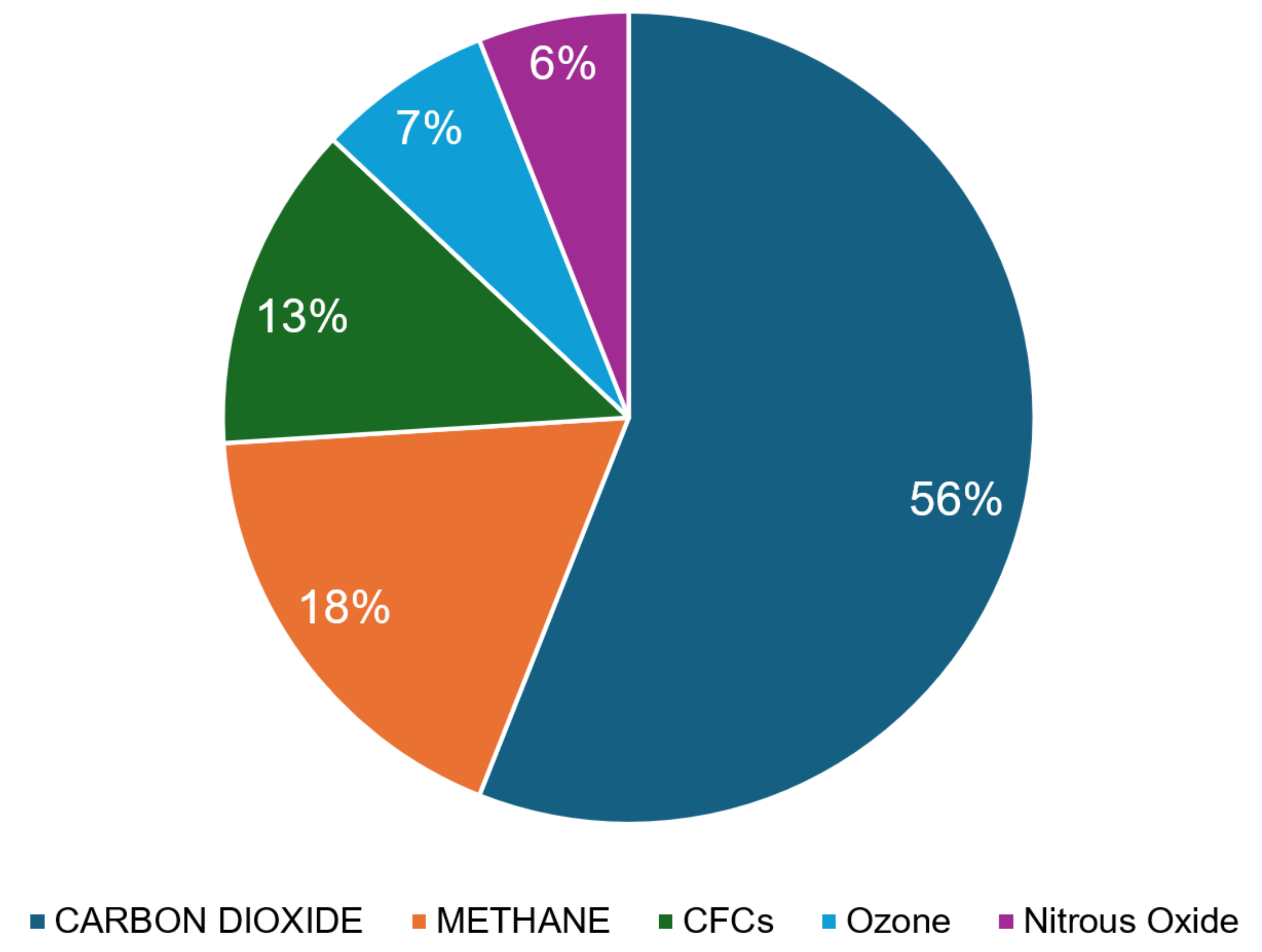
1.1.2 Disadvantages:

- Finite and depleting (limited).
- High greenhouse gas emissions (causing climate change).
- Environmental damage (mining, oil spills, air pollution).
- Geopolitical conflicts over resources.

What is the Impacts of Traditional Energy on Environmental?



Environmental Impacts and Challenges



Atmospheric Carbon Dioxide levels

Year	CO_2 ppm	% increase from previous year	% increase from 1959
1959	316	1.3	1.3
1965	320	1.9	3.2
1970	331	1.5	4.7
1980	339	2.4	7.3
1985	346	2.1	9.5
1990	354	2.3	12.0
1995	361	2.0	14.2
2000	369	2.2	16.8
2002	373	1.1	18.0
2004	378	1.3	19.6
2006	382	1.1	20.9
2008	386	1.0	22.2
2012	**395**		**25**

Safe level of atmospheric CO_2 is 350ppm.

1.2 Renewable Energy Resources

Renewable energy comes from naturally replenished sources and is sustainable in the long term. Examples:

01

Solar Energy – Energy from sunlight.

Example: Solar panels (photovoltaic cells) on rooftops.

02

Wind Energy – Energy from wind movement.

Example: Wind turbines.

03

Hydropower Energy – Energy from flowing or falling water.

Example: Hydropower plant to produce electricity.

04

Biomass Energy – Energy from organic materials (plants, animal waste).

Example: Biofuel.

05

Geothermal Energy – Energy from heat within the Earth.

Example: Geothermal power plants.

06

Tidal & Wave Energy – Energy from ocean tides and waves.

Example: Tidal Power Plant.

07

Hydrogen Fuel (when produced renewably) – Energy from hydrogen gas.

Example: Hydrogen fuel cells powering vehicles.

Watching a Video Together

https://www.youtube.com/watch?v=1kUE0BZtTRc&t=16s

1.2.1 Advantages:

Sustainable and inexhaustible.

Low or zero carbon emissions.

Reduces dependence on fossil fuels.

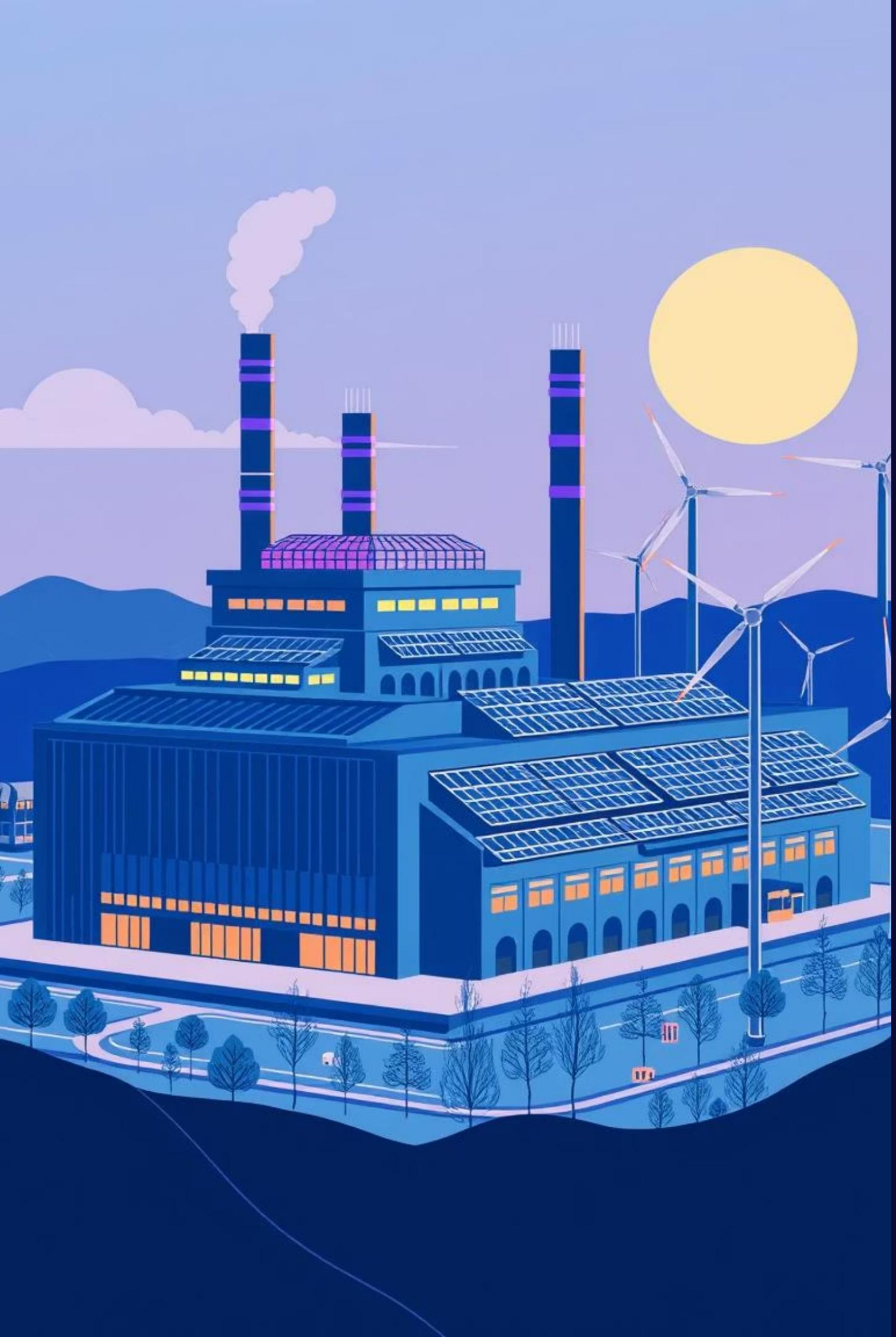
Lower long-term operational costs.

1.2.2 Disadvantages:

- High initial setup costs.
- Intermittency (depends on weather/sunlight).
- Requires large land areas (e.g., solar/wind farms).
- Energy storage challenges (batteries needed).

1.3 Comparison Summary

Factor	Traditional Energy	Renewable Energy
Availability	Limited (depleting)	Unlimited (sustainable)
Environmental Impact	High pollution	Low/zero emissions
Cost	Lower initial cost	Higher initial cost
Reliability	Stable supply	Dependent on weather



Mitigating Environmental Impact

1 Cleaner Fuels

Transitioning to natural gas and integrating carbon capture to reduce emissions.

2 Hybrid Plants

Hybrid plants combining renewables with thermal generation for stability.

Homework:

1.4 Exercises

1

State a brief comparison between traditional and renewable energy resources.

2

List five renewable energy resources and give an example for each one.

3

MCQ for Energy Resources

https://kahoot.it/challenge/07581743?challenge-id=77e98eab-e9c2-44bf-a781-290f87024bbf_1758883712499

Choose the Correct Answer (MCQ for Energy Resources)

1. **Which of the following is a traditional energy resource?**
   A) Solar B) Wind C) Natural Gas D) Biomass

2. **One advantage of traditional energy is:**
   A) Infinite availability B) Low greenhouse emissions C) High energy output D) Fully renewable

3. **Which of these is a disadvantage of renewable energy?**
   A) High greenhouse emissions B) High operational costs C) Intermittency D) High reliability

4. **Which energy source is NOT renewable?**
   A) Solar B) Coal C) Wind D) Geothermal

5. **Renewable energy is best described as:**
   A) Limited and polluting B) Cheap and non-renewable C) Sustainable and clean D) Dependent on fossil fuels

QUESTIONS

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Solar Energy

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Introduction

Solar energy is one of the most promising renewable energy sources because it is clean, abundant, and sustainable. It comes directly from the sun’s radiation and can be converted into heat or electricity through different technologies. With growing global energy demands and environmental concerns, solar energy provides a viable alternative to fossil fuels by reducing greenhouse gas emissions, lowering dependency on non-renewable resources, and supporting a shift toward green energy solutions. This lecture introduces the fundamentals of solar energy, its advantages and disadvantages, and the main technologies used to harness it, such as solar thermal systems and solar photovoltaic systems.

General Objective of the Lecture

Primary Goal

To provide students with an understanding of solar energy as a renewable resource and the main technologies used to harness it for practical applications.

Specific Objectives of the Lecture

1 Technology Identification

By the end of the lecture, students will be able to identify the two main types of solar energy technologies and describe their basic working principles.

2 System Comparison

Students will be able to compare active and passive solar water heating systems by outlining at least two differences in design or operation.

3 Practical Application

During the lecture session, students will solve a short problem or example that calculates the useful heat output of a flat-plate solar collector.

Solar Energy: The Power of the Sun

Solar energy, derived from the sun's radiation, is a clean, renewable, and inexhaustible energy source. As the world transitions toward sustainable energy solutions, solar power has emerged as a key alternative to fossil fuels, reducing greenhouse gas emissions and dependence on finite resources.

5500°C	1367	1000
Sun's Temperature	**Solar Irradiance**	**Maximum Ground Level**
Black body temperature of solar radiation	W/m^2 just outside Earth's atmosphere	W/m^2 global irradiance at sea level

Solar spectrum comprises 52% infrared, 43% visible light, and 5% UV radiation. Global irradiance consists of direct beam radiation from the sun and diffuse radiation scattered by the atmosphere.

Components of Global Irradiance

Global irradiance is actually made up of two components.

(i) *"Direct beam radiation"* from the sun

(ii) *"Diffuse radiation" from the sky* (radiation that has been *scattered* by the atmosphere)

Advantages of Solar Energy

Clean & Abundant

It is clean, cheap and abundantly available.

Renewable

It is re-usable source of energy.

Eco-Friendly

It is eco-friendly (i.e., pollution free)

Reduces Emissions

It decreases greenhouse gas emissions.

Disadvantage of Solar Energy

High Capital Cost

High capital cost due to requirement of large area.

Limited Hours

Energy generation limited to daylight hours and weather conditions

Sun Tracking Needs

Optimal efficiency requires tracking systems to follow the sun's movement

Storage Requirements

Energy storage systems needed for continuous power supply during non-sunny periods

Applications

Solar energy is used in:

Solar Water Heating

Heating water for domestic and commercial use

Solar Distillation

Purifying water through solar-powered distillation

Electric Power Generation

Converting solar energy into electrical power

Task 1: Test Your Knowledge

https://wayground.com/join?gc=01283122

1. **What is the solar constant outside the Earth's atmosphere?**
   A) 800 W/m^2
   B) 1000 W/m^2
   C) 1367 W/m^2
   D) 2000 W/m^2
2. **Solar radiation that is scattered by the atmosphere is called:**
   A) Direct beam radiation
   B) Global radiation
   C) Diffuse radiation
   D) Solar irradiance
3. **Which component of the solar spectrum is largest?**
   A) UV
   B) Infrared
   C) Visible
   D) Gamma
4. **A major disadvantage of solar energy is:**
   A) Pollution
   B) High maintenance
   C) Limited to sunshine hours
   D) Infinite fuel cost
5. **Which of the following is an application of solar energy?**
   A) Refrigeration
   B) Solar distillation
   C) Coal mining
   D) Hydroelectric dams

Solar Energy Technologies

Solar energy utilization technologies are divided into two main categories, each serving different energy conversion purposes and applications.

Solar Thermal Systems

Convert solar radiation directly into thermal energy or heat using absorber plates or surfaces. The absorbed energy increases temperature for heating applications.

- Flat-plate collectors
- Evacuated-tube collectors
- Concentrating collectors

Solar Photovoltaic Systems

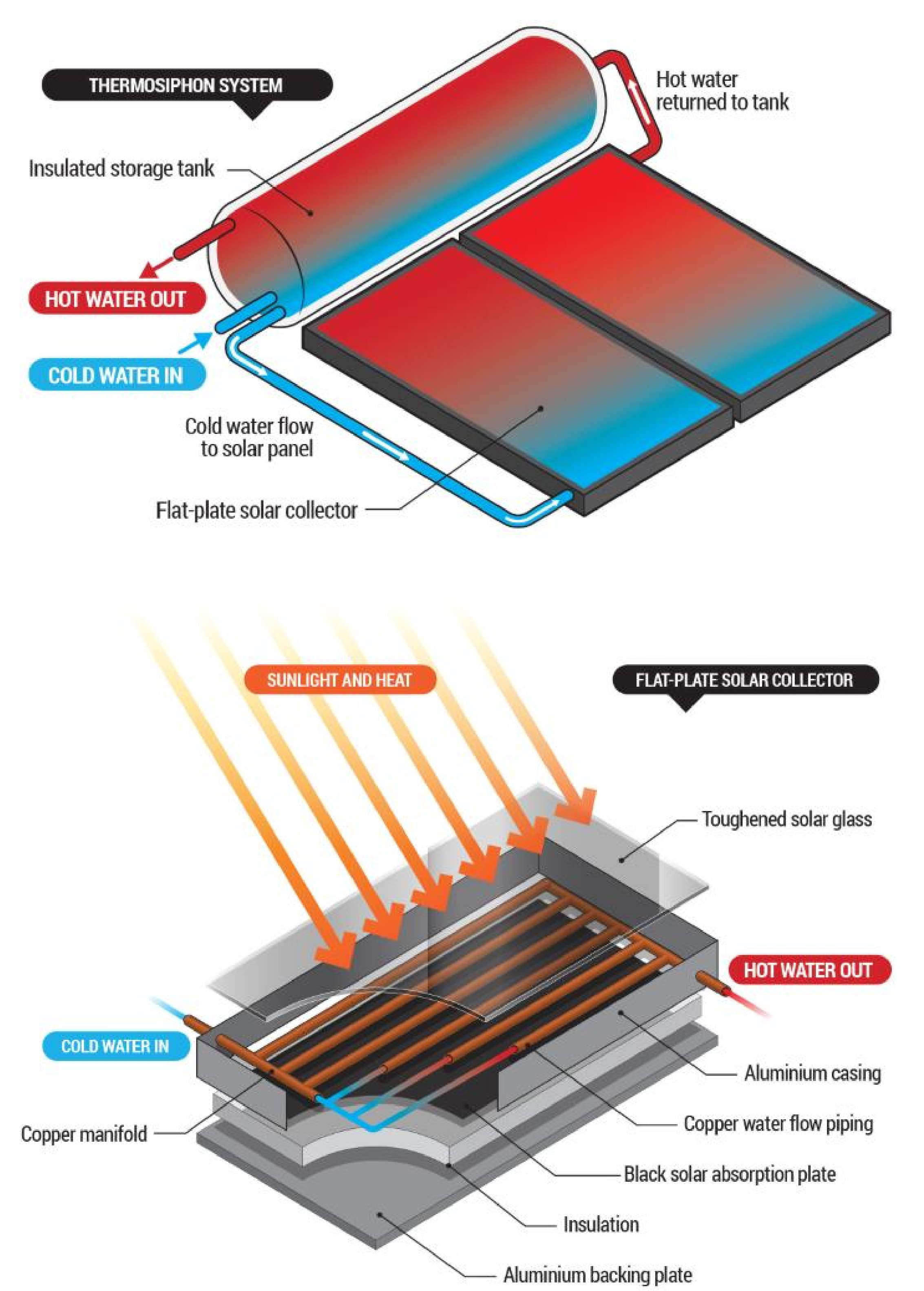
Convert solar energy directly into electrical energy through photovoltaic cells and semiconductor materials.

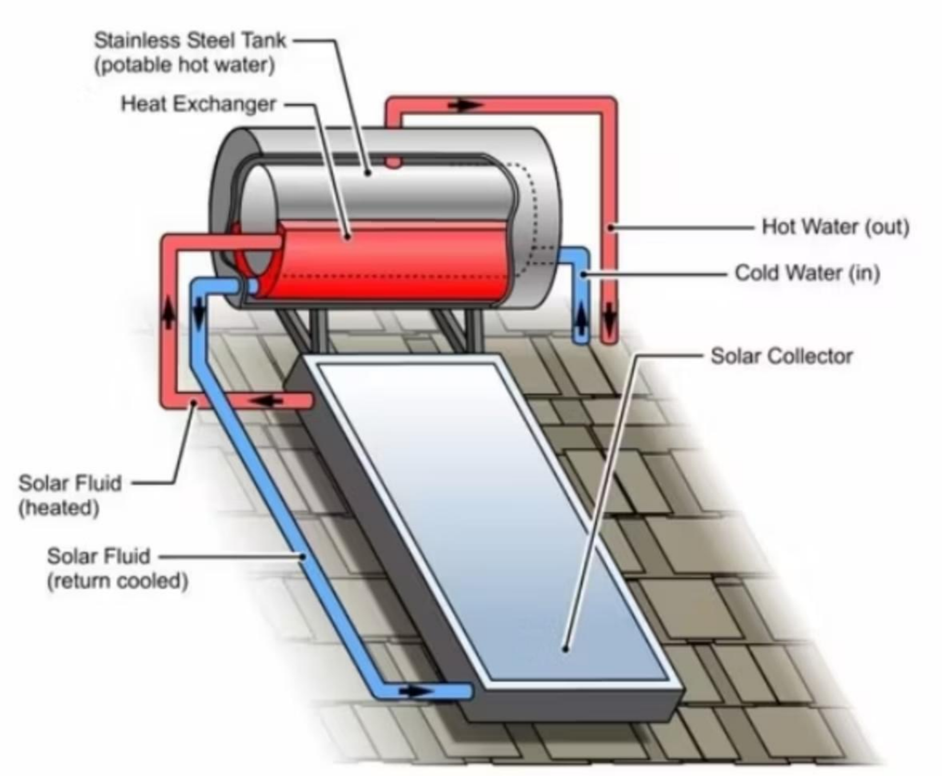
- Silicon-based panels
- Thin-film technologies
- Concentrated PV systems

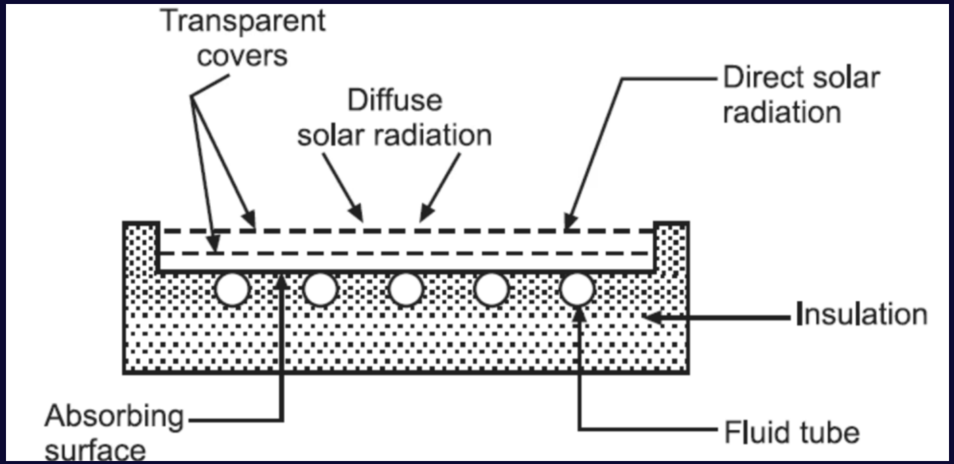
Solar Thermal Systems

Flat-Plate Collectors (FPC)

Flat-plate collectors are the most common type of solar thermal collector, consisting of four essential components working together to capture and convert solar energy efficiently.







Flat-Plate Collector Components

1

Absorber Plate

Metallic plate (copper, aluminum, or steel) that intercepts and absorbs solar radiation. Coated to enhance absorption and minimize infrared emission. Heat transport fluid passes through integral passages.

2

Transparent Covers

One or more glass sheets of solar radiation transmitting materials placed above the absorber. Allow solar energy to reach the plate while reducing convection, conduction, and re-radiation losses.

3

Insulation

Positioned beneath the absorber plate to minimize heat losses and protect the absorbing surface from thermal losses to the environment.

4

Box Structure

Contains all components and keeps them in proper position, providing structural integrity and weather protection.

Selective Absorber Coatings/Surfaces

In order to reduce thermal losses from the absorber plate of a solar heating panel, an efficient way is to use selective absorber coatings. An ideal selective coating is a perfect absorber of solar radiation as well as a perfect reflector of thermal radiation. A selective coating, thus, increases the temperature of an absorbing surface.

A selective surface has high absorptance for shortwave radiation (less than 2.5 μm) and low emittance of longwave radiation (more than 2.5 μm).

A selective surface should possess the following characteristics:

1. Its properties should not change with use;
2. It should be of reasonable cost;
3. It should be able to withstand the temperature levels associated with the absorber plate surface of a collector over extended period of time;
4. It should be able to withstand atmospheric corrosion and oxidation.

Advantages of Flat Plate Collector

Uses All Radiation

Both beam and diffuse solar radiations are used.

Low Maintenance

Require little maintenance.

No Tracking

The orientation of the sun is not required (i.e. no tracking device needed)

Simple Design

Mechanically simpler than the focusing collectors.

Disadvantages of Flat Plate Collector

Low Temperature

Low temperature is achieved.

Heavy Weight

Heavy in weight.

Heat Losses

Large heat losses by conduction due to large area.

Flat Plate Collector Applications

Flat plate collectors serve various thermal applications where moderate temperatures are sufficient for effective operation.

Solar Water Heating

Primary application for domestic and commercial hot water production

Heating & Cooling

Space heating and absorption cooling systems for buildings

Factors affecting the performance of a flat-plate collector

The following factors affect the performance of a flat-plate collector:

1. **Incident solar radiation**

   The collector's efficiency is directly related to solar radiation falling on it and increases with rise in temperature.

2. **Number of glass cover**

   The increase in number of glass cover plates reduces the internal connective heat losses.

3. **Spacing between absorber plate and glass cover**

   The more the space between the absorber and the cover plate, the less is the internal heat loss.

4. **Tilt of the collector**

   In order to achieve better performance, flat-plate collector should be tilted at an angle of latitude of the location. — The collector is placed with south facing at northern hemisphere to receive maximum radiation throughout the day.

5. **Selective surface**

   The selective surface should be able to withstand high temperature, should not oxidize and should be corrosion resistant.

6. **Fluid inlet temperature**

   With the increase in the inlet temperature of the fluid, there is an increase in operating temperature of the collector and this leads to decrease in efficiency.

7. **Dust on cover plate**

   The collector's efficiency decreases as dust particles increase on the cover plate. Thus, frequent cleaning is required to get the maximum efficiency of the collector.

Evacuated-Tube Collectors

The evacuated tube consists of two glass tubes. The outer tube is made of extremely strong transparent glass. The inner tube is also made of glass, but coated with a special selective coating which features excellent solar heat absorption and minimal heat reflection properties. The air is evacuated from the space between the two glass tubes to form a vacuum.

Superior Insulation

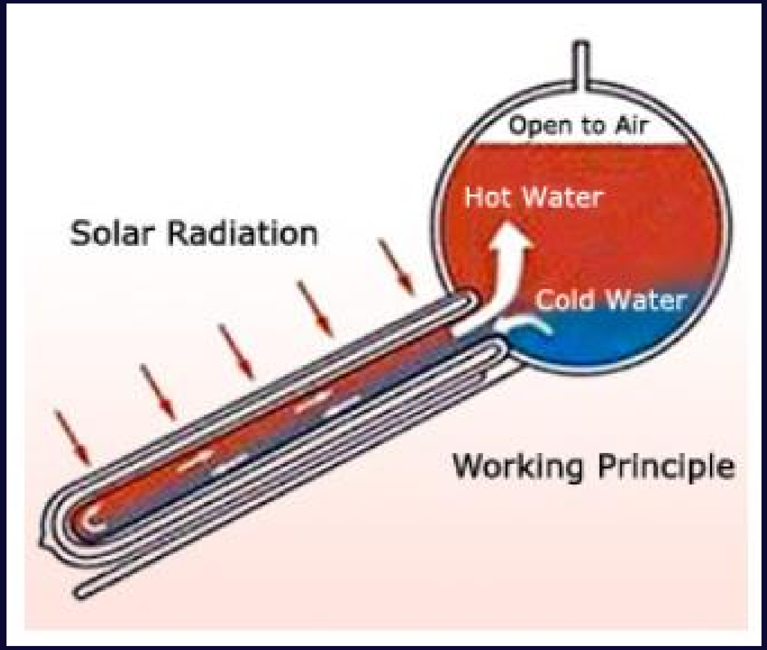
Vacuum between tubes eliminates convective heat losses

High Efficiency

Impressive efficiency compared to flat-plate systems

High Temperatures

Can reach temperatures above 80°C consistently



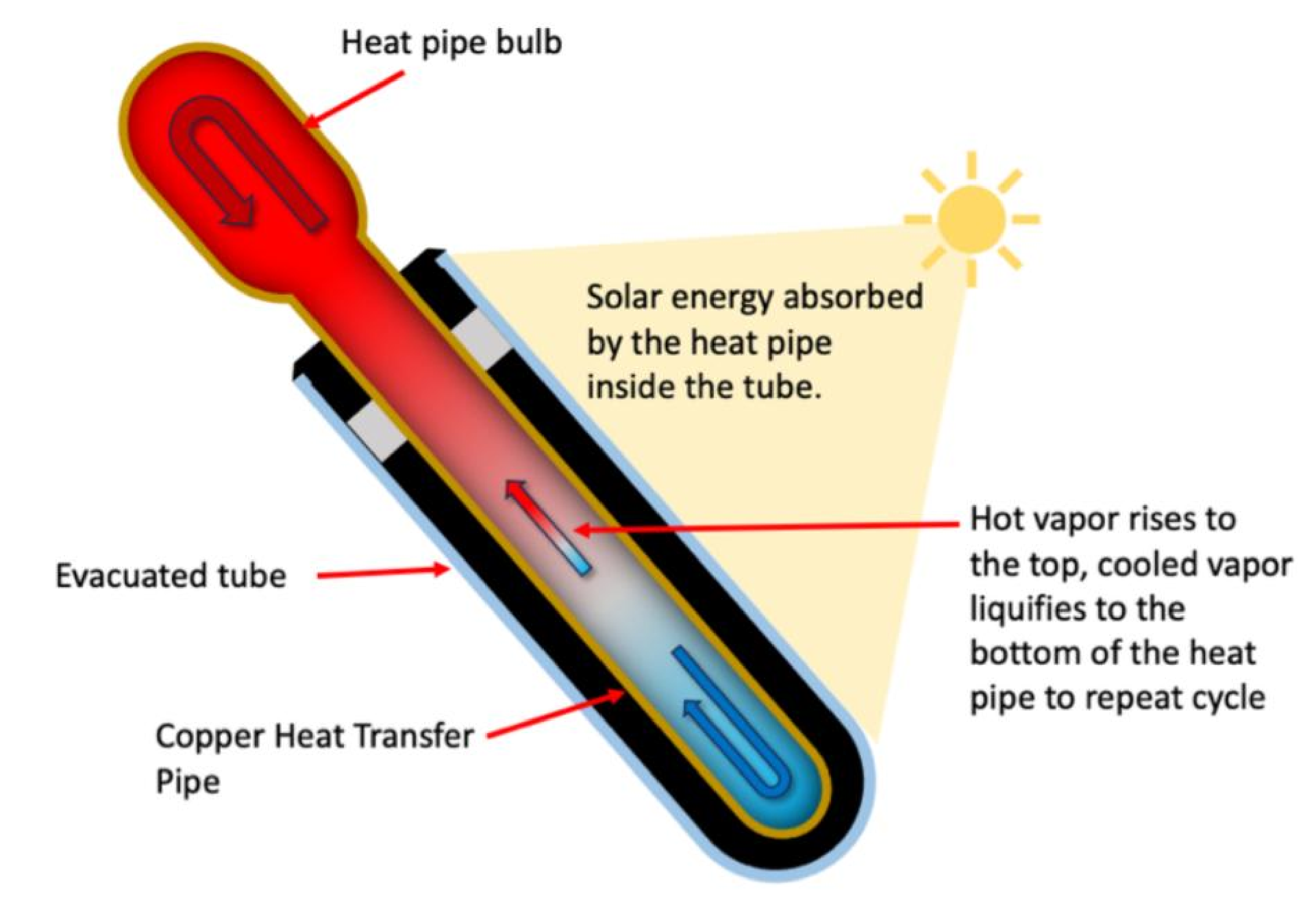
Task 2: Test Your Knowledge

1. **What is the purpose of a flat-plate collector's absorber plate?**
   A) Reflect solar radiation
   B) Transmit heat
   C) Absorb solar energy
   D) Store solar fluid
2. **Which material is NOT typically used in absorber plates?**
   A) Copper
   B) Aluminum
   C) Steel
   D) Plastic
3. **The function of the transparent cover in a flat-plate collector is to:**
   A) Cool the fluid
   B) Minimize heat loss
   C) Reflect solar radiation
   D) Absorb sunlight
4. **Which factor decreases the performance of a flat-plate collector?**
   A) Clean cover glass
   B) High solar radiation
   C) Tilted orientation
   D) Dust accumulation
5. **What increases solar collector efficiency?**
   A) Dust buildup
   B) Poor tilt angle
   C) High optical efficiency
   D) Shading

https://wayground.com/join?gc=27284530

Heat Pipe Solar Collector

The heat pipe solar collector consists of two tubes. The outer tube is made of extremely strong transparent glass. The inner tube is also made of cupper and coated with a special selective coating which features excellent solar heat absorption and minimal heat reflection properties. The air is evacuated from the space between the two glass tubes to form a vacuum.



Heat Pipe Operation Process

01

Liquid State

The interior part contains a small amount of volatile fluid such as an alcohol.

02

Low Temperature Conditions

In the absence of the solar radiation, the plate and tube temperatures are low, and the fluid lies at the bottom of the tube in liquid state.

03

Solar Heating Process

If the sun shines, the heat transfer to the tube to vaporize the fluid. The vapor rases by natural convection and reaches the top of the tube, where a bulb acts as a condenser.

Concentrating Solar Collector

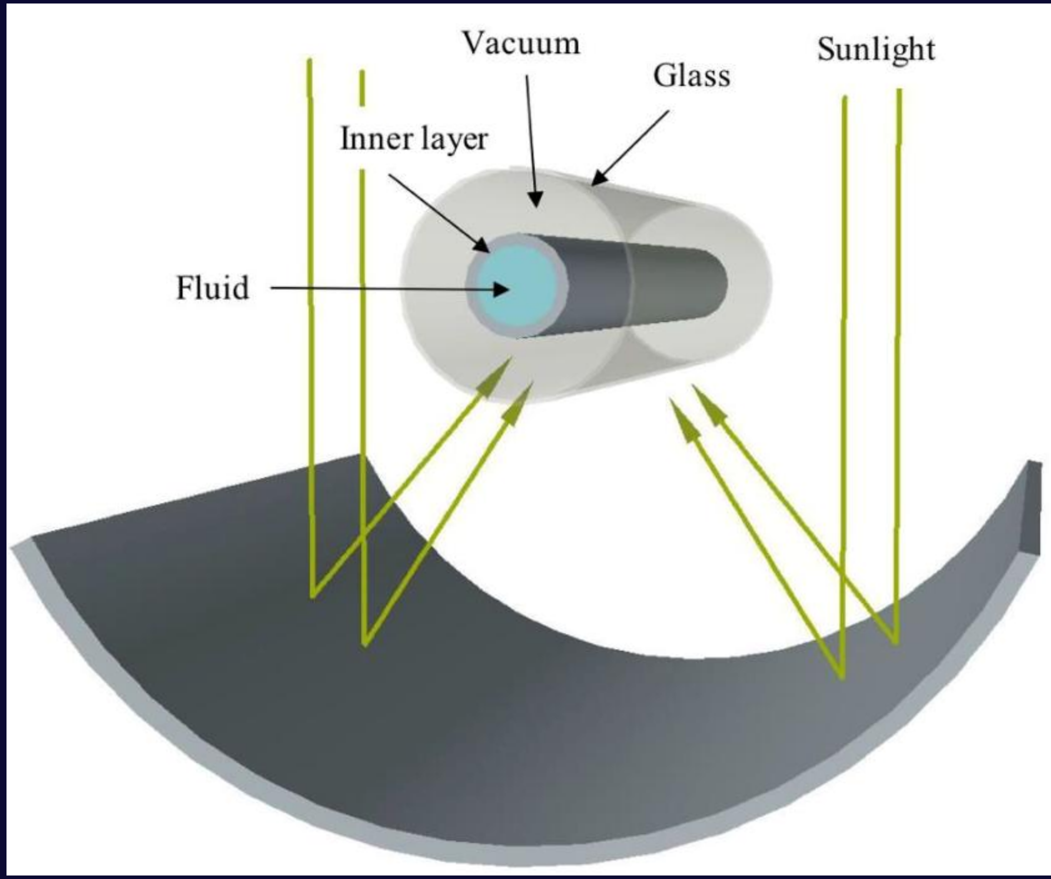
The method of producing electricity from solar energy is to use the heat produced in a solar collector to generate electricity by means of a heat engine. This is the most easily accomplished when water is heated above its boiling point to produce steam that can then be used to drive a steam turbine.

Focusing collectors are necessary for this purpose because flat plate collectors are not suitable for achieving the required temperatures.

Parabolic troughs

Parabolic dishes

Central receivers



Parabolic Troughs

- Parabolic trough collectors heat a fluid that is flowing through a pipe located at the focus of a parabolic trough.
- The parabolic troughs rotate to track the sun to ensure that the radiation is properly focused on the fluid-carrying pipes.

Parabolic Dishes

Alternative Geometry

An alternative to the parabolic trough geometry is the parabolic dish geometry

Configuration Options

Units may be either individual parabolic dishes or arrays of dishes

Point Focus Design

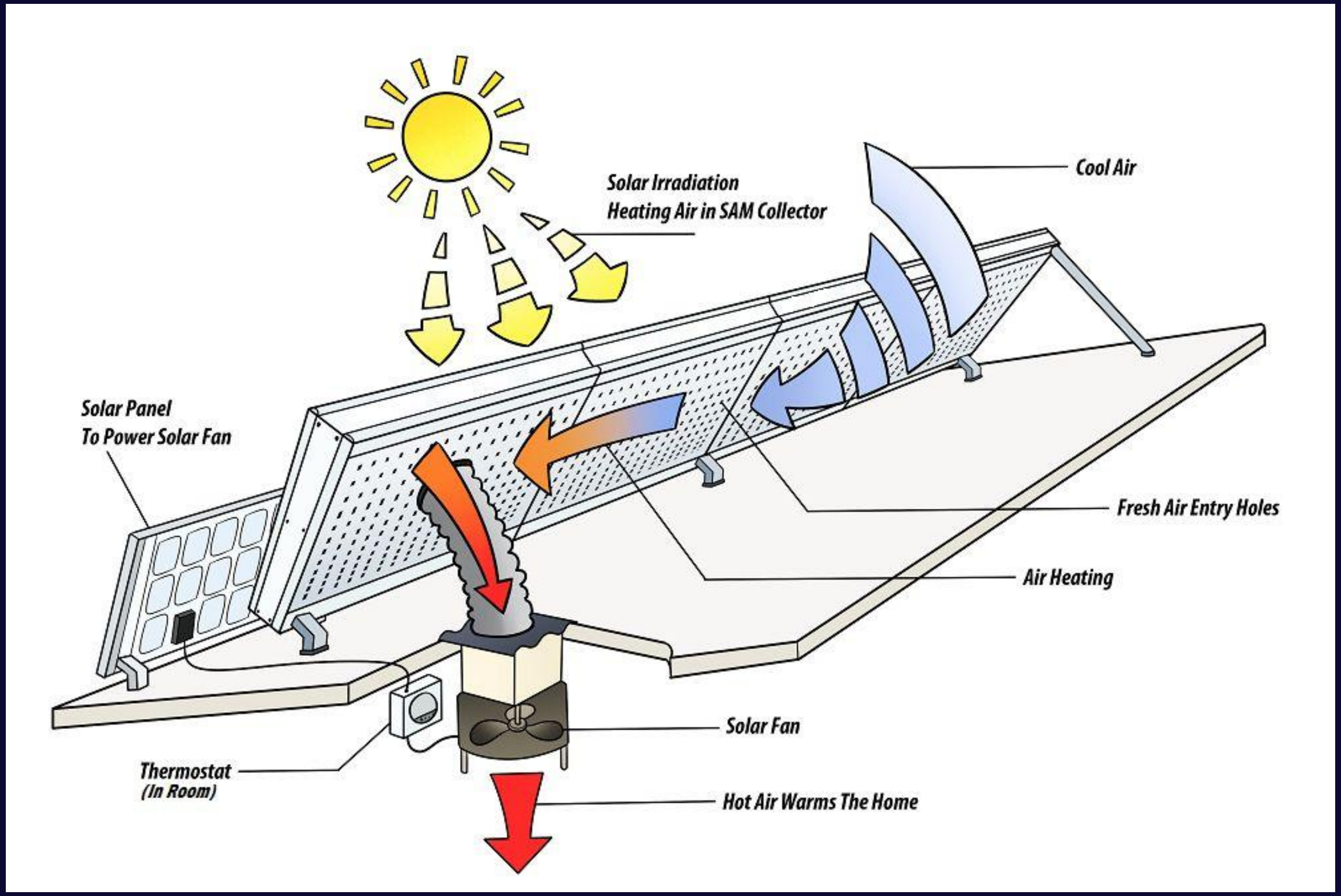
Instead of a line focus, as is the case for the parabolic trough, the parabolic dish has a point focus.

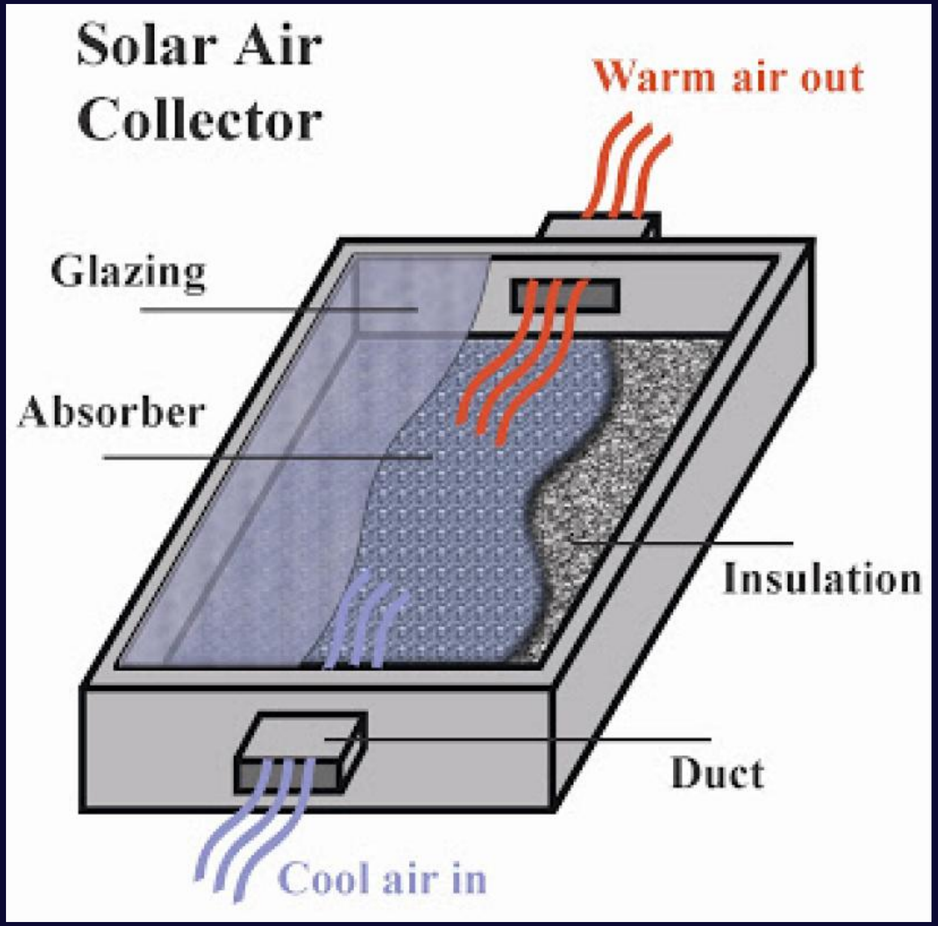
Central Receivers

- Another possibility for the conversion of solar energy to electricity by means of a heat engine is by means of a central receiver.
- The individual mirrors are referred to as heliostats, and the central receiver is called power tower.
- This is similar to a single large parabolic dish except that the parabolic dish is replaced with a planar array of computer-controlled mirrors, each of which tracks the sun and reflects the sunlight onto a single point.
- A working fluid, circulated through the focal point at the top of the tower, is used to produce steam to either drive a turbine/generator to generate electricity directly or as a mechanism to store thermal energy for later use

Solar Air Heater

A solar air heater is a device that harnesses solar energy to heat air for residential, commercial, or industrial purposes. It typically consists of a flat or sloped surface, often made of metal or other heatabsorbing material, covered with a transparent material such as glass or plastic to allow sunlight to pass through.





Task 3: Test Your Knowledge

1. What is the purpose of the vacuum between the two glass tubes in a heat pipe solar collector?

A) To minimize heat loss by conduction and convection
B) To allow air circulation for faster heating
C) To increase the reflection of sunlight

2. In a heat pipe solar collector, what happens when the sun shines on the tube?

A) The fluid vaporizes and rises to the top
B) The vapor condenses at the bottom
C) The vapor escapes from the tube

3. Why are focusing collectors required for generating electricity from solar energy using steam turbines?

A) Flat plate and Evacuated collectors cannot achieve the required high temperatures
B) Focusing collectors do not need sun tracking
C) Parabolic collectors are cheaper than flat plates

4. In a parabolic trough collector, where is the fluid heated?

A) At the focal line of the parabolic trough
B) At the base of the trough
C) Inside the storage tank

5. What is the main difference between a parabolic trough and a parabolic dish?

A) Troughs have a line focus while dishes have a point focus
B) Dishes require tracking while troughs do not
C) Dishes work only at night

https://kahoot.it/challenge/02335332?challenge-id=77e98eab-e9c2-44bf-a781-290f87024bbf_1759493115188

Collector Performance Analysis

The mathematical relationships governing flat-plate collector performance involve heat transfer coefficients, optical properties, and temperature differences.

$$Q_c = A_{CS}\,[I_{cs}(\tau\alpha)_e - U_{oc}(T_{fi} - T_a)]$$

Introducing the heat removal factor F_R:

$$Q_c = A_{CS}\,[I_{cs}F_R(\tau\alpha)_e - F_R\,U_{oc}(T_{fi} - T_a)]$$

Collector efficiency represents the ratio of useful heat output to incident solar energy, providing a key performance metric for system evaluation.

$$\eta_c = \frac{Q_c}{A_{CS} \times I_{cs}}$$

Manufacturers typically express efficiency as:

$$\eta_c = F_R(\tau\alpha)_e - F_R\,U_{oc}\left(\frac{T_{fi} - T_a}{I_{cs}}\right)$$

The outlet temperature of collector heat transfer fluid is:

$$T_{fo} = T_{fi} + \frac{Q_c}{\dot{m} \times C_{pw}}$$

Where:

- Q_c = Useful heat output of flat-plate collector (W).
- A_{cs} = Collector surface area (m^2).
- I_{cs} = Intensity of solar radiation incident on the collector surface (W/m^2).
- τ = Transmission coefficient.
- α = Absorption coefficient.
- $(\tau\alpha)_e$ = Effective product of transmittivity of the transparent cover and absorptivity of the absorber.
- U_{oc} = Overall total heat loss coefficient of the collector (W/m°C).
- T_{fi} = collector fluid inlet temperature (°C), and
- T_a = Ambient air temperature (°C).

Example 1

The following data relate to a flat plate solar collector:

- The intensity of solar radiation on the collector's surface = 800 W/m^2;
- The inlet temperature of the fluid = 38 °C;
- The ambient air temperature = 25 °C
- Effective optical efficiency = 0.76
- Effective heat loss coefficient = 1.65 W/m^{2}K
- Mass flow rate of water = 0.019 kg/s
- Specific heat of water at constant pressure = 4187 J/kg K
- Collector area = 1 m^2

Calculate the following:

1. Useful heat output
2. Outlet temperature of the fluid.
3. The collector efficiency

Given: I_{cs} = 800 W/m^2; A_{cs} = 1m2; Tfi = 38 °C; T_a = 25 °C; FR $(\tau\alpha)_e$ = 0.76;

$F_R U_{oc}$ = 1.65 W/m^{2}K; m = 0.019 kg/s, c_{pw} = 4187 J/kg K.

Solution

01

Useful heat output; Qc

$$Q_c = A_{CS}\,[I_{cs} F_R\,(\tau\alpha)_e - F_R\,U_{oc}(T_{fi} - T_a)]$$

Q_c = 1 × [800 × 0.76 – 1.65 (38 – 25)] = **586.5 W**

02

Outlet temperature of the fluid, T_{fo}:

$$T_{fo} = T_{fi} + \frac{Q_c}{\dot{m} \times C_{pw}}$$

Tfo = 38 + 586.5/(0.019 × 4187)

Tfo = **45.4°C**

03

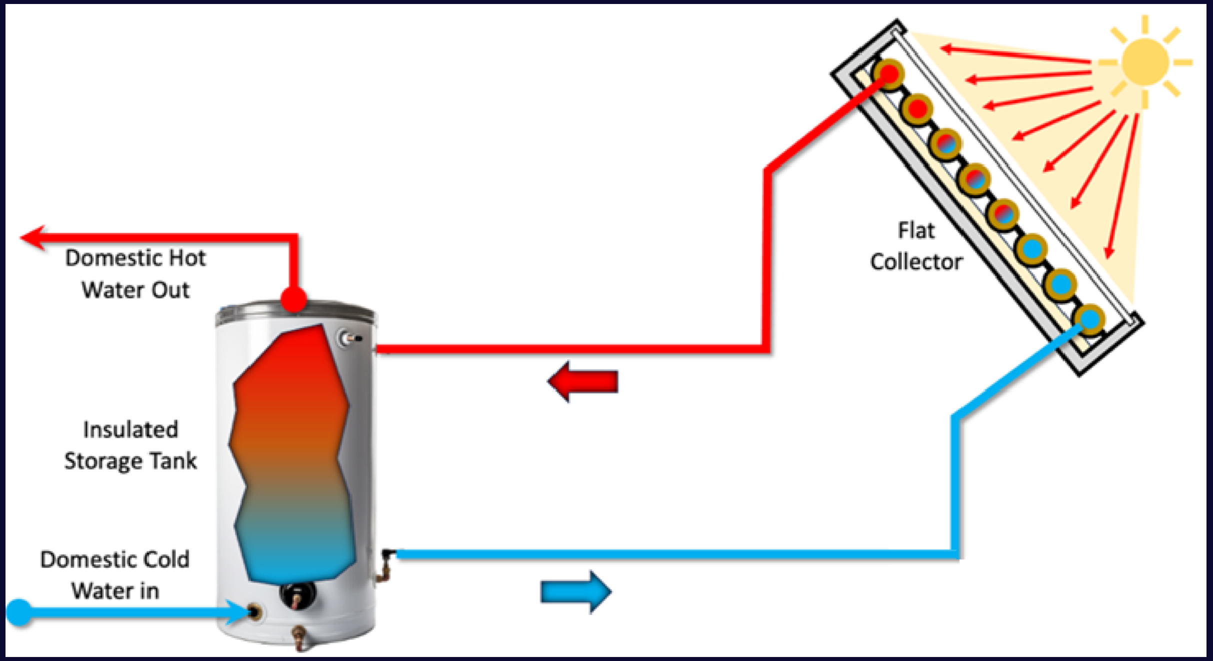
The collector efficiency

$$\eta_c = \frac{Q_c}{A_{CS} \times I_{cs}}$$

ηc = 586.5/(1 × 800) = 0.733 ≈ 73%

Solar Water Heating Systems

Solar water heating systems use sunlight to heat water for domestic, commercial, or industrial purposes. They are broadly classified into two main categories, each with distinct designs and applications based on circulation methods.

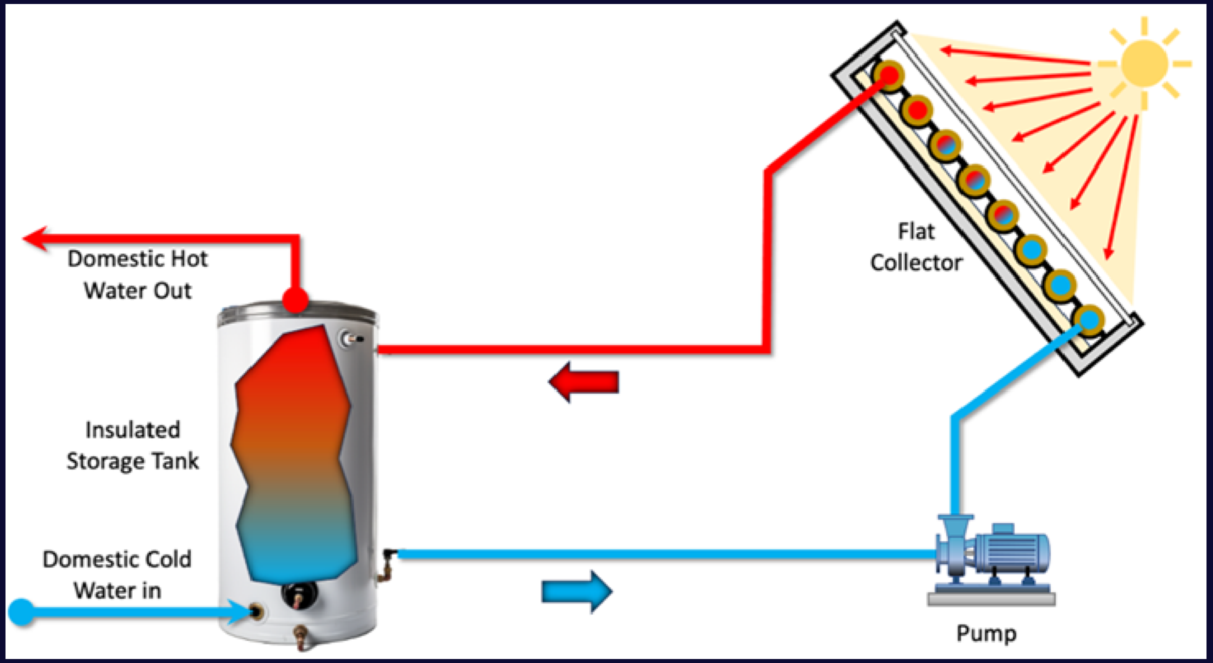


Active Systems

Use pumps and controls to circulate water or heat transfer fluid through the system

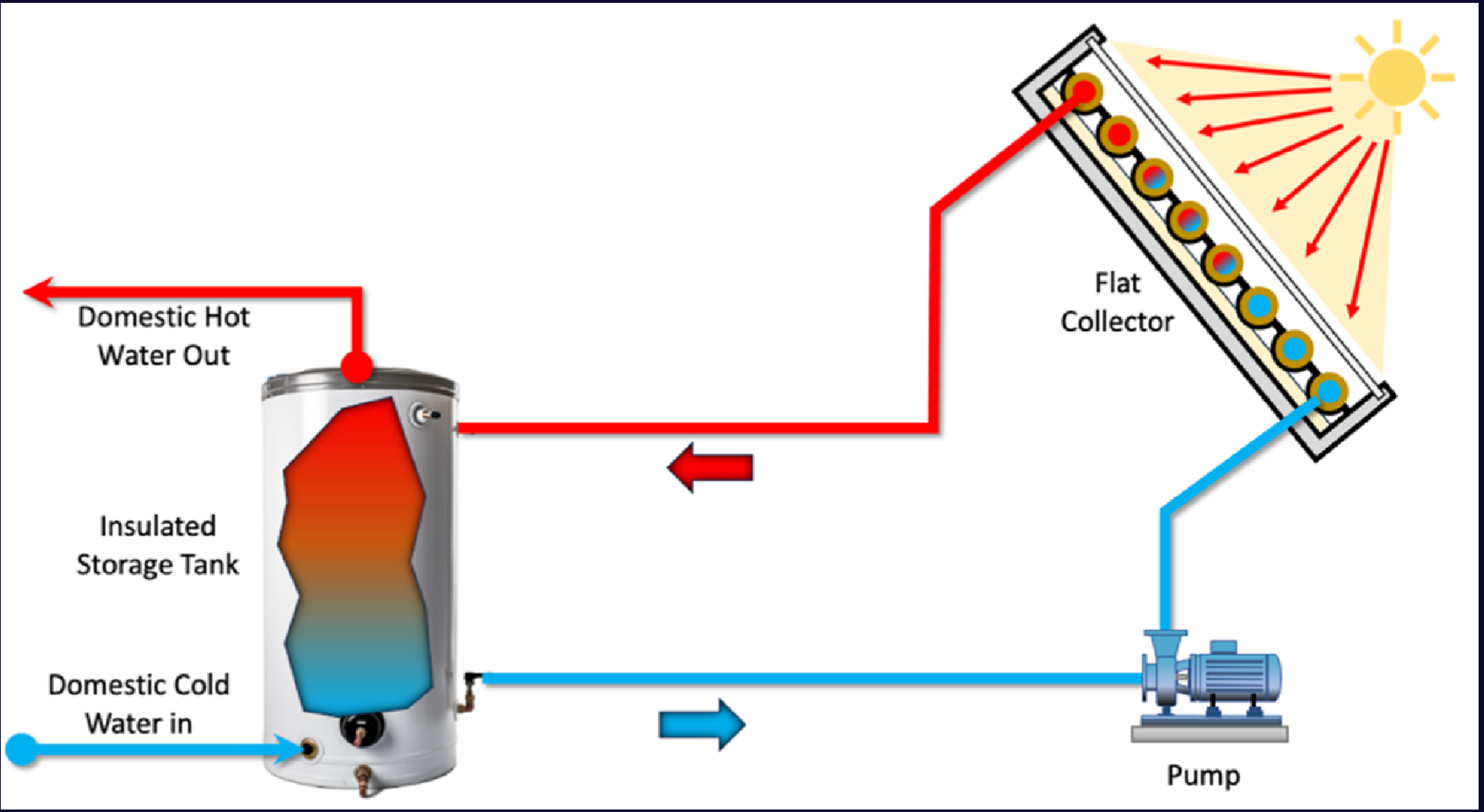
Passive Systems

Rely on natural convection and gravity for fluid circulation without mechanical components



Active Systems

Direct Circulation (Open-Loop) Systems



How it works:

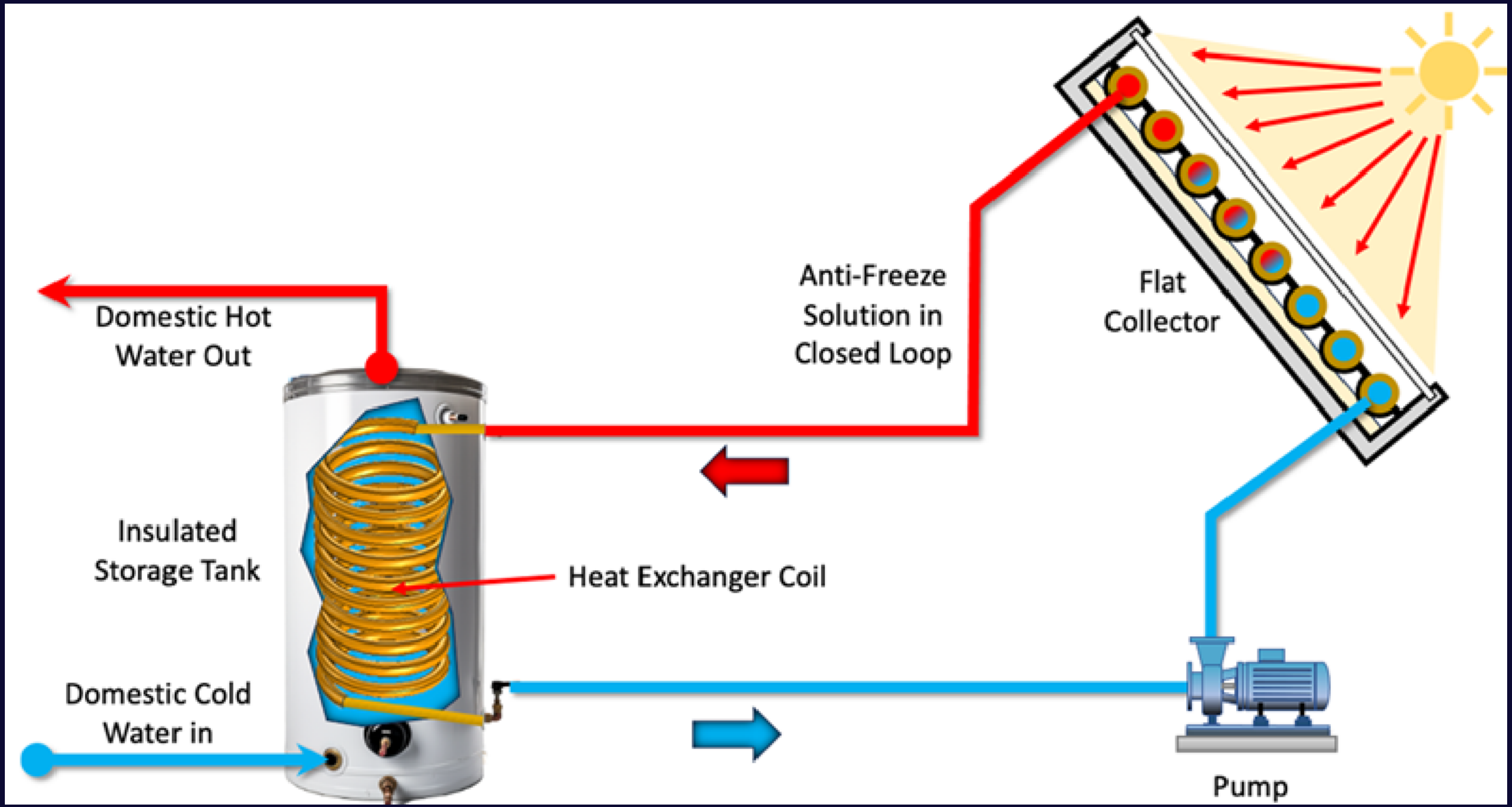
- Water flows directly through solar collectors.
- A pump circulates water when sunlight is available.

Best for:

Warm climates where freezing is rare.

Active Systems

Indirect Circulation (Closed-Loop) Systems



How it works:

- A heat transfer fluid (e.g., antifreeze) circulates through collectors.
- Heat is transferred to water via a heat exchanger.

Best for:

Cold climates (prevents freezing).

Passive Solar Water Heating

Passive systems rely on natural convection and gravity for fluid circulation, eliminating the need for pumps and electrical controls while providing reliable hot water heating.

Simple Design

Fewer moving parts

Lower Cost

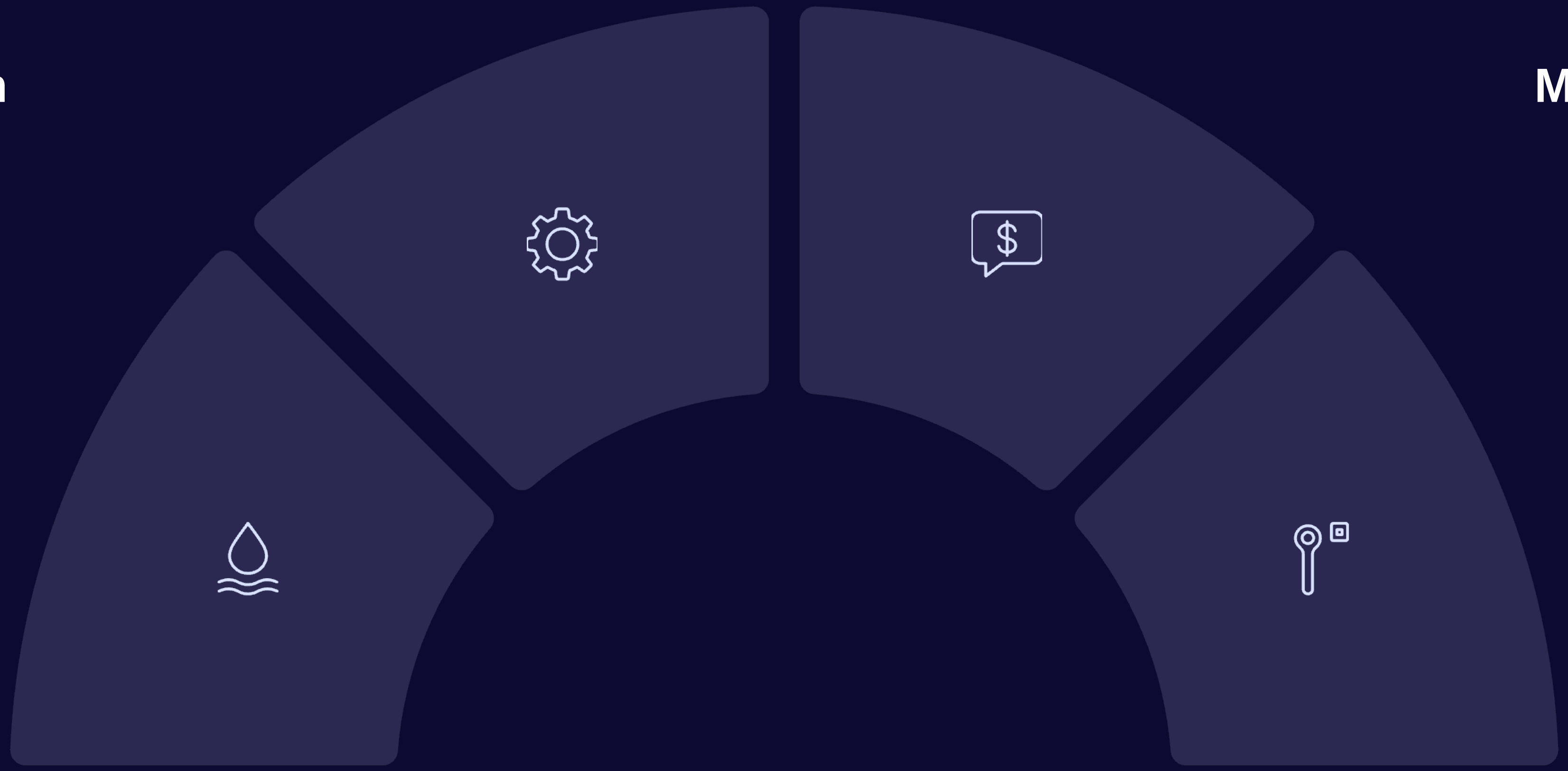
Reduced complexity

Natural Circulation

No pumps required

Minimal Maintenance

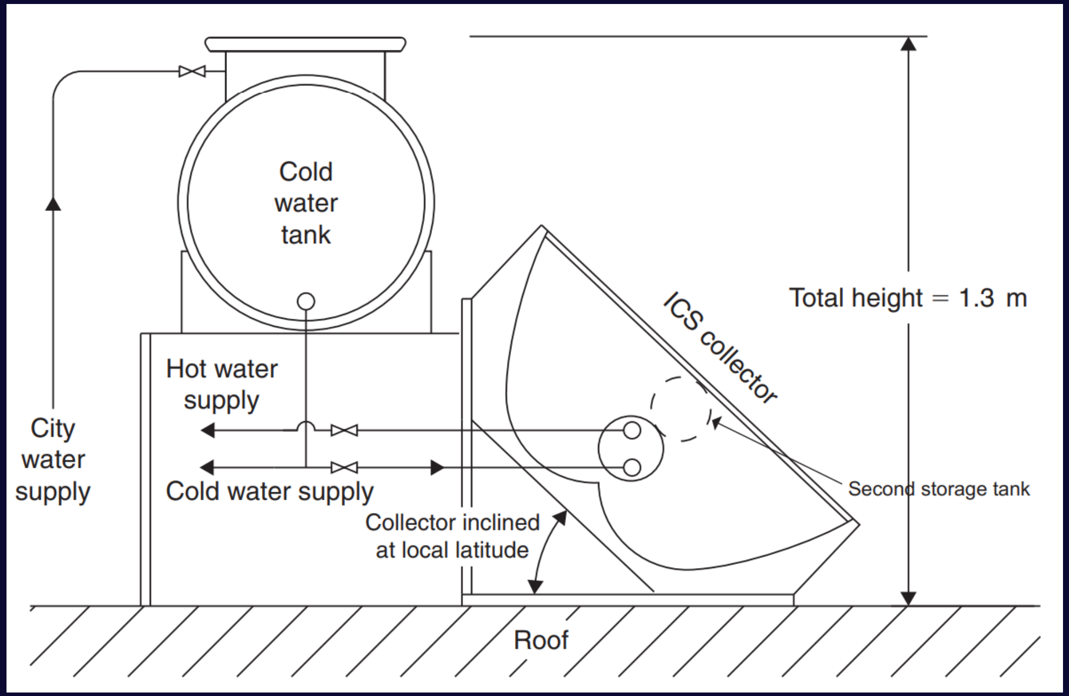
Less servicing needed



Integral Collector-Storage (ICS) Systems

How it works:

- Integrated collector storage (ICS) systems use the hot water storage as part of the collector, i.e., the surface of the storage tank is used as the collector absorber
- Gravity feeds hot water to the tank.



Best for:

Mild climates with minimal freezing.

Thermosiphon Systems

How it works:

- Water heated in collectors rises naturally to an insulated storage tank (mounted above collectors).
- Cold water sinks, creating a natural circulation loop.

Best for:

Warm to moderate climates.

Comparison of Solar Water Heating Systems

Feature	Active Systems	Passive Systems
Pump Required?	Yes	No
Freezing Risk	Low (indirect systems)	High (except thermosiphon)
Efficiency	Higher (controlled circulation)	Lower (natural flow)
Cost	Higher (pumps, controls)	Lower (simpler design)
Maintenance	More complex	Minimal

This comparison helps determine the most suitable solar water heating system based on climate conditions, budget constraints, and maintenance preferences.

Task 4: Test Your Knowledge

https://wayground.com/join?gc=44454962

1. **Active solar heating systems use:**
   A) Natural convection
   B) Gravity flow
   C) Pumps for circulation
   D) Thermosiphon effect
2. **Passive solar systems are typically:**
   A) More complex and expensive
   B) Less efficient but simpler
   C) Equipped with electrical pumps
   D) Used only in freezing climates
3. **Which system is ideal for freezing climates?**
   A) Direct circulation
   B) Passive thermosiphon
   C) Indirect circulation
   D) None of the above
4. **Thermosiphon systems is best suited for:**
   A) Cold climates
   B) Warm climates
   C) Moderate rainfall zones
   D) Mountain regions
5. **In a thermosiphon system, circulation occurs due to:**
   A) Electrical pumping
   B) Heat exchanger
   C) Pressure difference
   D) Density differences (temperature variations)

Homework

1) **State the advantages, disadvantages and applications of solar energy.**

2) **How are solar collectors classified?.**

3) **Give brief description of a flat-plate collector.**

4) **Discuss briefly selective coatings/surfaces.**

5) **State the advantages, disadvantages and applications of flat-plate collectors.**

6) **Explain briefly "Evacuated tube collectors".**

7) **Explain briefly the factors which affect the performance of a flat-plate collector.**

8) **What is the difference between passive and active Solar Water Heating Systems.**

Homework

An evacuated tube solar collector is exposed to solar radiation with an intensity of 830 W/m². Water enters the collector at a temperature of 42 °C, while the ambient air temperature is 26 °C. The collector has an effective optical efficiency of 0.83 and an effective heat loss coefficient of 1.35 W/m²·K. Water flows through the collector at a mass flow rate of 0.038 kg/s, and the specific heat capacity of water is 4200 J/kg·K. If the total collector area is 2 m², determine the useful heat output from the collector, the outlet temperature of the water leaving the collector and the collector efficiency.

Answer

Q_c = **1334.6 W**, $T_{fo} = 50.36$ C , $\eta_c = 80.4$ %

وزارة التعليم العالي والبحث العلمي

الجامعة التقنية الشمالية

الكلية التقنية الهندسية / الموصل

قسم هندسة تقنيات ميكانيك القوى

اسم المادة : الطاقة المتجددة

محاضرة بعنوان

Variation in Extraterrestrial Solar Radiation

مدرس المادة:

م. محمد طه محمد

Variation in Extraterrestrial Solar Radiation

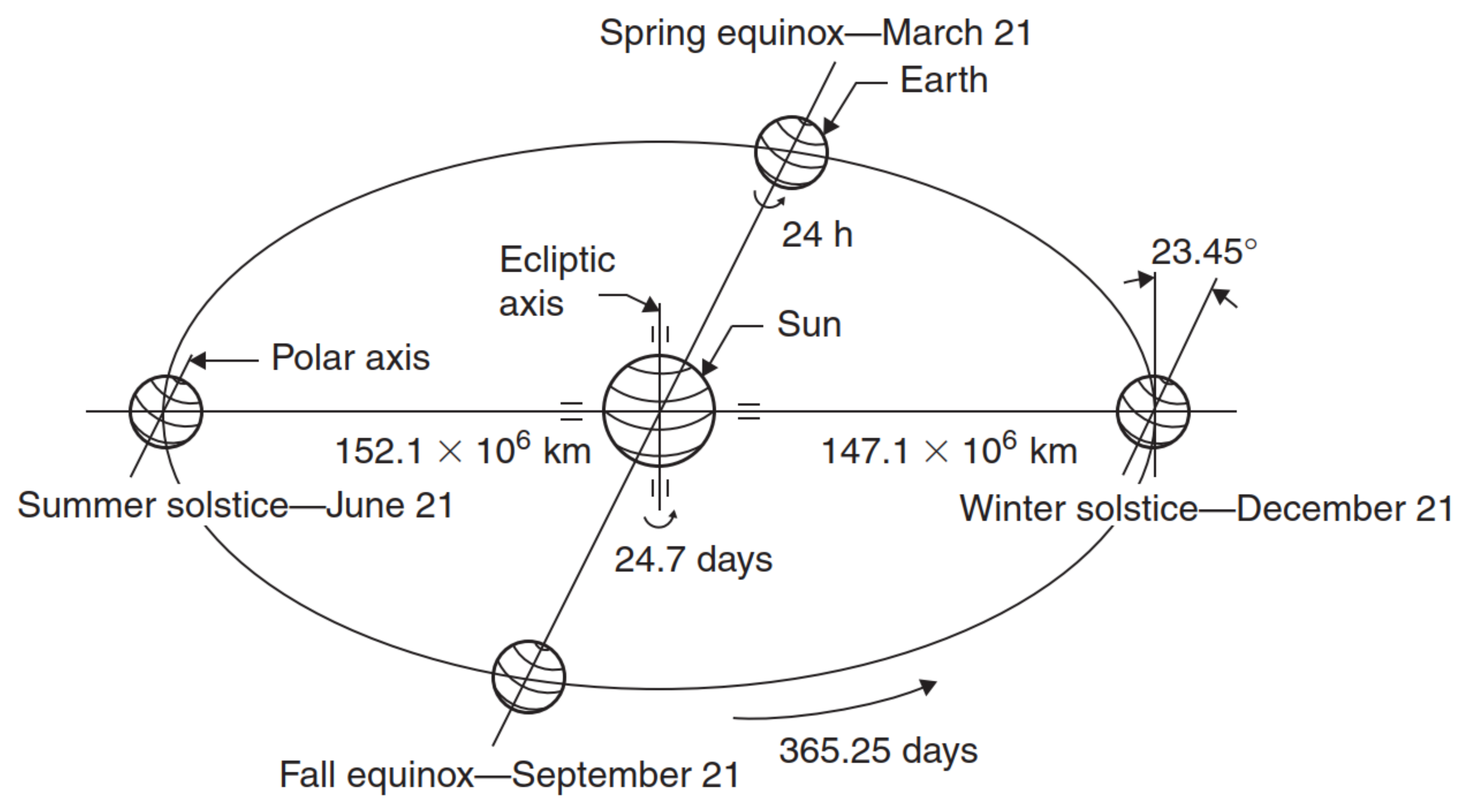
Two primary sources cause variation in extraterrestrial radiation that must be considered for solar energy applications.

Solar Emission Variation

The radiation emitted by the sun itself varies. Conflicting reports suggest small periodic variations (less than ±1.5%) related to sunspot activities and different periodicities.

Earth-Sun Distance Variation

The distance between the Earth and the Sun varies throughout the year, leading to a variation of extraterrestrial radiation flux in the range of 3.3%.



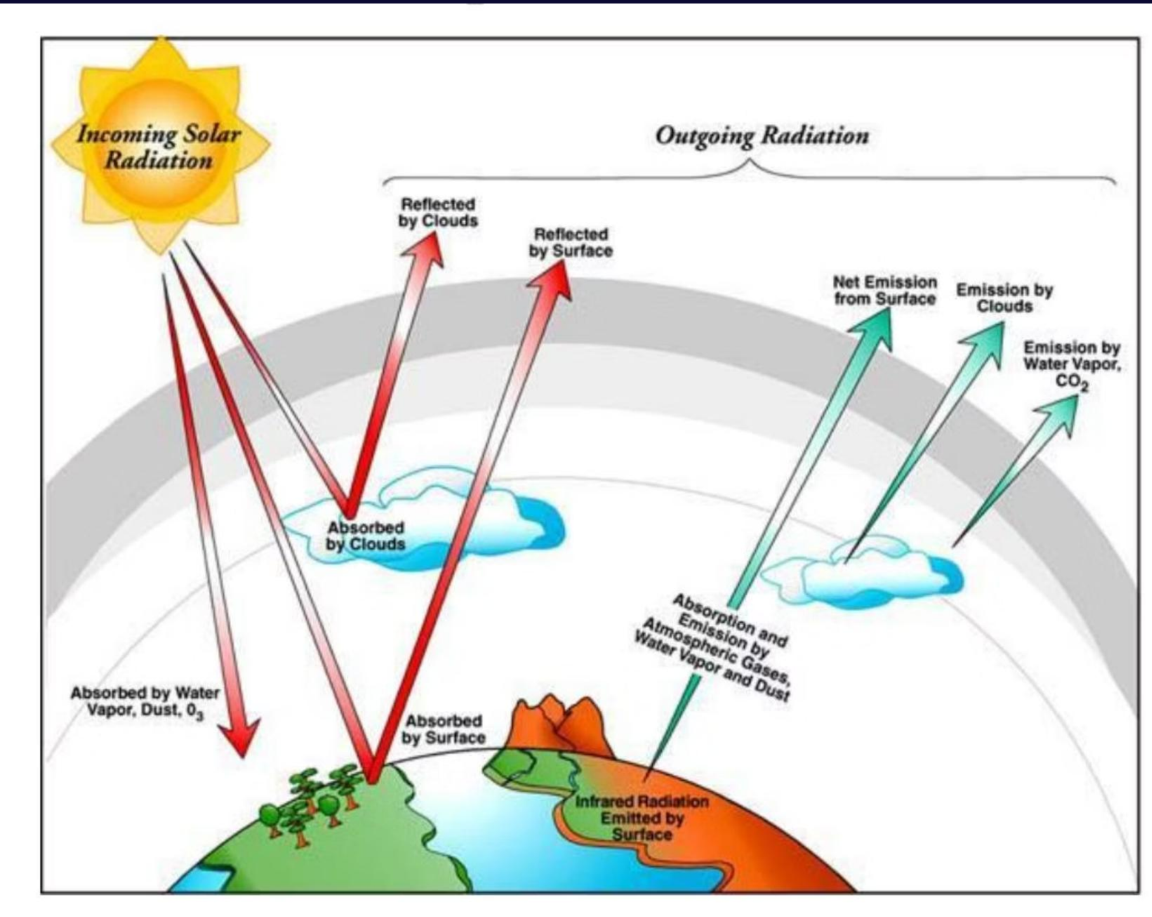
Available Solar Radiation on Earth

Extraterrestrial radiation is significantly affected as it passes through the Earth's atmosphere. This section details the mechanisms that alter solar radiation and describes the properties of the solar radiation that ultimately reaches the Earth's surface.

Understanding these atmospheric effects is crucial for accurately modeling and designing solar energy systems.

1. Atmospheric Attenuation

When solar radiation with normal incidence passes through the atmosphere, it is subject to two main sources of attenuation: scattering and absorption.



Scattering

Radiation interacts with air molecules, water, and dust, changing its direction.

Absorption

Radiation is converted to heat by atmospheric particles, primarily in the UV and IR ranges.

Mechanisms of Attenuation

Scattering

Scattering occurs when radiation interacts with air molecules, water, and dust. The degree of scattering depends on the radiation's wavelength relative to particle size, particle concentration, and the total air mass traveled.

The most important process is **Rayleigh scattering**, where light is scattered off air molecules. This is most effective for shorter wavelengths (blue end of the spectrum, <0.6 μm).

Absorption

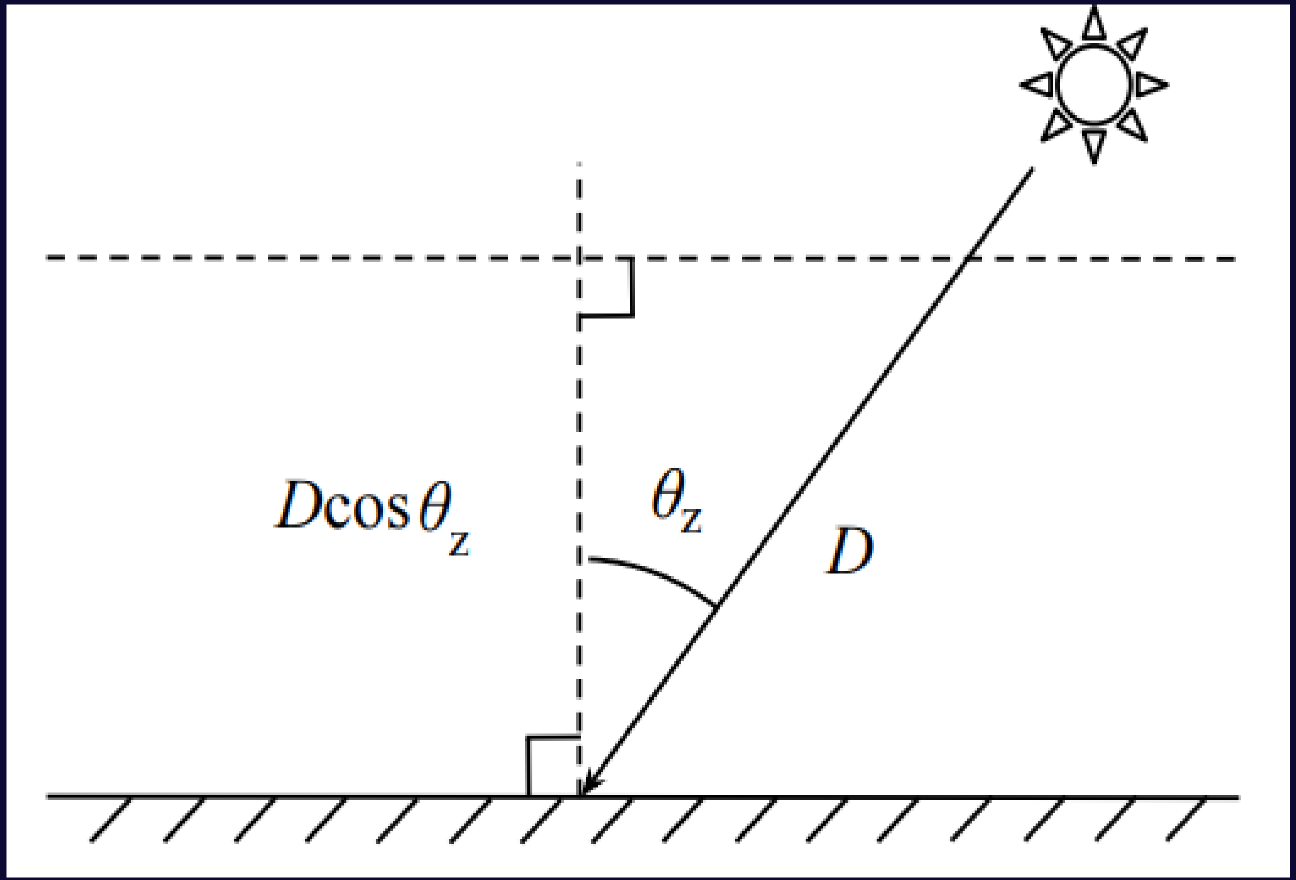
Absorption converts solar radiation into heat, which is then emitted as long-wave radiation by the particles.

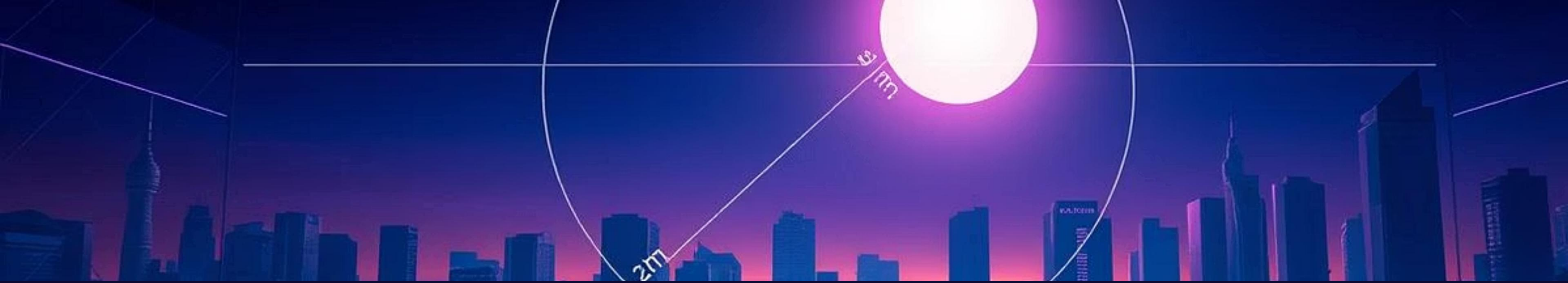
- UV range absorption is primarily due to **ozone**.
- IR range absorption is mainly caused by **water** and **carbon dioxide**.

Air Mass: Measuring Path Length

Solar radiation attenuation is directly related to the distance the radiation must travel through the atmosphere. A longer path length means more particle interactions and greater attenuation.

This path length varies daily and seasonally, with the longest path occurring when the Sun is close to the horizon (evenings). The concept of **Air Mass** is used to describe this path length variation.





Defining Air Mass (Am)

Formally, air mass (Am) is the ratio of the atmospheric mass through which the radiation passes from the Sun's current position to the mass it would pass through if the Sun were at the zenith (directly overhead).

For example, at Am = 2, the path length is twice as long as when the Sun is directly overhead. The formula for Air Mass is:

$$Am = \frac{1}{\cos \theta_z}$$

This formula is accurate for zenith angles θ_z less than 70°. For higher angles, the curvature of the Earth becomes influential, leading to errors (e.g., 10% error at θ_z = 85°).

The AM1.5 Standard Spectrum

Since atmospheric conditions constantly vary, a standard spectrum for radiation at ground level is essential for developing and testing solar devices.

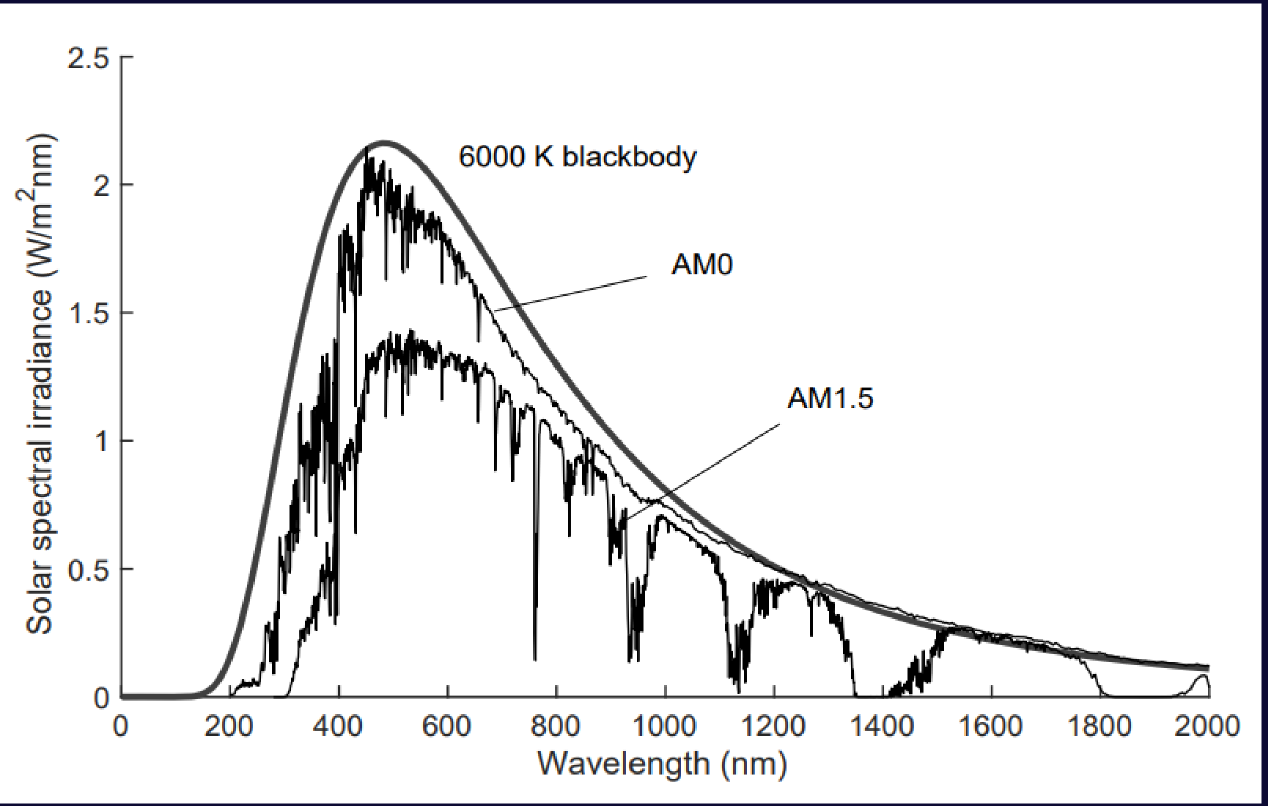
The accepted standard is the distribution for **Air Mass 1.5 (AM1.5)** spectrum, which corresponds to a zenith angle of 48.2°. This standard allows for consistent comparison and evaluation of solar technologies.

The AM1.5 spectrum is often compared to the extraterrestrial WRC spectrum and a 6000 K black-body distribution to illustrate the effects of atmospheric filtering.

Comparing Solar Spectra

The figure below visually compares the standard AM1.5 spectrum (radiation at ground level) with the extraterrestrial WRC spectrum (radiation outside the atmosphere) and a theoretical 6000 K black-body distribution.

The difference between the extraterrestrial and AM1.5 spectra highlights the energy lost due to atmospheric scattering and absorption, particularly in specific wavelength bands.



Types of Solar Radiation: Beam Radiation

1

Definition

Beam radiation is the solar radiation received directly from the sun without having been scattered by the atmosphere.

2

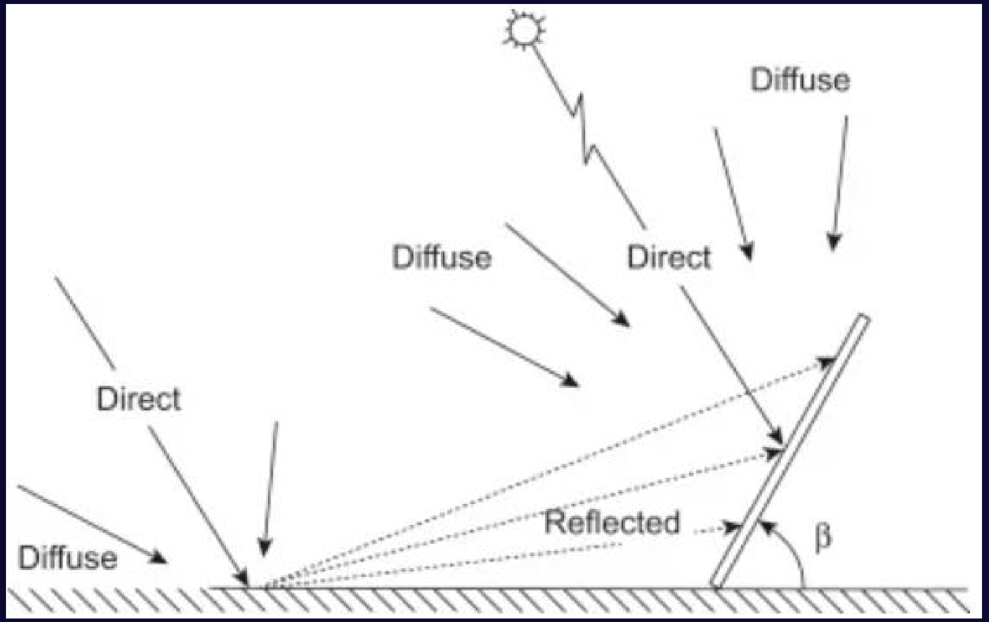
Alternative Term

It is often referred to as **direct solar radiation**. We use "beam radiation" to avoid confusion with subscripts.

3

Characteristics

This radiation travels in a straight line from the sun and casts sharp shadows.



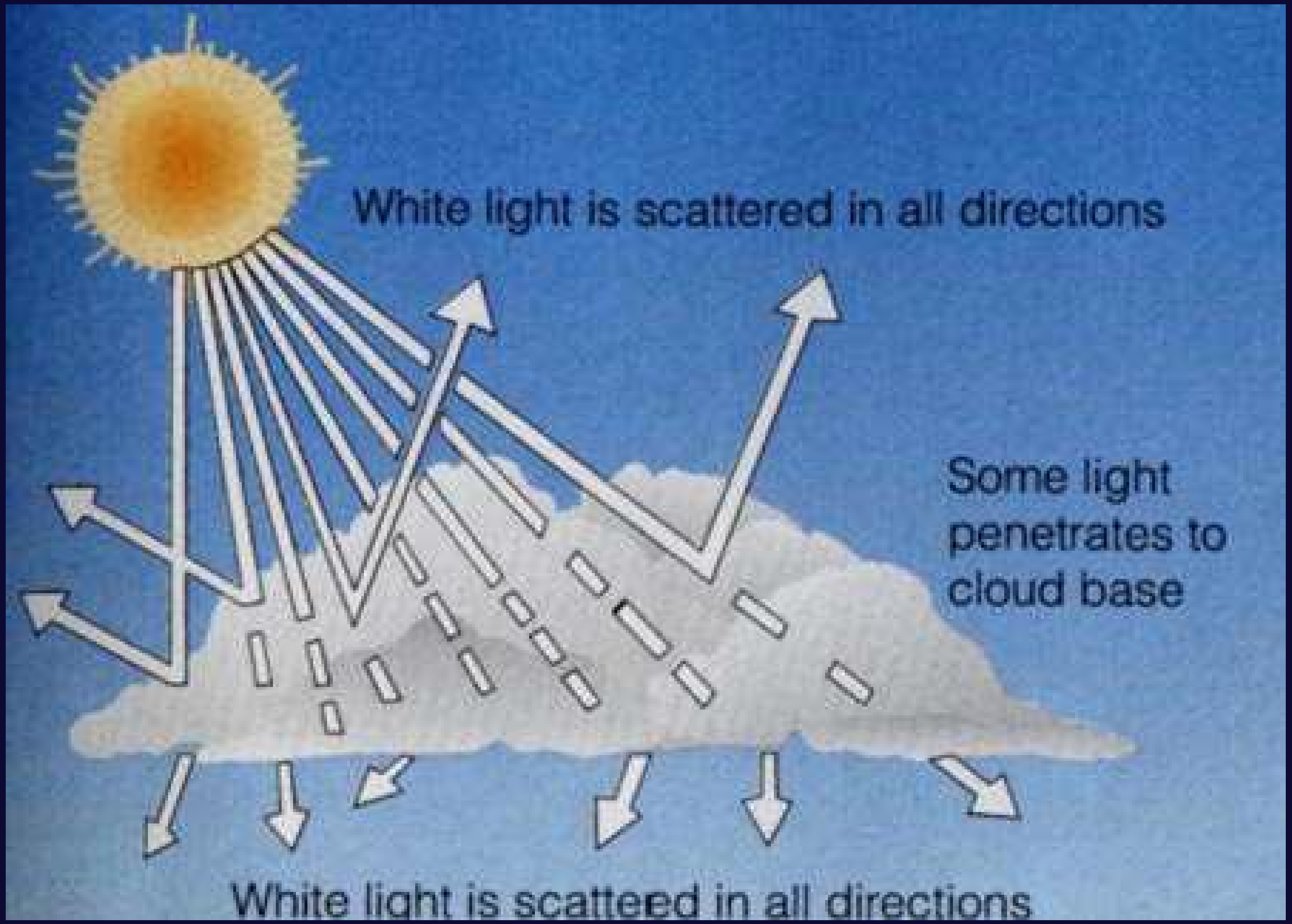
Types of Solar Radiation: Diffuse Radiation

Scattered Light

Diffuse radiation is solar radiation that has changed direction after being scattered by atmospheric components like air molecules, clouds, and aerosols.

Omnidirectional

It arrives at the Earth's surface from all directions of the sky, not just directly from the sun's disk.



Alternative Names

In some meteorological literature, it is called **sky radiation** or **solar sky radiation**.

Understanding Solar Energy: Radiation, Time, and Angles

This presentation explores the fundamental concepts governing solar energy, from measuring radiation intensity to calculating solar time and understanding the Earth's angular relationship with the sun.

Defining Total Solar Radiation

Total Solar Radiation

The sum of the beam and the diffuse solar radiation incident on a surface.

Global Radiation

The most common measurement of solar radiation, often referring to the total radiation on a horizontal surface.

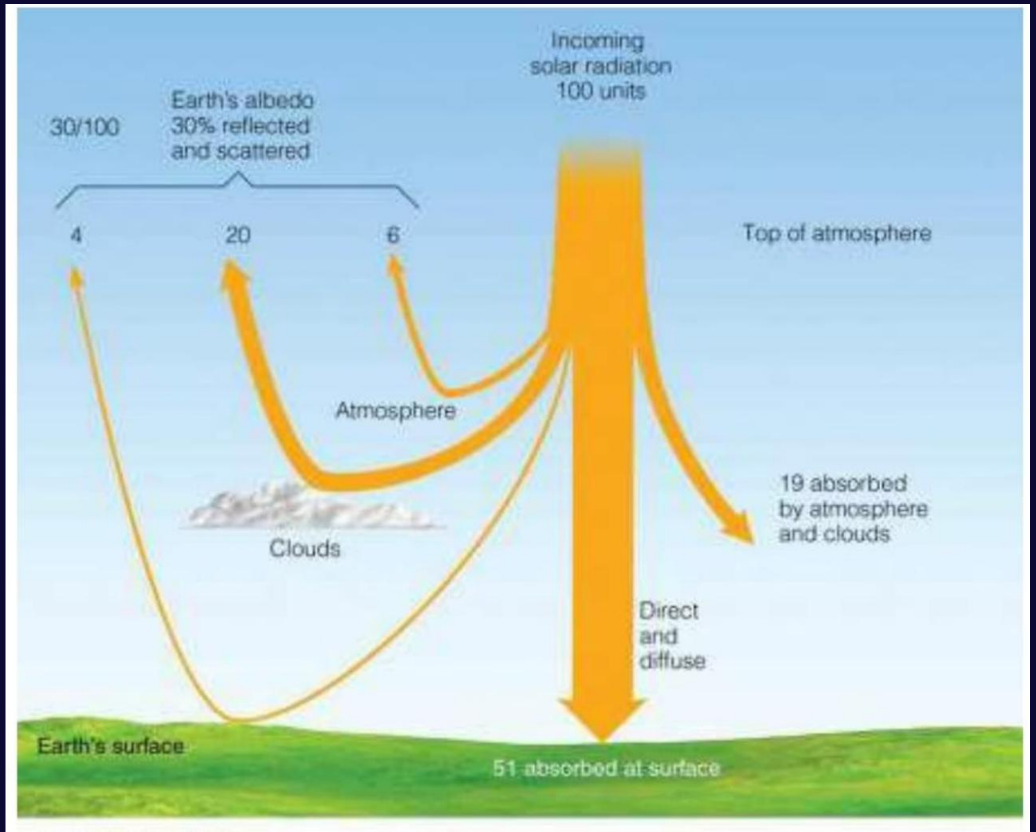
Solar Time vs. Local Clock Time

Solar time is based on the apparent angular motion of the sun across the sky, with solar noon being the moment the sun crosses the observer's meridian. This is the time used in all sun-angle relationships and does not coincide with local clock time.

Converting Standard Time to Solar Time

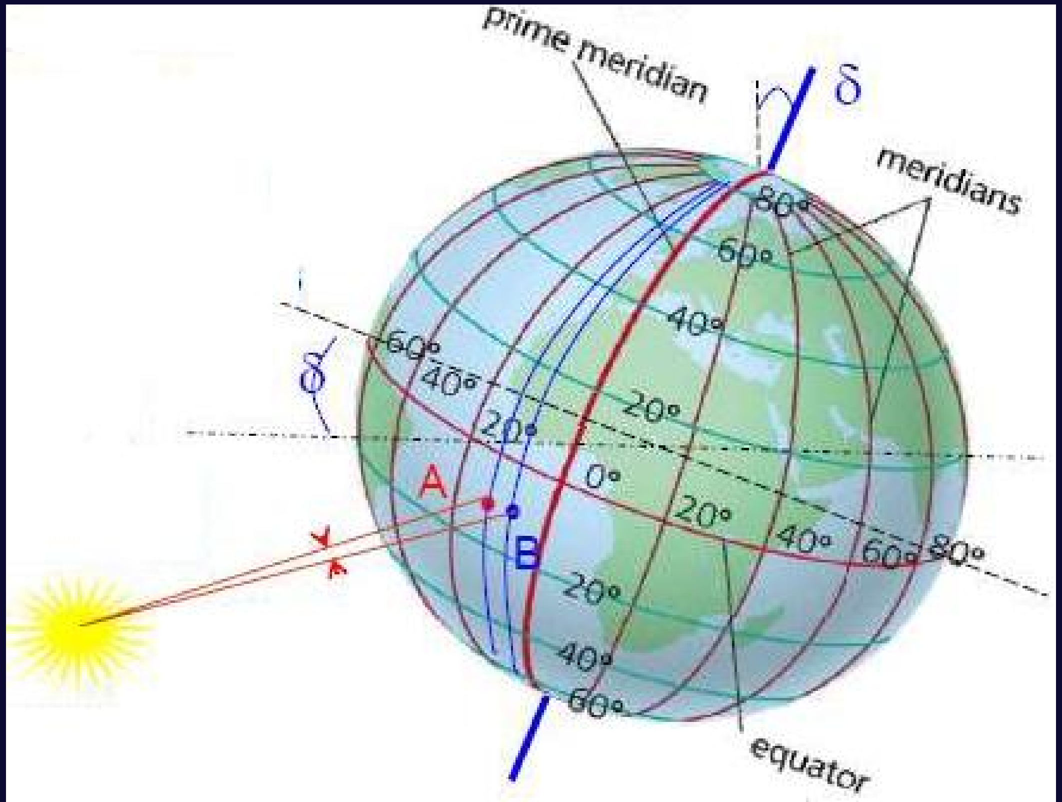
Two primary corrections are necessary to convert standard time to solar time:

- A constant correction for the difference in longitude between the observer's meridian and the standard time meridian.
- A correction using the equation of time, which accounts for perturbations in the Earth's rotation rate.



Earth's Rotation and Longitude

The Earth's longitudinal lines are essential for calculating solar time and position. The planet is divided into 360° longitudinal lines passing through the poles, with the zero longitudinal line passing through Greenwich.



360°	24	15°
Longitudinal Lines	**Hours in a Day**	**Rotation Rate**
Total degrees of longitude around the Earth.	Time for the Earth to complete one full rotation.	The Earth rotates 15° of longitude every hour.

Longitude and Inclination

The declination angle, δ varies seasonally

δ = 23.27 at summer and winter solstice
δ = 0 at equinoxes
δ takes all intermediate values

The incident solar radiation on a slope plane with an inclination angle β , ($I_{\beta G}$) can be evaluated as the sum of direct-beam, sky-diffuse, and ground reflected components. It can be given as:

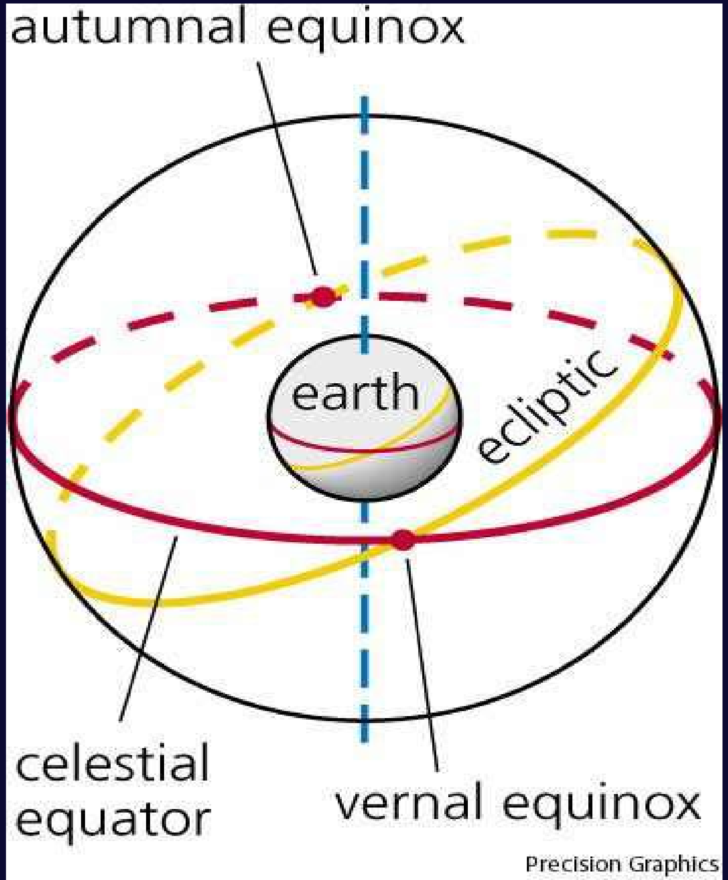
$$I_{\beta G} = I_{\beta B} + I_{\beta D} + I_{\beta R}$$

Where: $I_{\beta B}$ - is the beam radiation, w/m^2, $I_{\beta D}$ - is the sky-diffuse radiation, w/m^2, $I_{\beta R}$ - is the ground reflected radiation, w/m^2.

$$\delta = 23.45 \sin\left[\frac{360}{365}(n-81)\right]$$

January	$n = 1$	July	$n = 182$
February	$n = 32$	August	$n = 213$
March	$n = 60$	September	$n = 244$
April	$n = 91$	October	$n = 274$
May	$n = 121$	November	$n = 305$
June	$n = 152$	December	$n = 335$

Day Numbers for the First Day of Each Month



Solar Radiation Measurement Instruments

A detailed look into the construction and working principles of key instruments used for measuring solar radiation: the Pyranometer, Pyrheliometer, and Sunshine Recorder.

The Pyranometer: Measuring Global Radiation

The Pyranometer is designed to measure both beam (direct) and diffuse solar radiation, often referred to as global radiation. It is a fundamental tool in meteorology and solar energy research.

Function

Measures total solar radiation incident on a horizontal surface.

Application

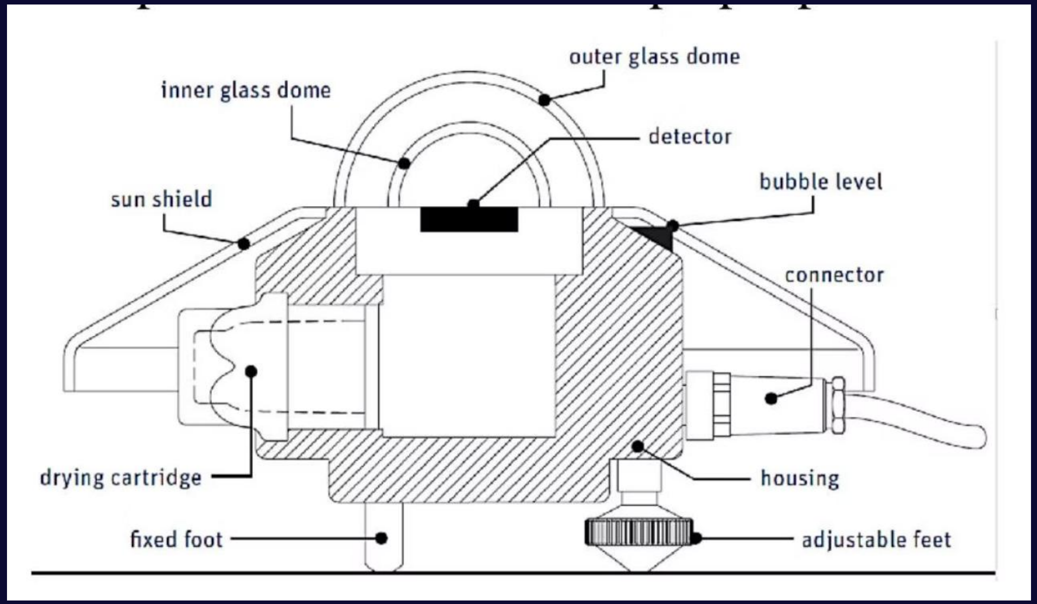
Essential for calculating solar energy potential and climate monitoring.

Construction of the Pyranometer

The Pyranometer is built around a black surface designed to absorb solar radiation. This surface receives both the direct beam and diffuse radiation.

- **Black Surface:** Absorbs incoming solar and diffuse radiation, causing a temperature rise.
- **Glass Dome:** A protective glass dome prevents the loss of radiation received by the black surface, ensuring accurate measurement.

A thermocouple assembly is used as the sensor.



The Thermocouple Sensor

Temperature Sensor

A thermocouple is a temperature sensor that detects the heat absorbed by the black surface.

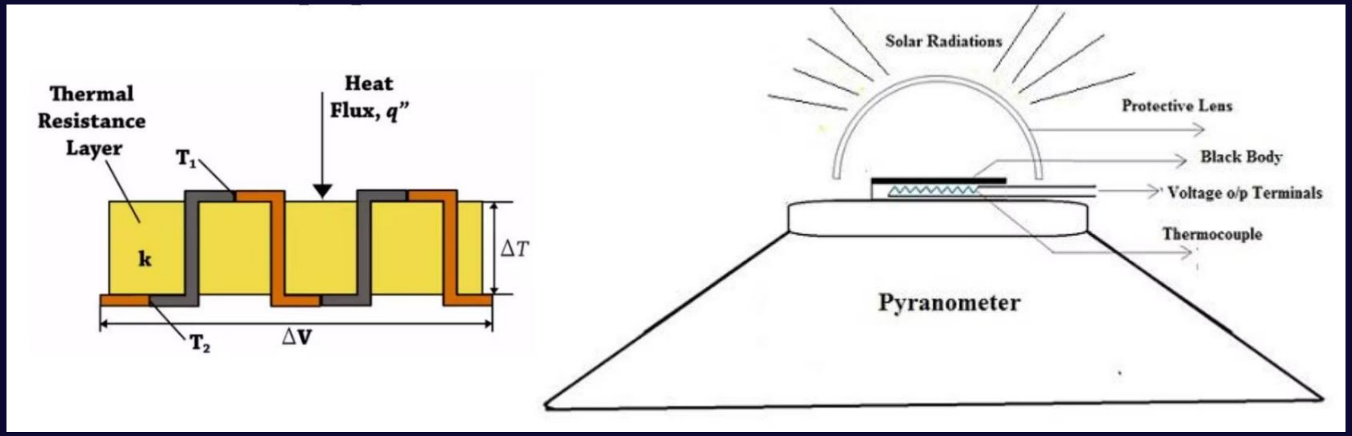
Increased Sensitivity

It consists of multiple thermocouples connected in series (a thermopile) to significantly increase the overall sensitivity of the device.

Supporting Stand

A supporting stand ensures the black surface is maintained in the correct, stable position for accurate readings.

Working Principle of the Pyranometer



Exposure to Sun

The Pyranometer is exposed to the sun, starting the reception of solar radiation.

Absorption & Heating

The black surface absorbs the radiation, causing its temperature to rise.

Detection by Thermocouples

The increase in the absorbing surface's temperature is detected by the thermopile.

EMF Generation

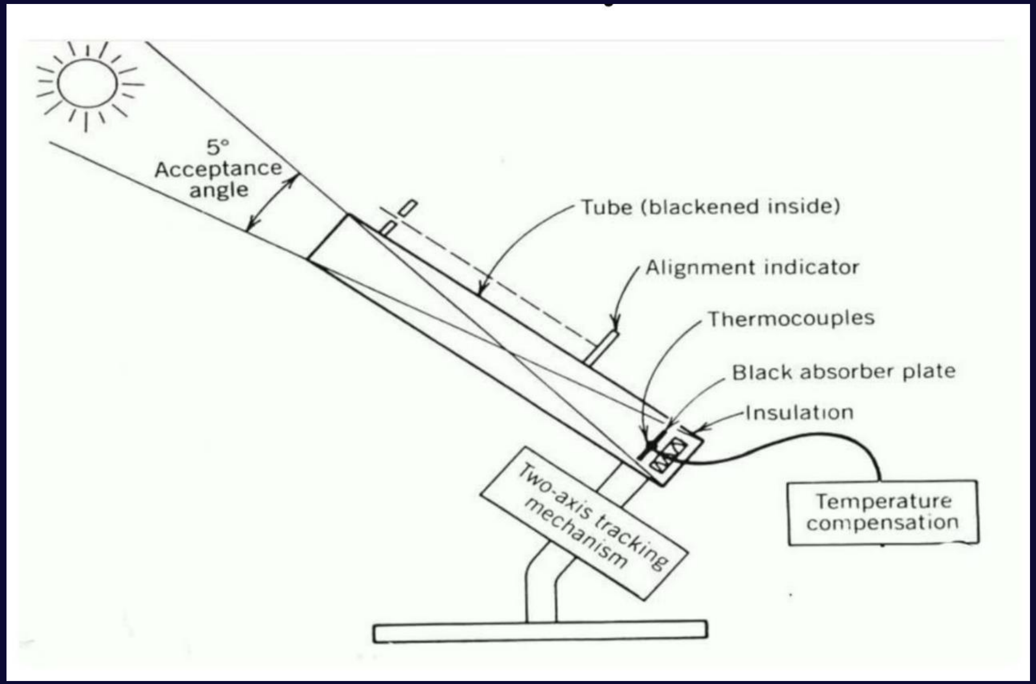
The thermocouples generate a thermo electromotive force (emf) directly proportional to the absorbed radiation.

The Pyrheliometer: Measuring Direct Radiation

Unlike the Pyranometer, the Pyrheliometer is specifically designed to measure only the beam, or direct, solar radiation. It uses a collimated detector to ensure only radiation coming directly from the sun is measured.

> It collimates the radiation to determine the beam intensity as a function of incident angle, focusing on solar radiation from the sun and a small portion of the surrounding sky at normal incidence.

Construction and Function of the Pyrheliometer



The core of the Pyrheliometer is a long collimator tube that ensures only parallel rays of sunlight reach the sensor.

- **Collimator Tube:** A long tube that restricts the field of view, allowing only direct sunlight to pass through.
- **Black Absorber Plate:** Located at the end of the tube, this plate absorbs the incoming beam radiation.
- **Thermopile:** In contact with the absorber plate, it measures the temperature difference.

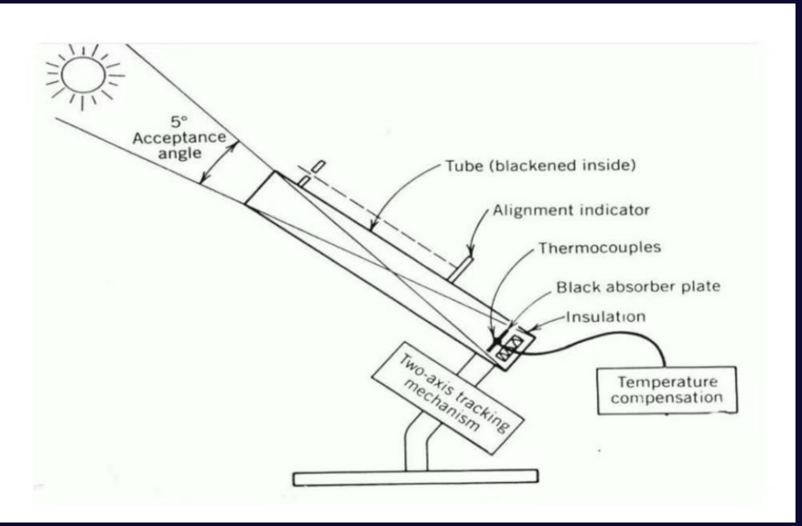
Working Principle of the Pyrheliometer

Sunlight Entry

Sunlight enters the long collimator tube, ensuring only direct rays are incident.

Absorption

The light strikes and is absorbed by the black absorber plate.



Heat Generation

The black plate absorbs heat, creating a temperature difference between the hot and colder surfaces.

EMF Measurement

This temperature difference generates an emf via the thermopile, which is used to measure the value of the beam radiation.

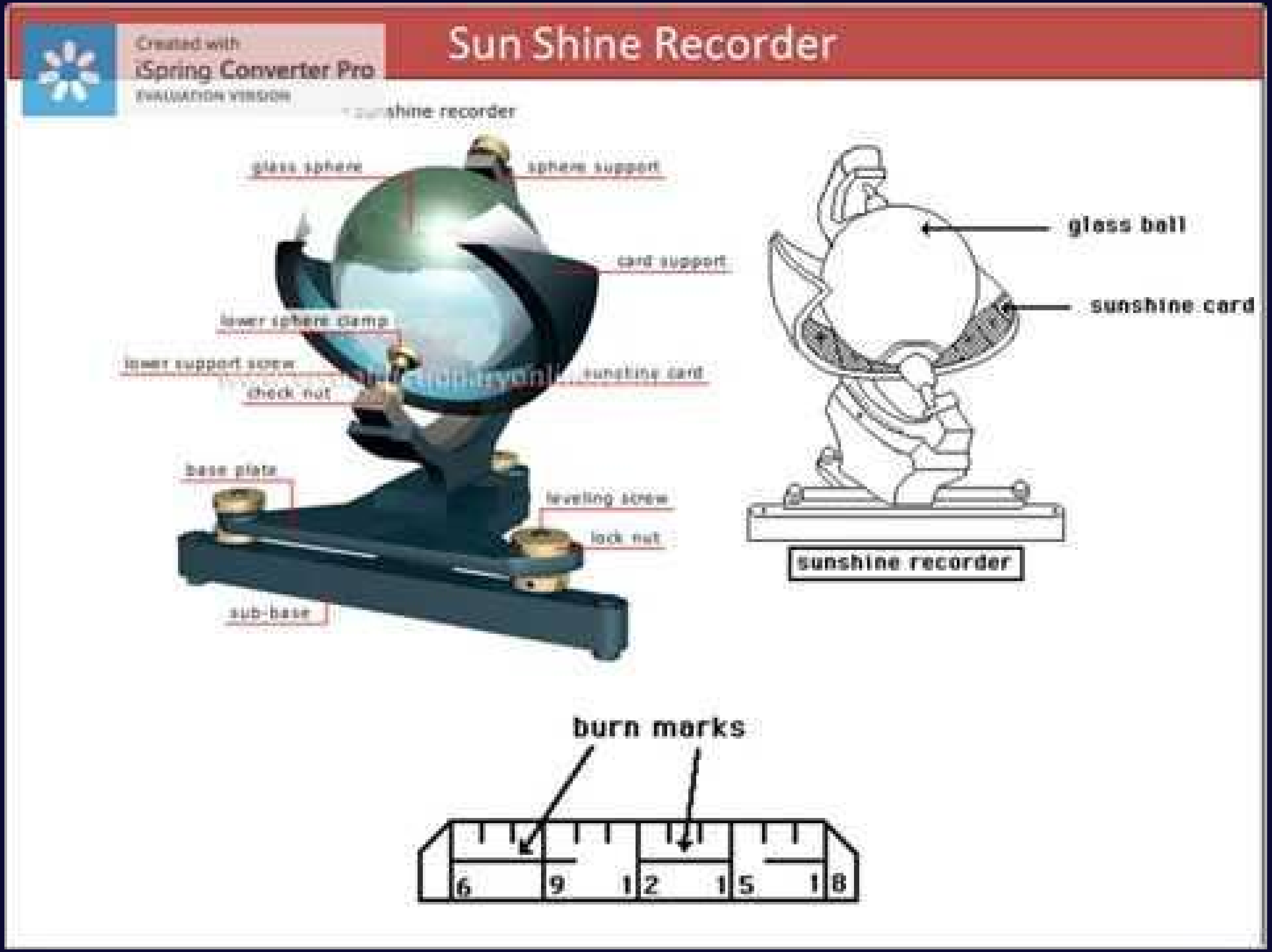
The Sunshine Recorder

The Sunshine Recorder is a meteorological instrument used to measure the duration of bright sunshine in a day, providing valuable data for climate studies and agriculture.

Construction and Working of the Sunshine Recorder

The device consists of a glass sphere installed within a spherical metal bowl. The bowl has grooves to hold a recorder card strip.

- **Glass Sphere:** Acts as a convex lens, focusing the sun's rays.
- **Recorder Card Strip:** Held in a groove, this strip is marked by the focused sunlight.
- **Spherical Bowl:** Mounted concentrically with the sphere, it holds the card strip in place.



The glass sphere focuses the sun's beams to a point on the card strip. When the sun is bright enough, the focused heat burns a trace on the card, marking the duration of bright sunshine.

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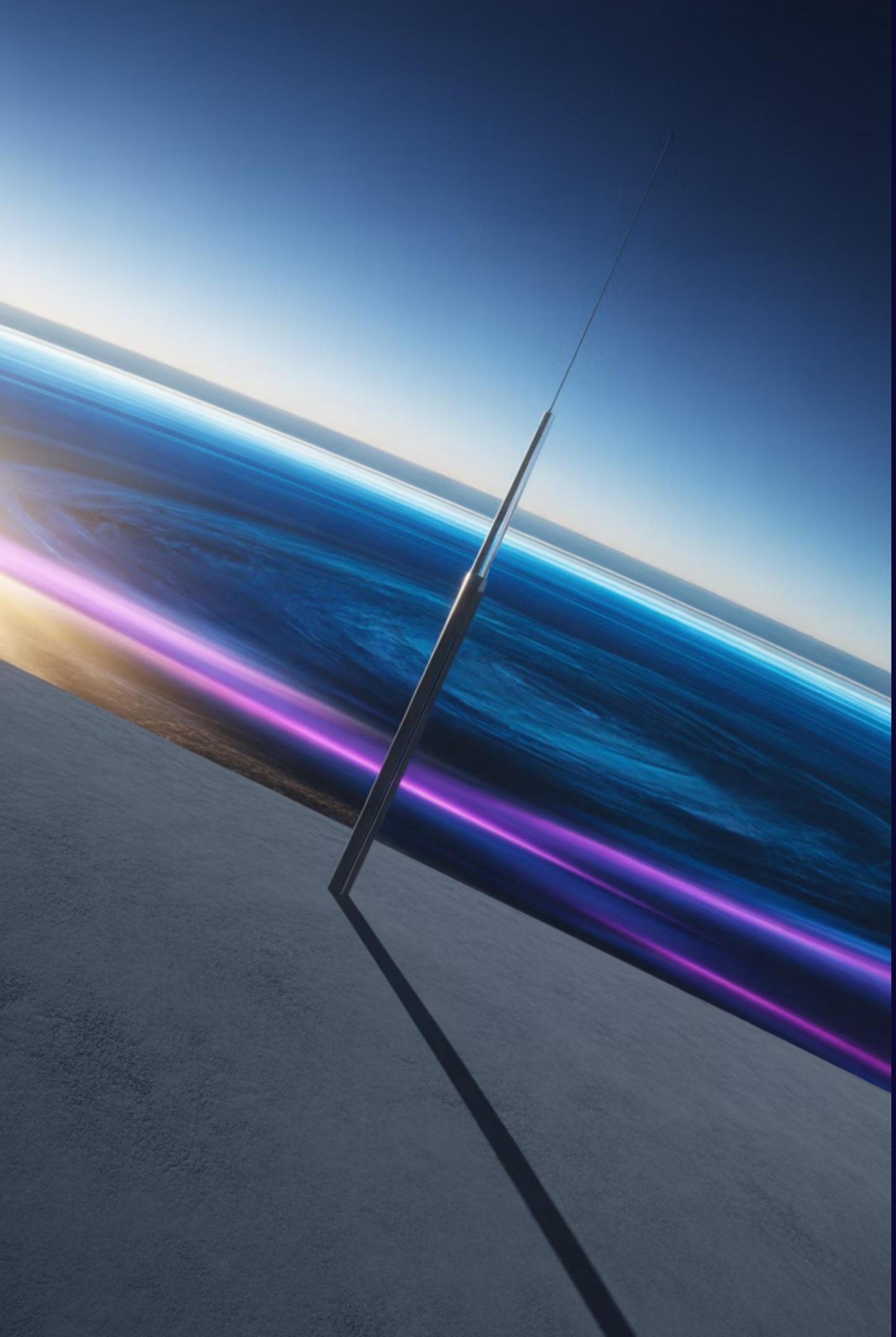
اسم المادة : الطاقة المتجددة

محاضرة بعنوان

Calculation of Solar Radiation

مدرس المادة:

م. محمد طه محمد

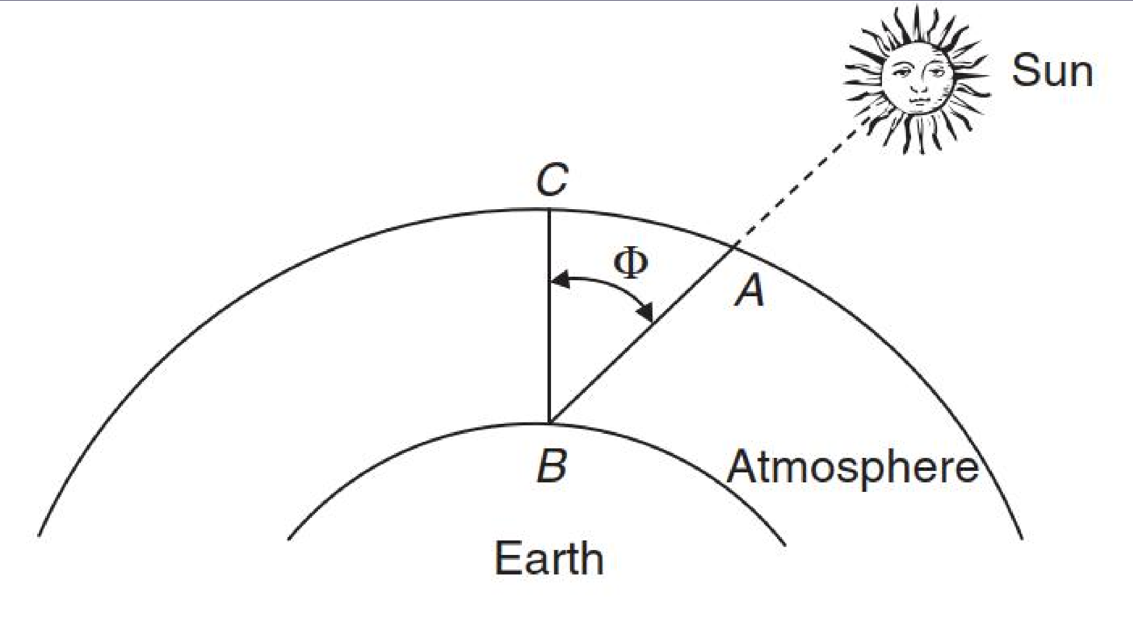


Understanding Solar Radiation and Air Mass

Air mass is a fundamental concept in solar energy that describes the path length light takes through the atmosphere. Understanding air mass is crucial for calculating solar radiation intensity and optimizing solar panel placement.

What is Air Mass?

The Air Mass is the path length which light takes through the atmosphere normalized to the shortest possible path length (that is, when the sun is directly overhead).



Basic Formula

$$AM = \frac{AB}{BC} = \frac{1}{\cos\phi}$$

Where ϕ is the angle from vertical (zenith angle)

The air mass represents the proportion of atmosphere that the light must pass through before striking the Earth relative to its overhead path length, and is equal to AB/BC.

Measuring Air Mass with Shadows

01

Place a Vertical Pole

Set up a pole of known height (h) in direct sunlight

02

Measure the Shadow

Measure the shadow length (s) cast by the pole

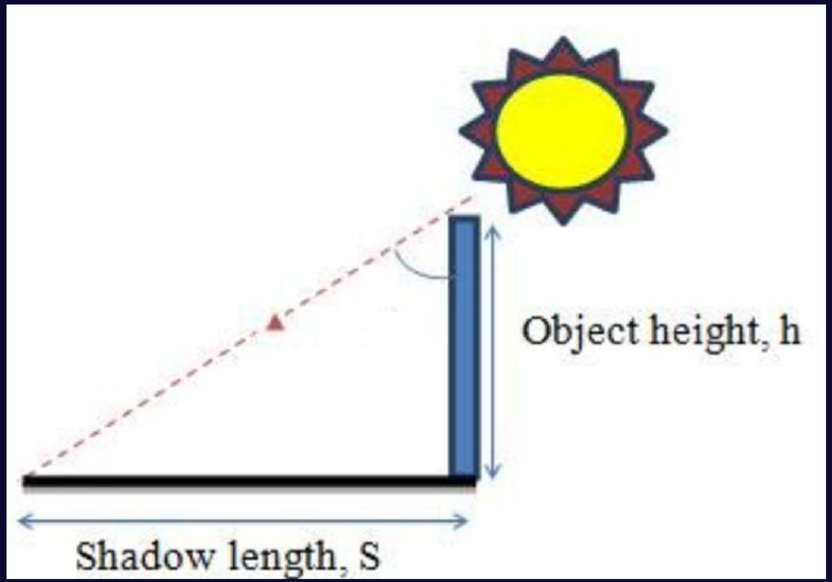
03

Apply Pythagoras

Calculate air mass using the relationship between height and shadow

$$AM = \sqrt{1 + (\frac{s}{h})^2}$$

This simple method provides an accurate air mass measurement using basic geometry and assumes a flat horizontal atmospheric layer.



Visualizing Air Mass

The air mass represents the ratio AB/C, where AB is the actual path length through the atmosphere and AB is the shortest overhead path. As the sun moves lower in the sky, this ratio increases dramatically, meaning light must travel through more atmosphere.

Accounting for Earth's Curvature

The Limitation

The flat atmosphere assumption breaks down near the horizon. At sunrise (ϕ = 90°), the simple formula predicts infinite air mass, but the actual atmospheric path length is finite due to Earth's curvature.

The Solution

A more accurate equation incorporates atmospheric curvature:

$$AM = \frac{1}{\cos\phi + 0.505(96.08 - \phi)^{-1.634}}$$

Solar Constant and Beam Radiation

1367

Solar Constant

W/m² - The intensity of solar radiation at the top of Earth's atmosphere

70%

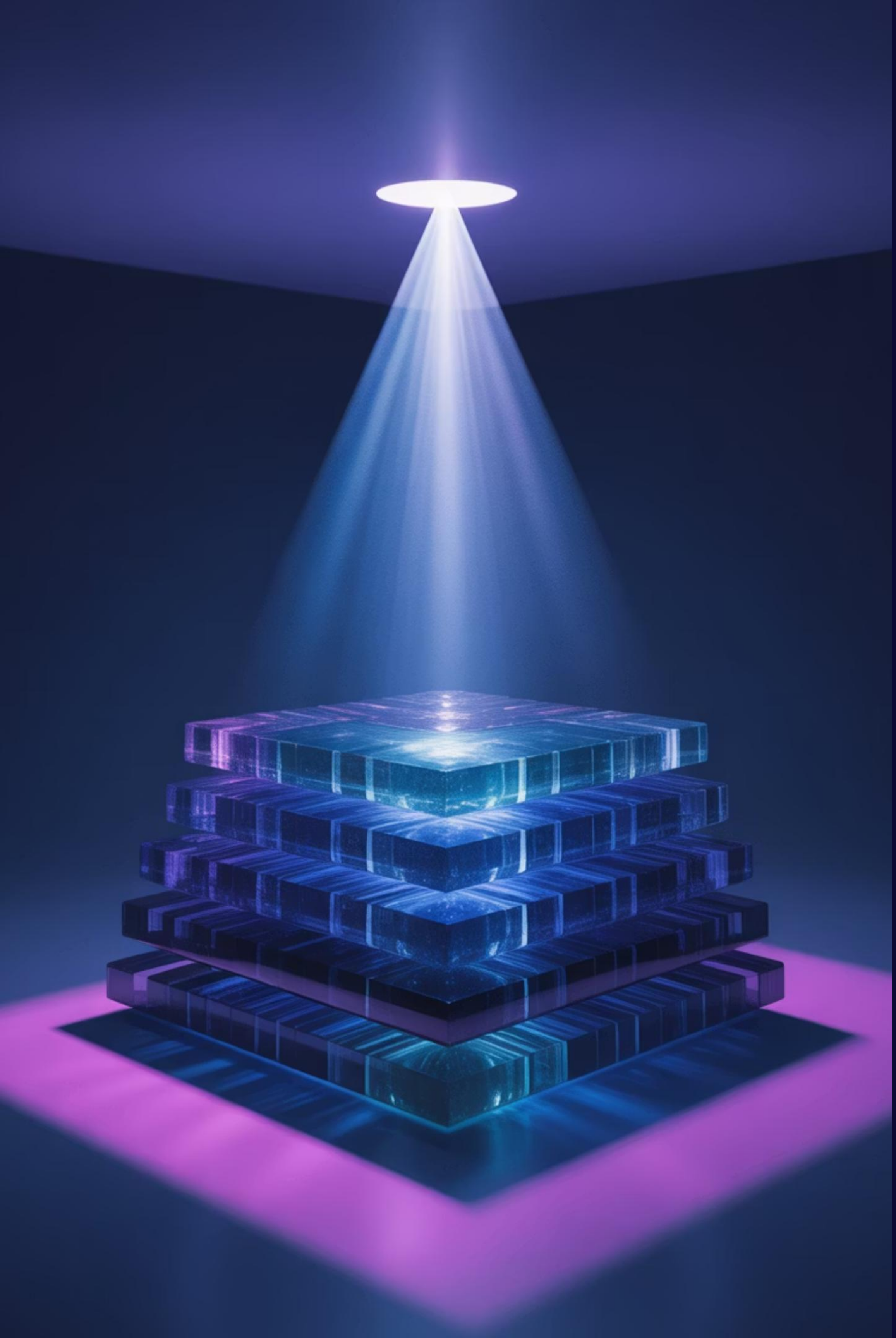
Atmospheric Transmission

Approximately 70% of incident radiation reaches Earth's surface on a clear day

0.678

Empirical Factor

Power term accounting for non-uniformities in atmospheric layers



Calculating Beam Radiation Intensity

The intensity of direct sunlight (beam radiation) on a plane perpendicular to the sun's rays can be determined using an experimentally derived equation that accounts for atmospheric absorption:

$$I_B = 1367 \times 0.7^{AM^{0.687}}$$

Where I_B is the beam intensity in W/m² and AM is the air mass. This equation combines the solar constant with atmospheric transmission factors, modified by the empirical 0.678 exponent that captures real-world atmospheric behavior.

Altitude Effects on Solar Intensity

Higher Elevation = More Power

Sunlight intensity increases with altitude above sea level.

Altitude-Corrected Formula

$$I_B = 1367 \times \left[(1 - aH)0.7^{AM^{0.687}} + aH\right]$$

Where a = 0.14 and H is the height above sea level in kilometers. This empirical fit accurately models conditions up to several kilometers elevation.

Understanding Diffuse Radiation

Diffuse Component

Even on clear days, diffuse radiation accounts for about 10% of beam radiation

Global Multiplier

Global irradiance equals 1.1 times the beam radiation

Diffuse radiation is sunlight scattered by the atmosphere. The global irradiance on a module perpendicular to the sun's rays combines both beam and diffuse components:

$$I_G = 1.1 \times I_B$$

Worked Example: Setup

Problem Statement

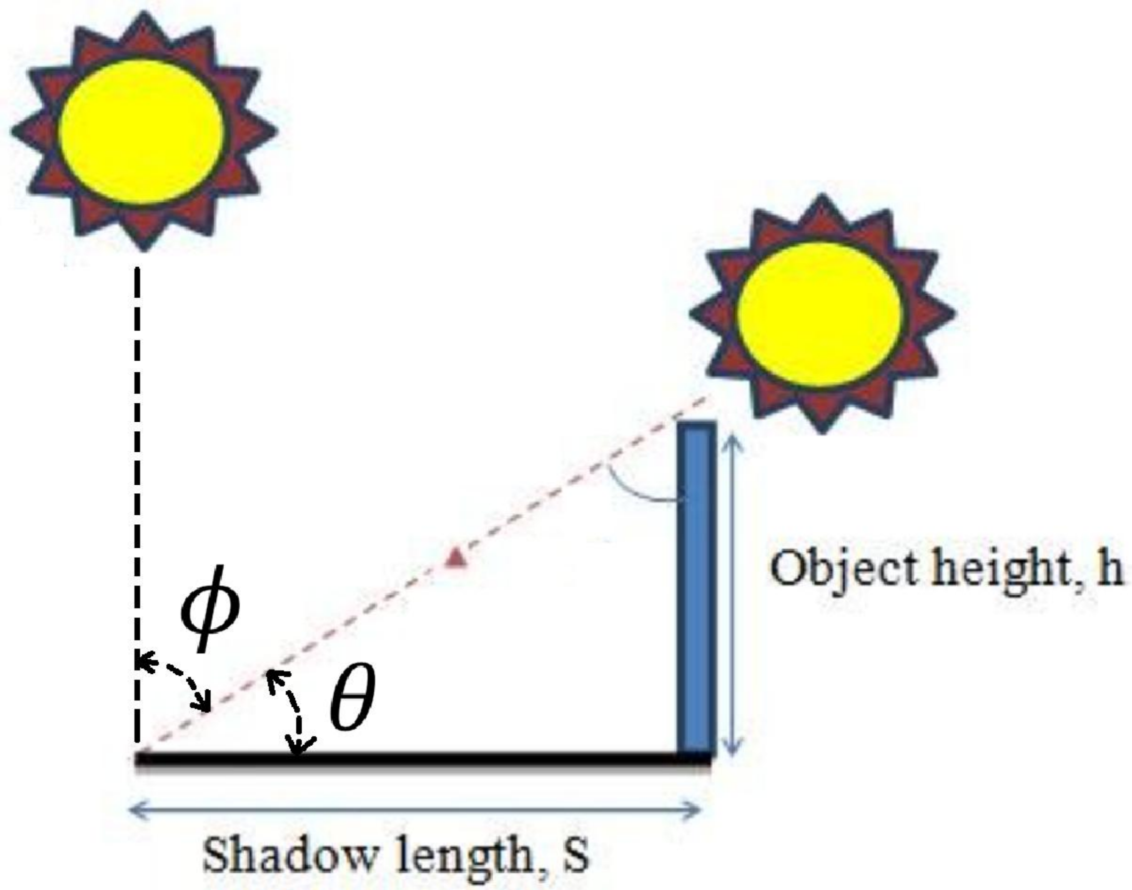
Find the beam, diffuse, and global solar radiation at sea level when a vertical object with height 30 cm with the height of 30 cm has the shadow of 55 cm

Given Data

- Object height: h = 30 cm
- Shadow length: s = 55 cm
- Location: Sea level

Find

- Beam radiation (IB)
- Diffuse radiation (ID)
- Global radiation (IG)



Step 1: Calculate Air Mass

Method 1: Flat Atmosphere Assumption

$$AM = \sqrt{1 + \left(\frac{s}{h}\right)^2} = \sqrt{1 + \left(\frac{55}{30}\right)^2} = 2.088$$

Method 2: Using Zenith Angle

First, find the angle from horizontal:

$$\theta = \tan^{-1}\left(\frac{h}{s}\right) = \tan^{-1}\left(\frac{30}{55}\right) = 28.61°$$

Then calculate zenith angle:

$$\phi = 90 - \theta = 90 - 21.61 = 61.389°$$

Calculate air mass:

$$AM = \frac{1}{\cos\phi} = \frac{1}{\cos 61.389} = 2.088$$

Step 2: Account for Atmospheric Curvature

Using the more accurate formula that incorporates Earth's curvature:

$$AM = \frac{1}{\cos 61.389 + 0.505(96.08 - 61.389)^{-1.634}} = 2.0816$$

Flat Atmosphere	Curved Atmosphere	Difference
AM = 2.088	AM = 2.0816	0.064 (0.3% variation)

The difference is small at this zenith angle but becomes significant near the horizon.

Step 3: Calculate Radiation Components

1

Beam Radiation

$$I_B = 1367 \times 0.7^{2.0816^{0.687}} = 760.55\,W$$

2

Global Radiation

$$I_G = 1.1 \times I_B = 1.1 \times 760.55 = 836.605\,W$$

3

Diffuse Radiation

$$I_D = I_G - I_B = 836.605 - 760.55 = 76.055\,W$$

Final Results Summary

760.55

Beam Radiation

Watts per square meter - Direct sunlight component

76.055

Diffuse Radiation

Watts per square meter - Scattered light component

836.605

Global Radiation

Watts per square meter - Total solar energy available

Practice Problem

Homework Challenge

Resolve the example to find beam, diffuse, and global solar radiation when the object is positioned at 3 km above sea level, with the height of the object and its shadow being equal (symmetrical).

01

Determine Air Mass

With h = s, calculate AM using shadow method

02

Apply Altitude Correction

Use the altitude-adjusted formula with H = 3 km

03

Calculate All Components

Find I_B, I_G, and I_D at the elevated location

Hint: When height equals shadow length, the zenith angle is 45°, making some calculations simpler!

Solar photovoltaic systems

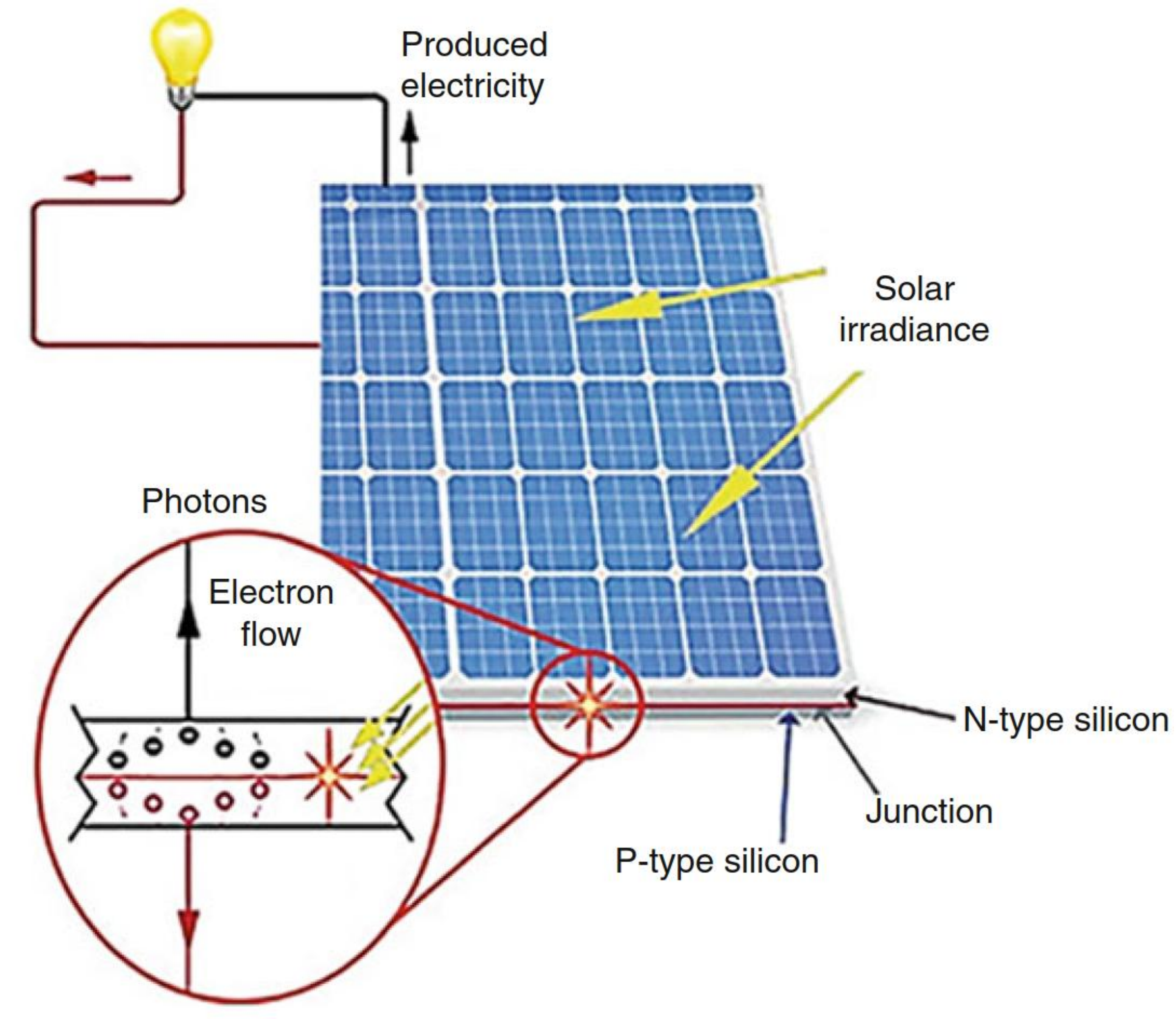
Photovoltaic Technology

- **Photovoltaic (PV) cells:** is a method of producing electricity, using solar cells.

- A solar cell is a device that converts solar optical energy (solar radiation) directly into electrical energy. It is essentially a semiconductor device fabricated in a manner which generates a voltage when solar radiation falls on it.

- When sunlight falls on the semiconductor surface, it excites electrons, creating a voltage across the cell. This process allows the optical energy of the sun to be transformed into usable electrical power.

- An attractive aspect of photovoltaics is the ability to implement this technology on a wide range of scales from milliwatt devices suitable for running watches and pocket calculators to multimegawatt installations



Solar Energy

Monofacial and Bifacial solar cells differ mainly in how they capture sunlight and generate electricity:

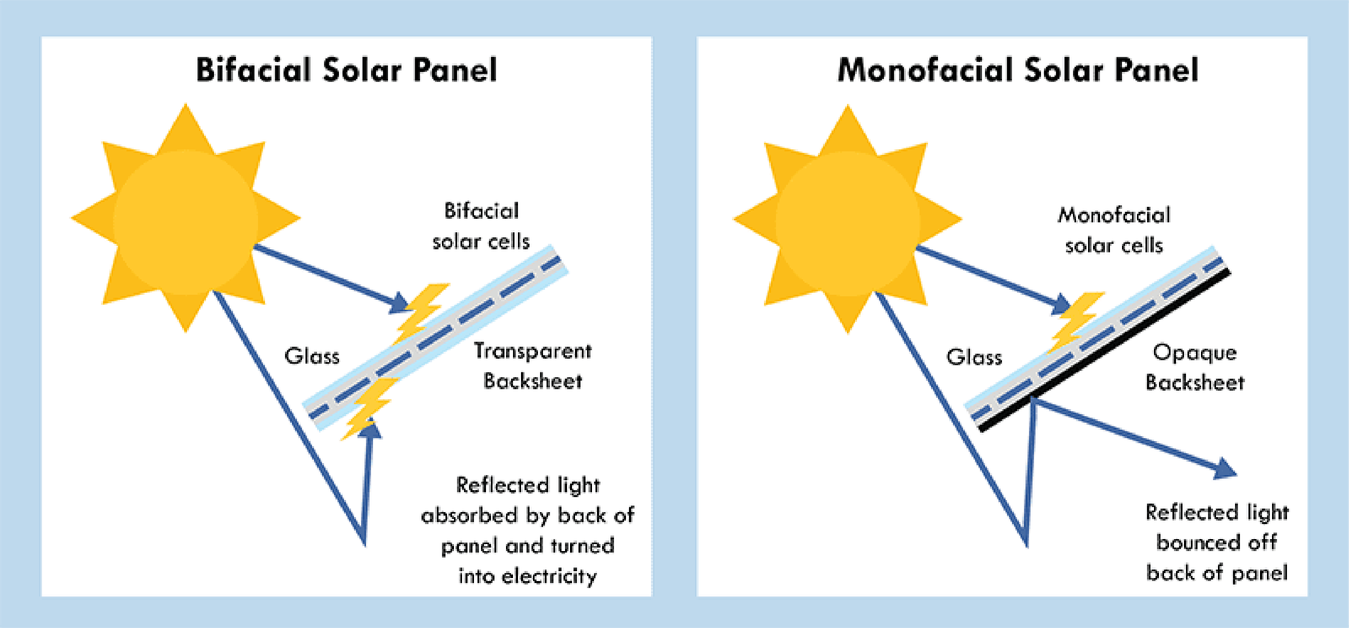
Monofacial Solar Cells

These cells capture sunlight only on the front side, where the sun directly hits the cell. The back side is typically covered with a backing material, such as metal or plastic, to protect the cell and improve durability.

Bifacial Solar Cells

These cells can capture sunlight from both the front and back sides. The rear side can absorb reflected light from the ground or surrounding surfaces, increasing the amount of energy produced.

Bifacial panels perform best in environments with high surface reflectivity, such as snowy or sandy areas, capturing 5% to 30% more power



Monofacial Solar Cells Vs Bifacial Solar Cells

Solar Energy

Connection of solar cells: Parallel and Series connections are fundamental concepts in the arrangement of solar cells to form solar panels.

In a series connection:

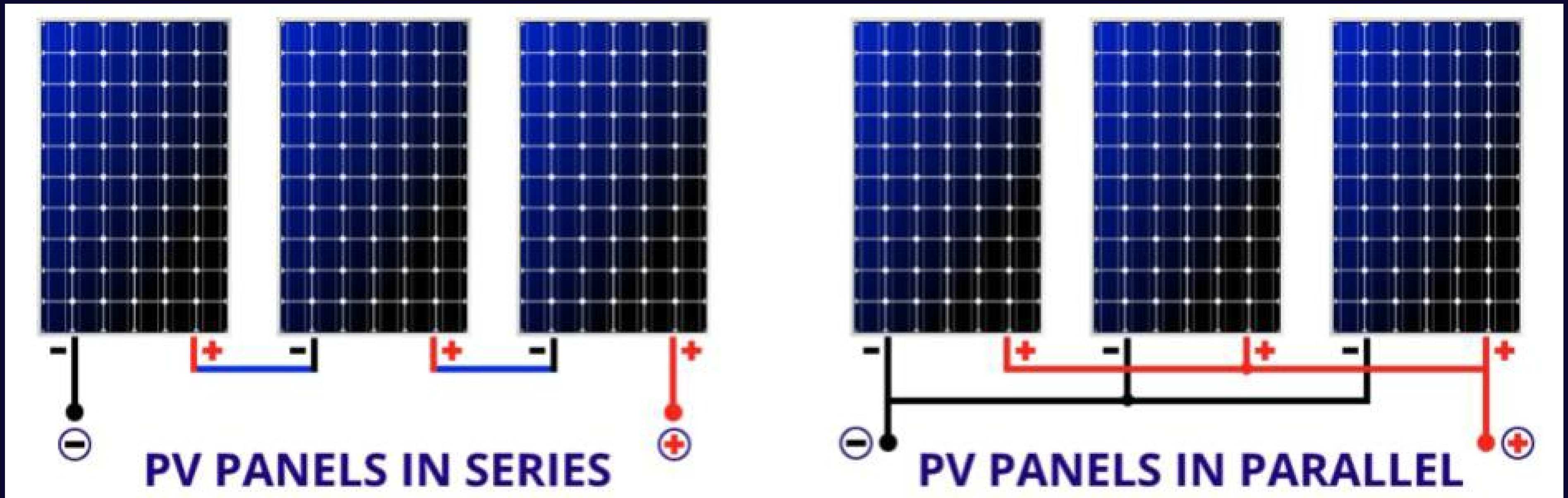
$$V_{series} = V_1 + V_2 + V_3$$

$$I_{series} = I_1 = I_2 = I_3$$

In a parallel connection:

$$I_{series} = I_1 + I_2 + I_3$$

$$V_{series} = V_1 = V_2 = V_3$$



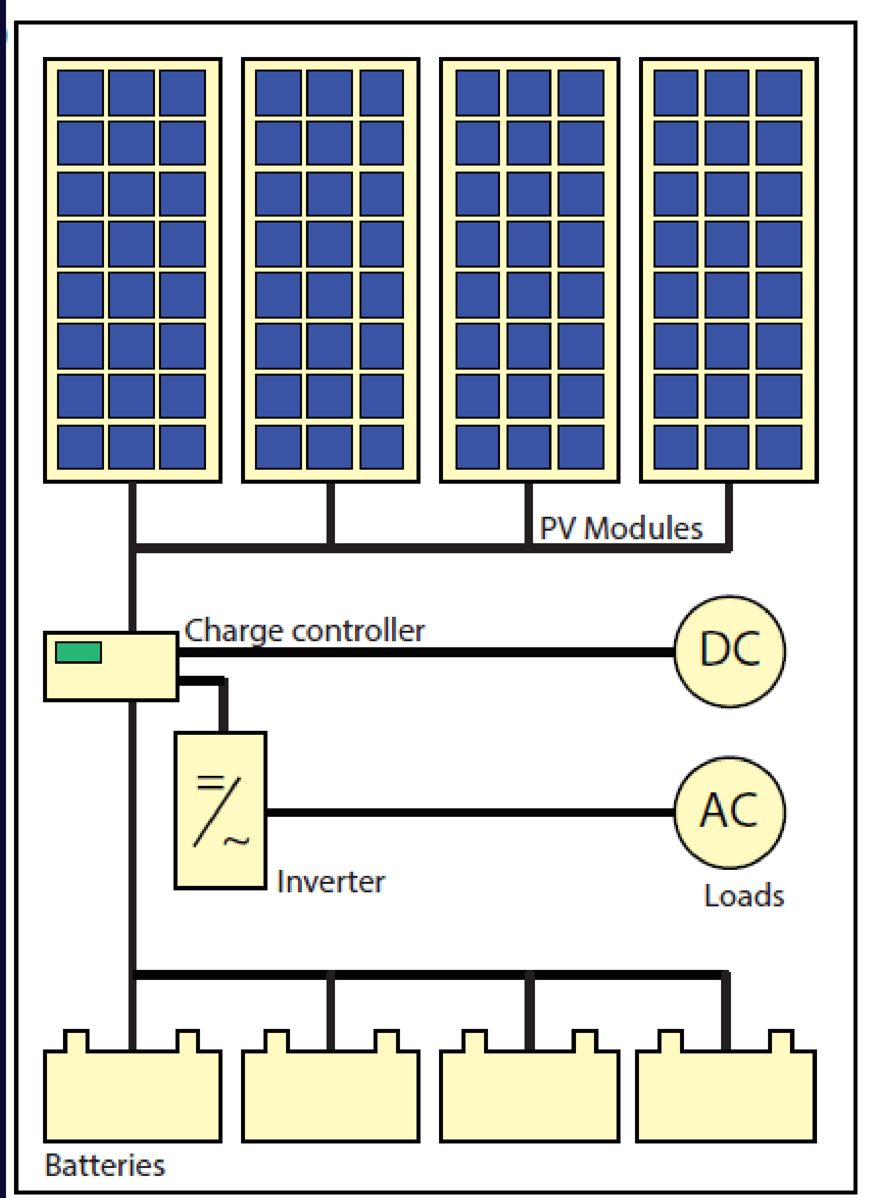
Series vs Parallel Connection Comparison

Description	Series connection	Parallel connection
Configuration	the positive terminal of one solar cell is connected to the negative terminal of the next cell	all the positive terminals of the solar cells are connected together, and all the negative terminals are connected together,
Effect on Voltage	The voltage of each solar cell adds up across the series connection. For example, if each solar cell produces 0.5 volts and five cells are connected in series, the total voltage output would be 2.5 volts	The voltage remains constant across all cells in a parallel connection. The total voltage output is equal to the voltage output of an individual solar cell.
Effect on current	The current remains constant across all cells in a series connection. The total current output is determined by the current output of the individual solar cells.	The current output of each solar cell adds up across the parallel connection. For example, if each solar cell produces 3 amps and five cells are connected in parallel, the total current output would be 15 amps
Application	Series connections are used to increase the voltage output of the combined cells while maintaining a constant current. This configuration is suitable for applications requiring higher voltage, such as systems with high voltage requirements for charging batteries.	Parallel connections are used to increase the current capacity of the combined cells while maintaining a constant voltage. This configuration is suitable for applications requiring higher current, such as off-grid solar systems or systems with high power output requirements.

Solar Energy

Modern PV modules often contains:

- 60 solar cells arranged as (10 x 6)
- 72 solar cells arranged as (9 x 8)
- 96 solar cells arranged as (12 x 8)



Solar panel involves one or more solar modules (Module1 + Module2 + Module3 + Module4).

Types of Grid Systems:

Grid-On System

Grid-Off System

Hybrid System

Task 5: Test Your Knowledge

1. **Photovoltaic cells convert solar energy into:**
   A) AC electricity
   B) Mechanical energy
   C) Heat
   D) DC electricity

2. **A disadvantage of solar PV systems is:**
   A) Noisy operation
   B) High greenhouse gases
   C) Low efficiency and high-cost
   D) Poor aesthetics

3. **Which of the following best describes a bifacial solar cell?**
   A) Captures sunlight only from the front side
   B) Captures sunlight from both front and back sides
   C) Is always covered with metal backing
   D) Works only under direct sunlight without reflection

4. **What is the typical arrangement of solar cells in a modern PV module?**
   A) 30 cells in (6 × 5) arrangement
   B) 60 cells in (10 × 6) arrangement
   C) 80 cells in (8 × 10) arrangement
   D) 50 cells in (5 × 10) arrangement

5. **In a parallel connection of solar cells, what happens to the current output?**
   A) It decreases with each additional cell
   B) It adds up across all the connected cells
   C) It stays the same for each cell
   D) It becomes equal to the lowest producing cell

https://kahoot.it/challenge/02066581?challenge-id=77e98eab-e9c2-44bf-a781-290f87024bbf_1759495500971

Homework

1. Explain the working principle of a photovoltaic (PV) cell and describe how solar radiation is converted into electrical energy.

2. Compare monofacial and bifacial solar cells. In what conditions would bifacial cells be more efficient? Give a real-world example.

3. A PV system has **5 solar cells connected in series**, each producing **0.6 V**.
    - What is the total voltage output?
    - If each produces 3 A of current, what is the total current?

4. Another PV system has **5 solar cells connected in parallel**, each producing **0.6 V and 3 A**.
    - What is the total voltage output?
    - What is the total current output?

وزارة التعليم العالي والبحث العلمي

الجامعة التقنية الشمالية

الكلية التقنية الهندسية / الموصل

قسم هندسة تقنيات ميكانيك القوى

اسم المادة : الطاقة المتجددة

محاضرة بعنوان

Wind Energy

مدرس المادة:

م. محمد طه محمد

Lecture Content

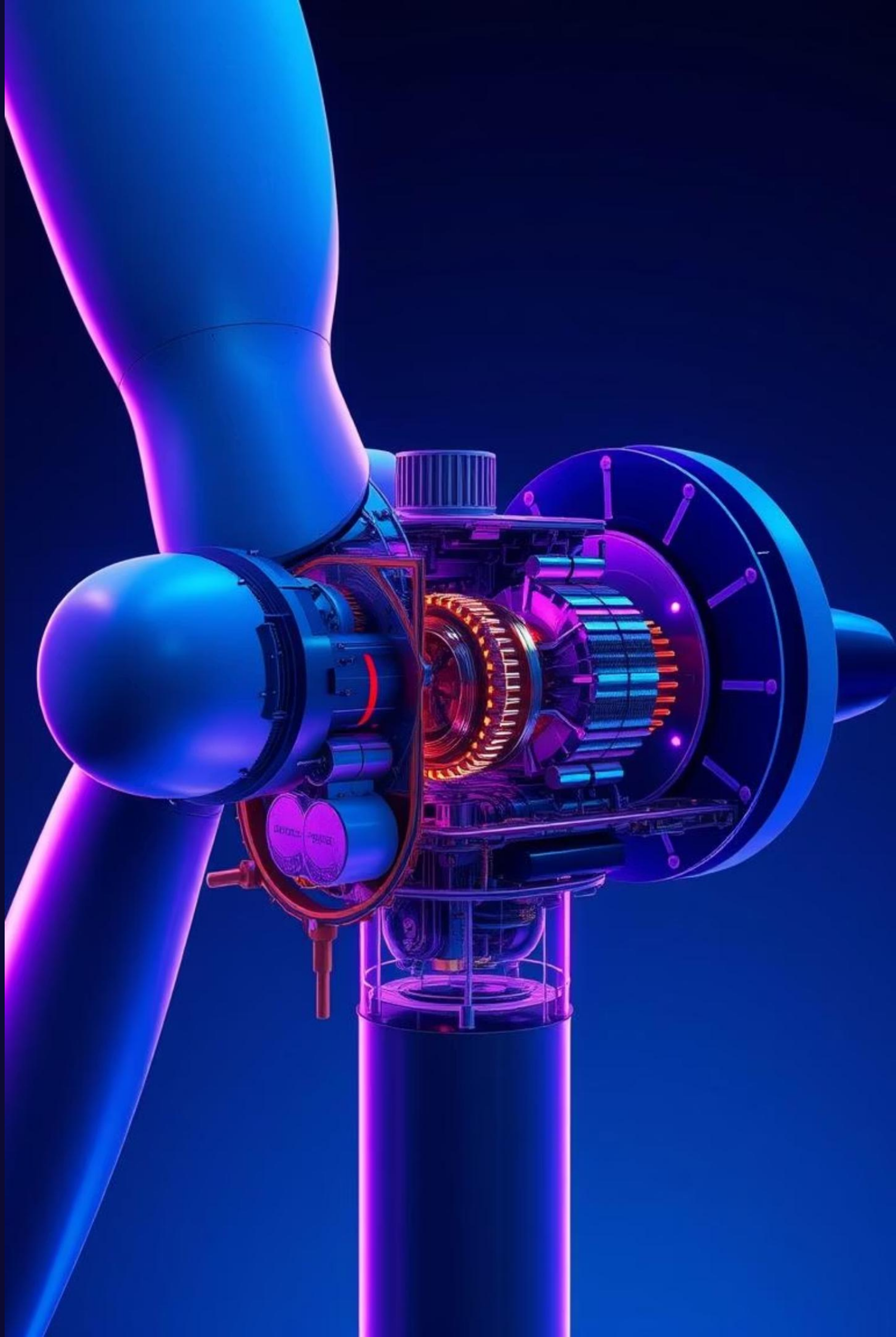
- Advantages Wind Energy
- Disadvantages Of Wind Energy
- Environment Impacts of Wind Energy
- Sources/Origins of Wind
- Components of Wind Power Plant
- Wind Turbine Control System
- Power Output Prediction
- Classification of Wind Turbine
- Power coefficient and Betz Limit

Introduction

Wind energy is one of the fastest-growing sources of renewable power worldwide. It converts the kinetic energy of moving air into mechanical and electrical energy using wind turbines. With continuous improvements in turbine technology, wind energy offers a clean, sustainable, and increasingly cost-effective alternative to fossil fuels. Understanding how wind turbines operate, their components, and their environmental impacts is essential for engineers working in the renewable energy field.

General Objective of the Lecture:

To understand the principles, components, and performance characteristics of wind energy systems and their role in sustainable power generation.



Specific Objectives of the Lecture:

1

Identify and describe key components

Identify and describe at least **five key components** of a wind power plant and explain their individual functions.

2

Analyze impacts and characteristics

Analyze the **advantages, disadvantages, and environmental impacts** of wind energy by the end of the lecture.

3

Apply theoretical concepts

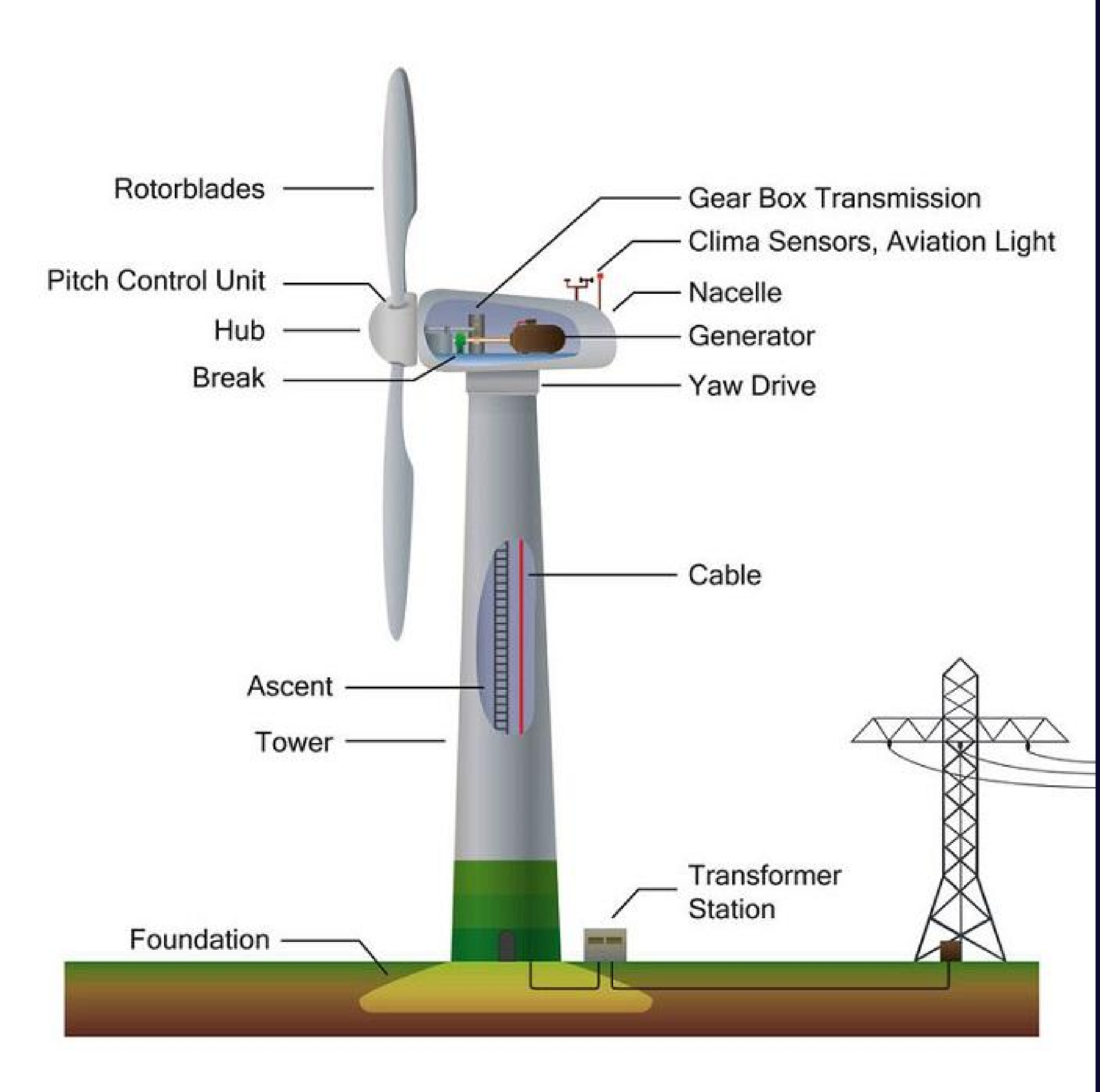
Apply the **Betz limit and power coefficient concepts** to calculate the theoretical maximum power output of a wind turbine during class exercises.

3 Wind Energy

Wind energy is the process of converting the kinetic energy of wind into electrical energy using wind turbines.

- A wind turbine is a mechanical machine that converts the kinetic energy of the fast-moving winds into electrical energy.

- Nature generates about 1.67×10^5 kWh of wind energy annually over land area of earth and 10 times this figure over the entire globe.



3.1 Advantages Wind Energy

Renewable Energy Source

It is a renewable energy source.

Non-Polluting

Wind power systems being non-polluting have no adverse effect on the environment.

Ideal for Remote Areas

Ideal choice for rural and remote areas and areas which lack other energy sources.

3.2 Disadvantages Of Wind Energy

1

Fluctuating Availability

Availability of energy is fluctuating in nature.

2

High System Weight

The overall weight of a wind power system is relatively high.

3

Large Area Requirements

Large areas are required for installation/operation of wind energy systems.

4

Limited Geographic Locations

Favorable winds are available only in a few geographical locations.

5

Complex Design

Wind turbine design, manufacture, and installation have proved to be most complex due to several variables and extreme stresses.

3.3 Environmental Impacts of Wind Energy

The *possible environmental impacts of wind energy* are

1. **Noise Pollution**

   Wind energy creates *noise pollution* because of mechanical (gear box) aerodynamic noise.

2. **Electromagnetic Interference**

   The wind turbine produces *electromagnetic interference* when placed between radio, television, etc., stations, as it reflects some electromagnetic radiation.

3. **Safety Considerations**

   Safety consideration for life because of *accidental braking of blade*.

4. **Bird Collisions**

   Fatal collisions of birds caused by rotating turbine blades.

3.4 Sources/Origins of Wind

Following are the two sources/origins of wind (a natural phenomenon):

1. Local winds

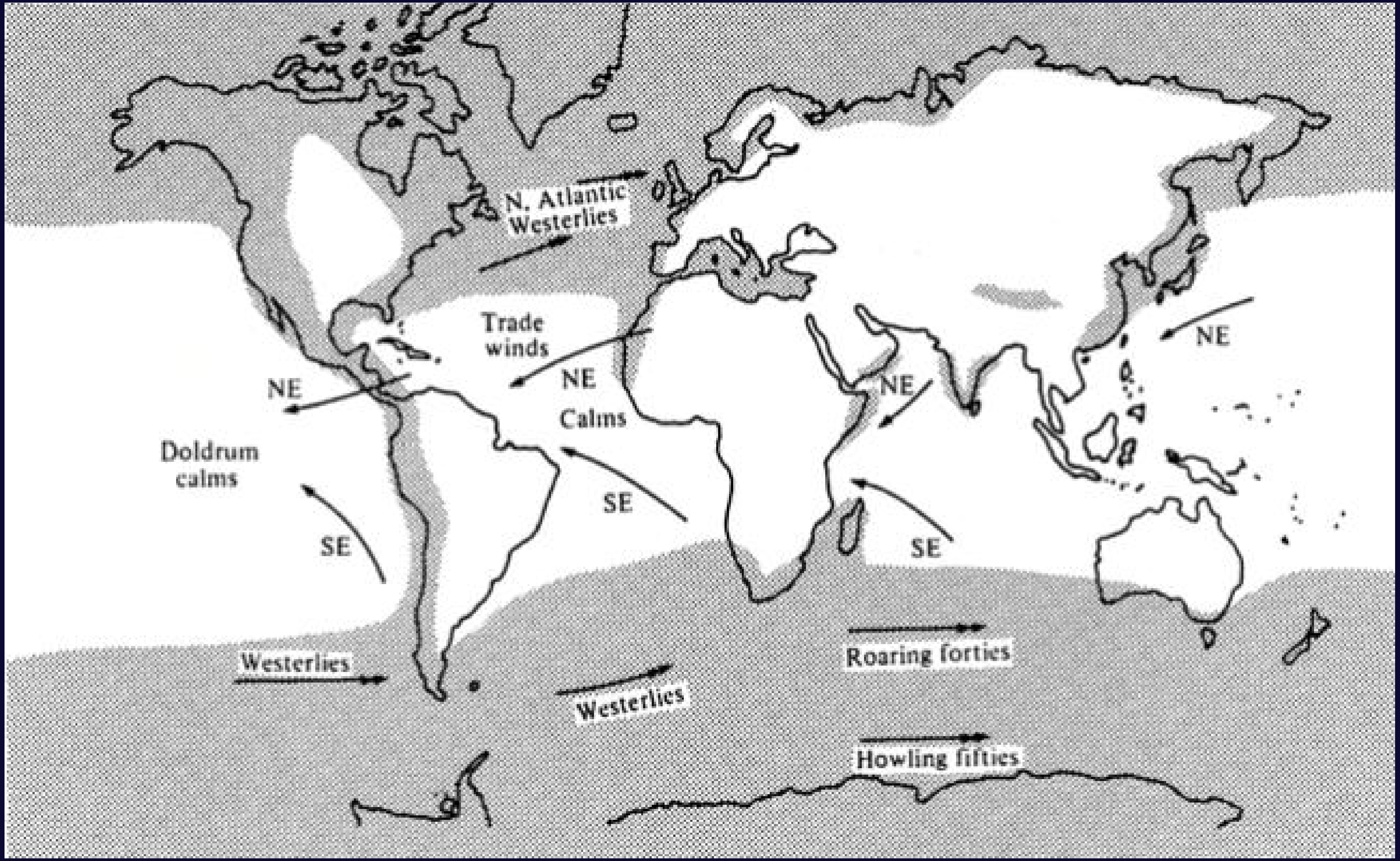
These winds are caused by unequal heating and cooling of ground surfaces and ocean/lake surfaces during day and night. During the day warmer air over land rises upwards and colder air from lakes, ocean, forest areas, and shadow areas flows

2. Planetary winds

These winds are caused by daily rotation of earth around its polar axis and unequal temperature between polar regions and equatorial regions. The strength and direction of these planetary winds change with the seasons as the solar input varies.

Wind Map

The below figure Prevailing strong winds. The shaded areas indicate regions of wind attractive for wind power development, with average wind speed >5 m/s and average generation ~33% of rated power.



3.5 Components of Wind Power Plant

1

Blades

are usually made of fiberglass or balsa wood. Most turbines have either two or three blades.

2

Rotor

It includes the blades and the hub together. The blades spin the rotor, which is attached to a shaft that transfers the torque it creates into the gearbox. The rotor provides pitch regulation for power output optimization and control. Its speed is variable to maximize aerodynamic efficiency.

3

Pitch

turns blades out of the wind to control the rotor speed and keep the rotor from turning in winds that are too high or too low to produce electricity.

4

Brake

is a disc that can be applied aerodynamically, electrically, or hydraulically to stop the rotor in emergencies. A brake shuts down the turbine if the winds become strong enough to impact the turbine's internal components.

5

Low-Speed Shaft

The rotor turns the low-speed shaft at about 15 to 30 rotations per minute.

6

Gear box

connect the low-speed shaft to the high-speed shaft and increases the rotational speeds from about 15 to 30 rotations per minute (rpm) to about 1000 to 1800 rpm, the rotational speed required by most generators (alternators) to produce electricity. This is an expensive and heavy part of wind turbines.

7

Generator

is usually an induction generator that produces 50-cycle AC electricity.

8

Controller

starts up the machine at wind speeds of about 3.5 to 7 m/s and shuts off the machine at about 25 m/s. Turbines do not operate at wind speeds above about 25 m/s because that might damage them.

9

Anemometer

It measures the wind speed and transmits the data to the controller. The controller then corrects the turbine's direction, pitch, and yaw to best harvest the available wind energy.

10

Wind vane

measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.

11

Nacelle

sits at the top of the tower and contains the gear box, low- and high-speed shafts generator, controller, and brake. It is essentially the cover for the machinery that translates wind power into electrical power.

12

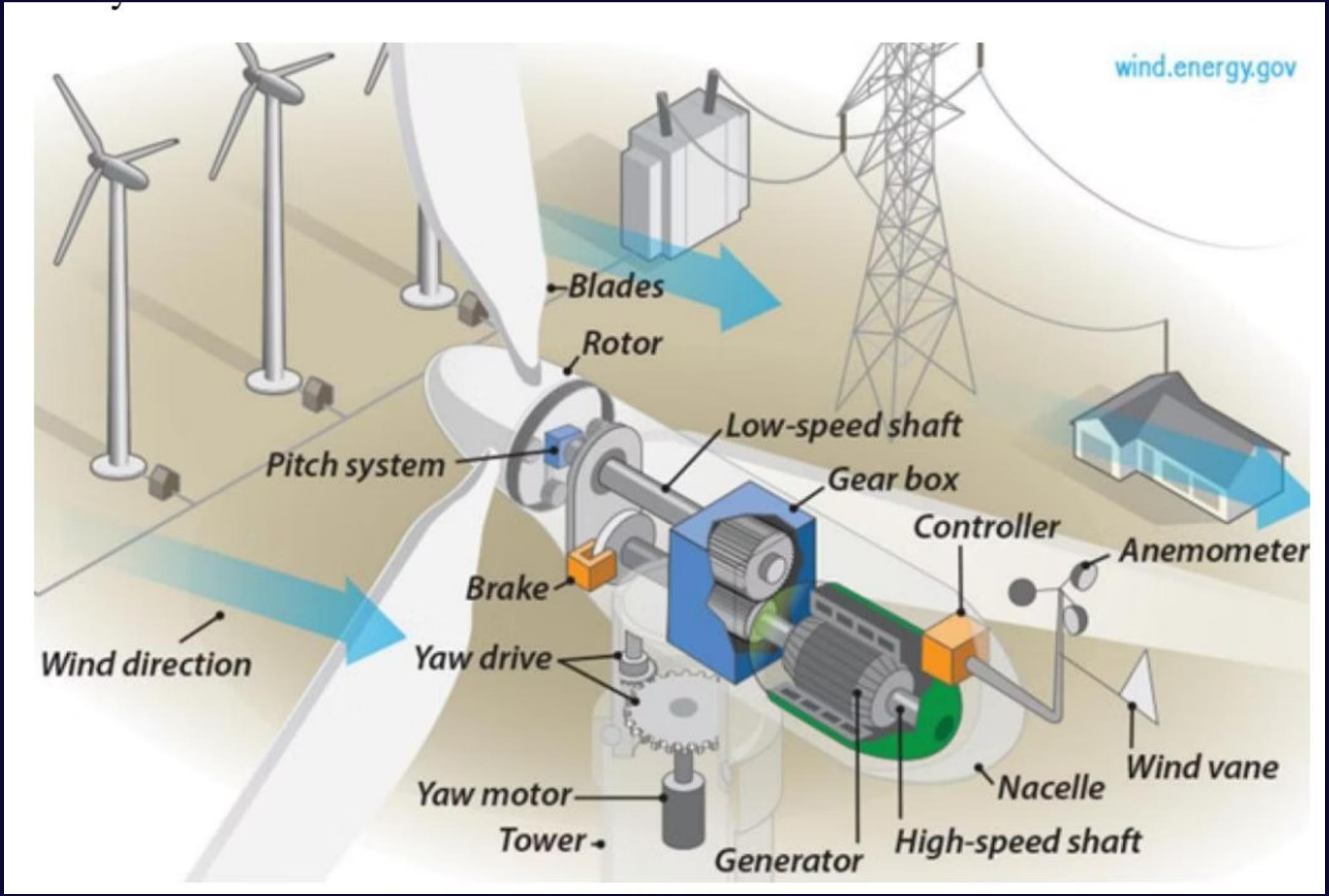
High-Speed Shaft

Drives the generator Yaw drive in upward turbines face into the wind. The yaw drive keeps the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive; the wind blows the rotor downwind Yaw Motor powers the yaw drive

13

Tower

is usually made from tubular steel, concrete, or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.


wind.energy.gov
Blades
Rotor
Low-speed shaft
Pitch system
Gear box
Controller
Anemometer
Brake
Wind direction
Yaw drive
Wind vane
Nacelle
Yaw motor
Tower
Generator
High-speed shaft

3.6 Wind Turbine Control System

The main degrees of freedom of wind turbine are:

Azimuth

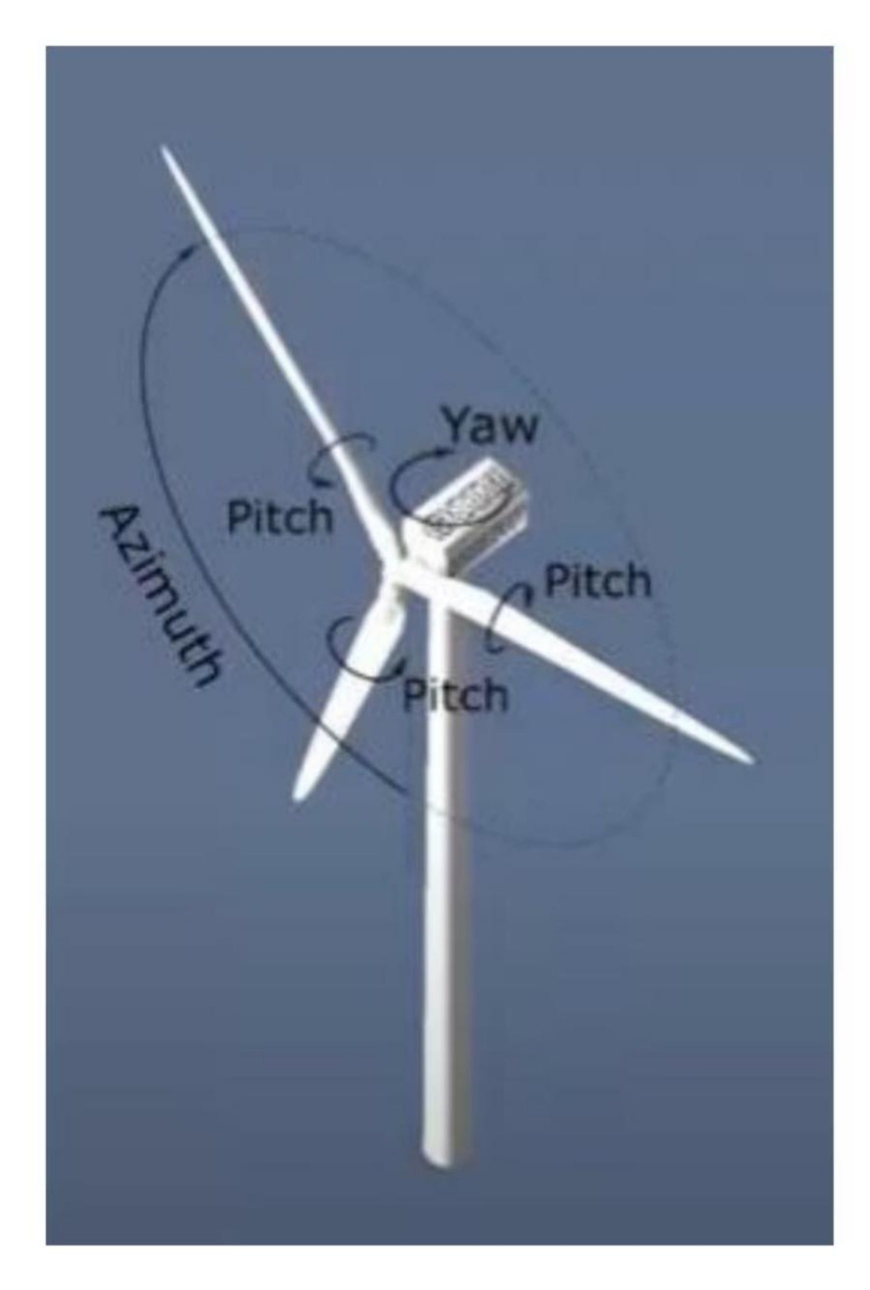
rotation of the rotor

Yaw motion

rotation of nacelle about the vertical axis

Pitch motion

rotation of the blades about their lengthwise axis



3.7 Power Output Prediction

- The power output of a wind turbine varies with wind speed and every wind turbine has a characteristic power performance curve.
- The performance of a given wind turbine generator can be related to three key points on the velocity scale:

Cut-in speed

the minimum wind speed at which the machine will deliver useful power.

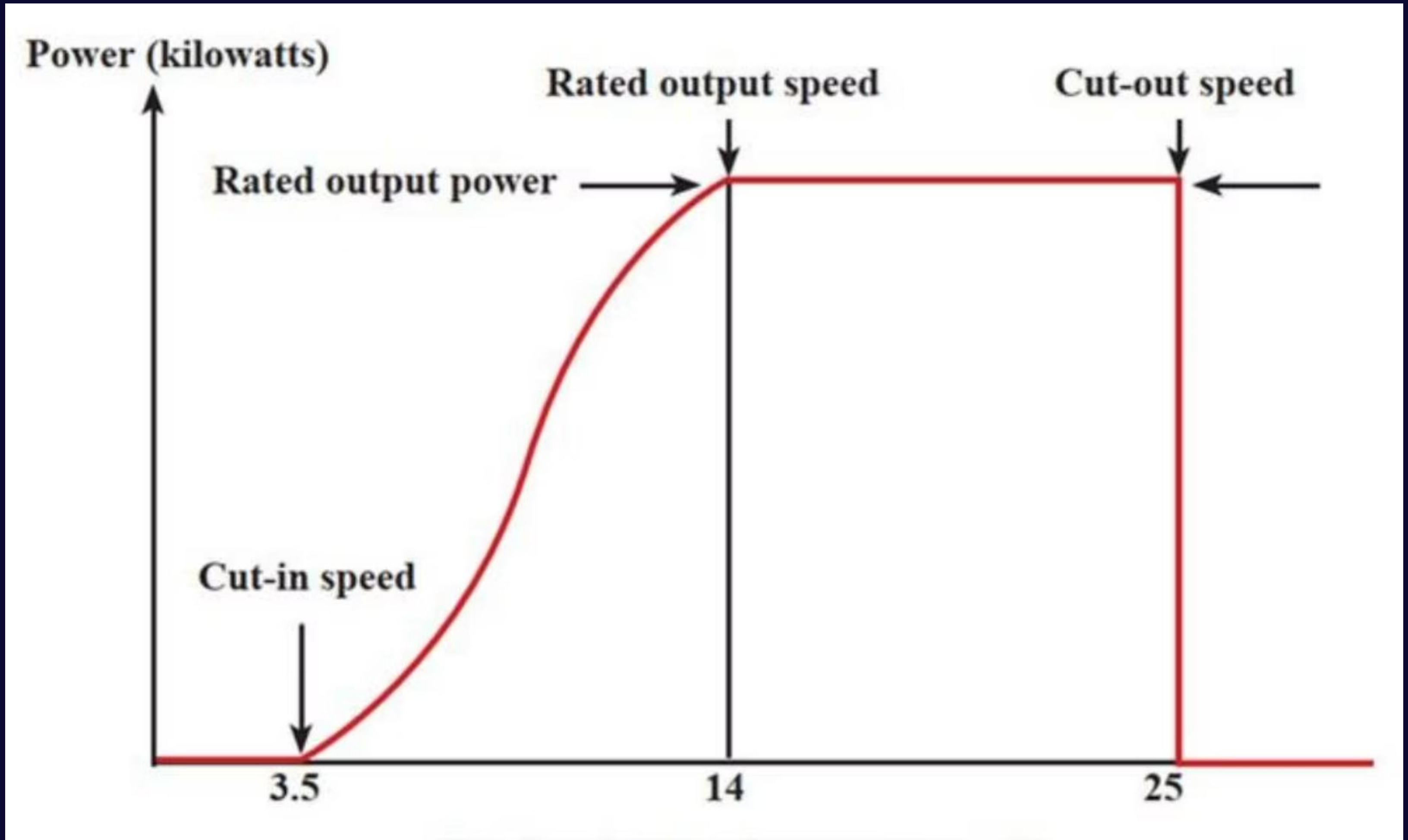
Rated wind speed

the wind speed at which the rated power (generally the maximum power output of the electrical generator) is reached.

Cut-out speed

the maximum wind speed at which the turbine is allowed to deliver power

The cut-in speed, at the lower end of the curve, is the threshold that the hub-height wind speed must reach for the turbine to begin generating electricity. In general, wind turbines begin to produce power at wind speeds of about 6.7 mph (3 m/s). A turbine will achieve its nominal, or rated, power at approximately 26 mph to 30 mph (12 m/s to 13 m/s); this value is often used to describe the turbine's generating capacity (or nameplate capacity). The turbine will reach its cut-out speed at approximately 55 mph (25 m/s). When wind speeds exceed this, the turbine will stop power production to protect itself from potentially damaging speeds. Variability in the wind resource results in the turbine operating at changing power levels. At good wind energy sites, this variability results in the turbine operating at approximately 35% to 40% of its total possible capacity over a year.



3.8 Classification of Wind Turbine

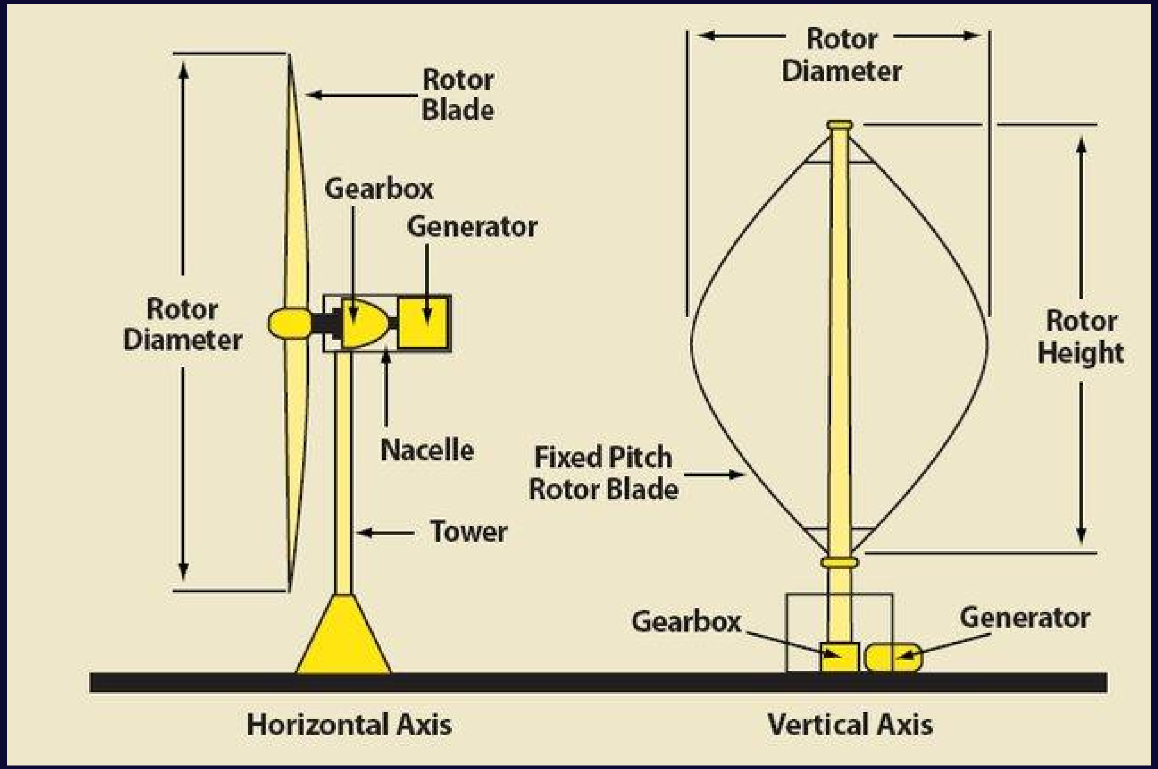
Wind turbines are classified as vertical axis turbines and horizontal axis turbines.

1

Vertical axis wind turbines (VAWTs)

2

Horizontal-Axis Wind Turbines (HAWT)



1. Vertical axis wind turbines (VAWTs)

where the rotation axis is perpendicular to the wind direction.

These turbines have a rotor that spins around a vertical axis, meaning they do not need to be oriented towards the wind.

More compact, less noise, can operate in low wind conditions.

Vertical Axis Wind Turbines are designed to rotate around a vertical axis, meaning they do not need to be oriented towards the wind direction.

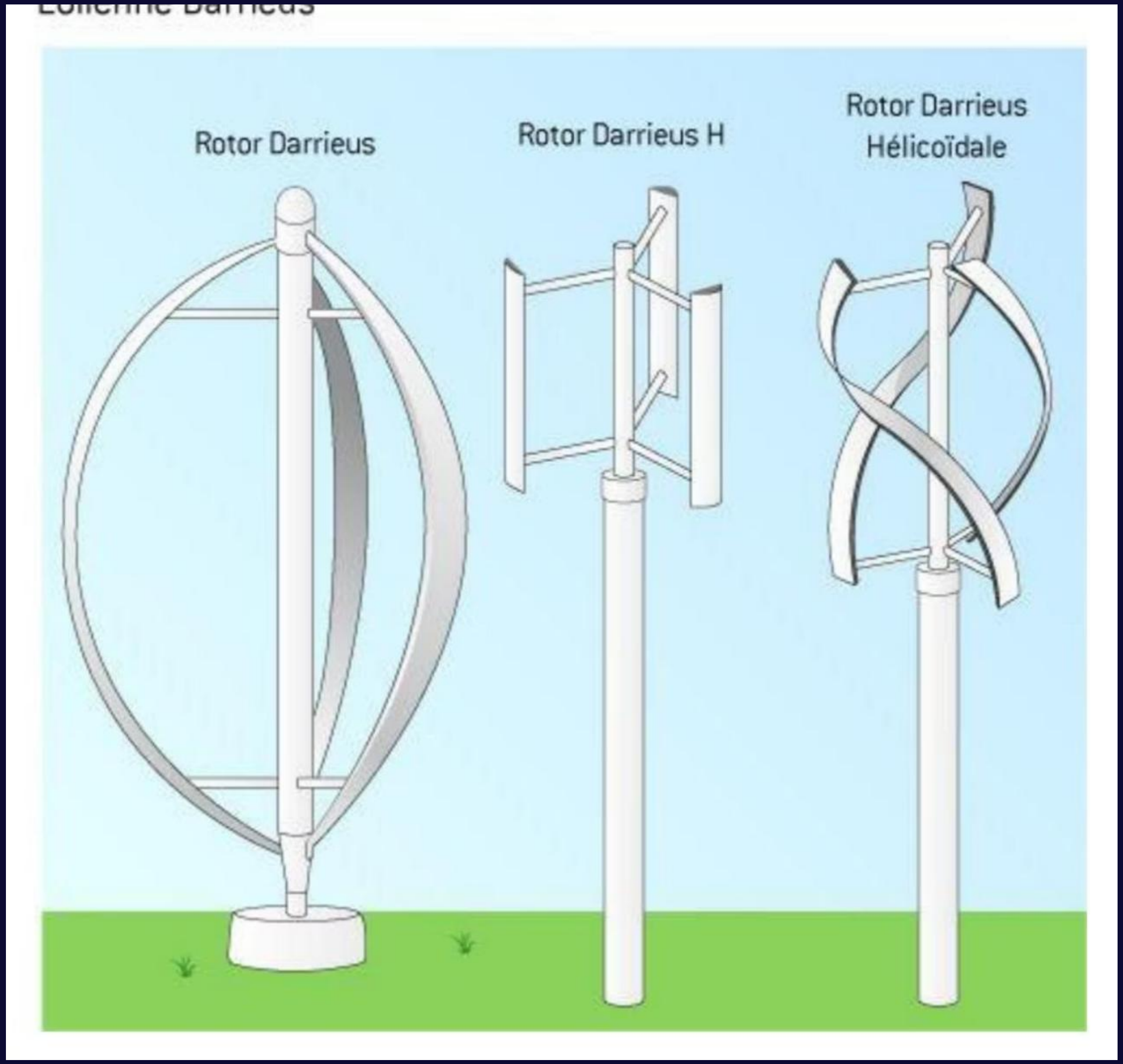
A- Darrieus Wind Turbine

The Darrieus turbine is one of the most common types of VAWTs. It typically has two or more blades that are shaped like an airfoil (similar to an airplane wing). These blades are attached to the central shaft in a vertical orientation.

The blades of a Darrieus turbine are curved and are designed to catch the wind from any direction, making it highly efficient in terms of power generation.

High efficiency at higher wind speeds and good power output.

The Darrieus turbine is not self-starting, meaning it requires an external force to begin rotating. It also tends to experience high mechanical stress.



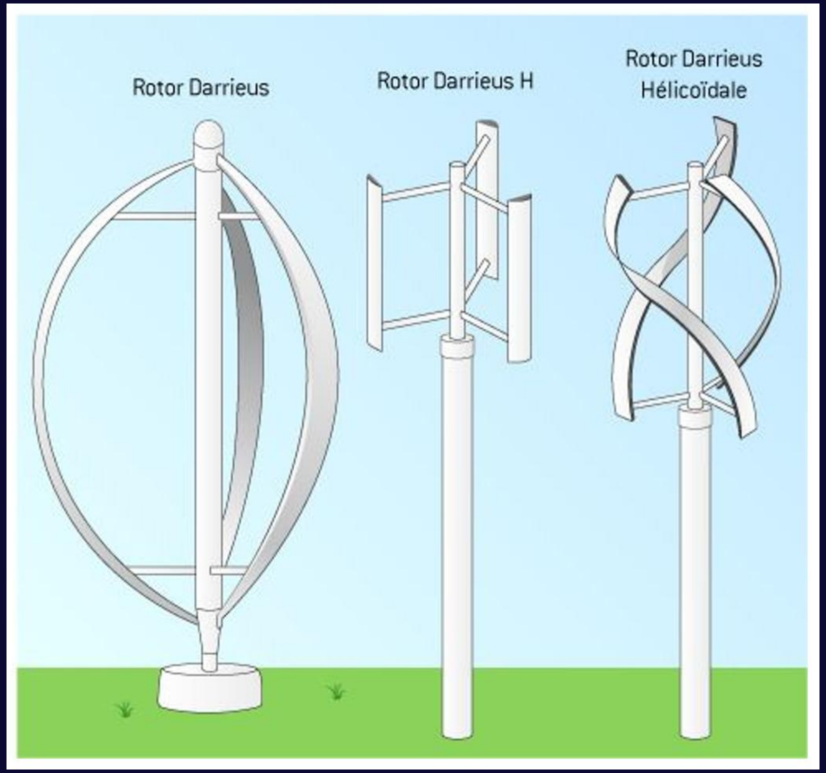
Subtypes of Darrieus Turbines:

Straight-Bladed Darrieus

Has straight vertical blades and is more common in largescale applications.

Curved-Bladed Darrieus

Features curved blades, which provide better aerodynamic performance and stability.

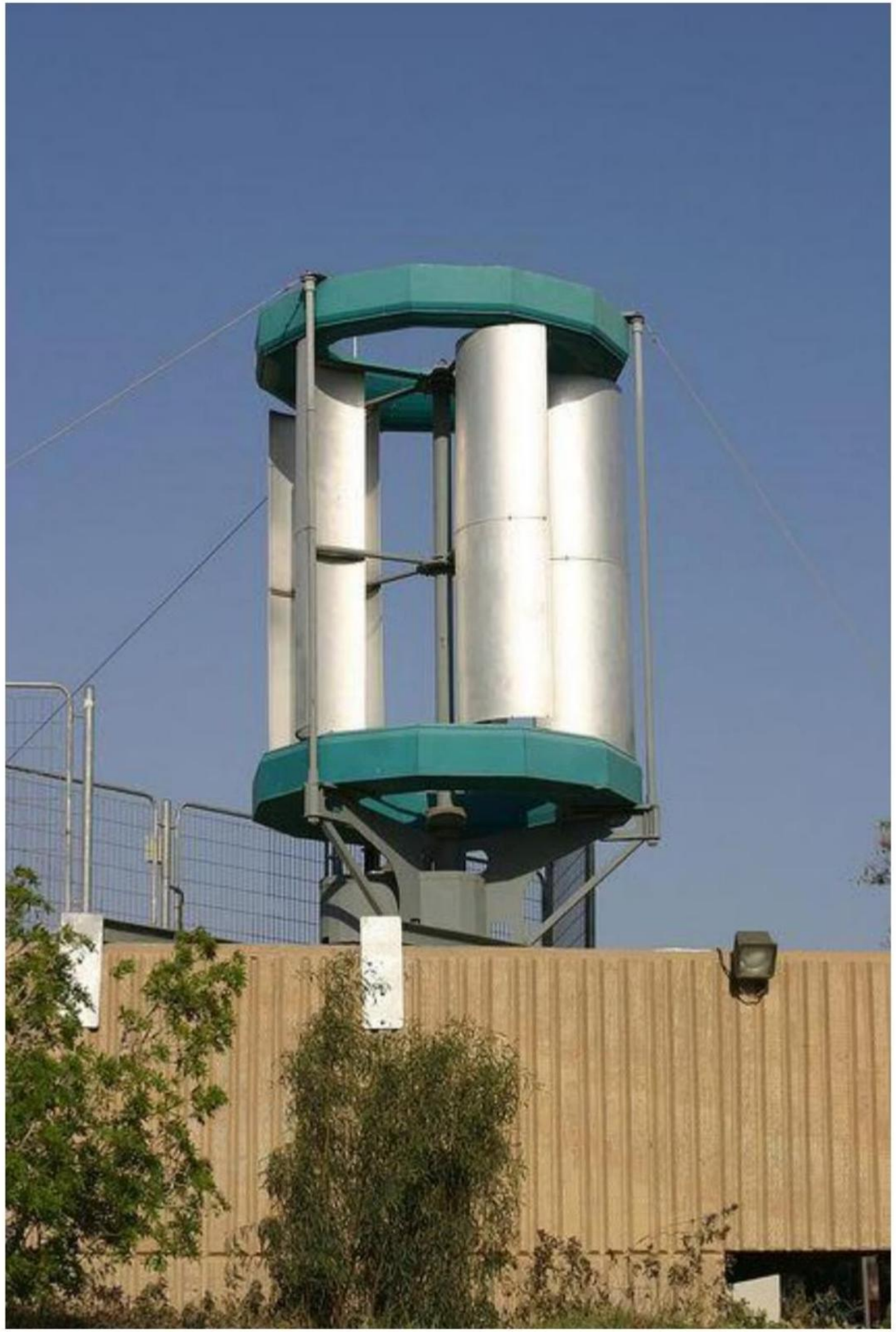


B- Savonius Wind Turbine

- The Savonius turbine is a type of VAWT that is often used in low-wind applications. It consists of two or more scoops or blades that are shaped like a "S"-curve and arranged in a vertical axis.

- Simple design, low maintenance, and ability to start in low wind conditions. It is also self-starting.

- Less efficient than Darrieus turbines, particularly in high wind speeds, due to high drag forces.



C- Giromill Wind Turbine

The Giromill is a type of VAWT that is similar to the Darrieus but features a slightly different blade configuration. It consists of blades mounted vertically on a central axis and has a more open, wind-turbine-like appearance.

The Giromill turbine has a more robust structure and can handle varying wind speeds better than the Darrieus turbine.

It can still face mechanical stress issues and is not as efficient at lower wind speeds.

2. Horizontal-Axis Wind Turbines (HAWT)

in which the rotation axis is in line with the wind direction.

It is typically having two or three blades that rotate around a horizontal axis, and they need to be oriented to face the wind.

High efficiency, easy to scale for large energy generation.

The HAWT ae generally have either two or three blades.

Classification of HAWT by Rotor Location

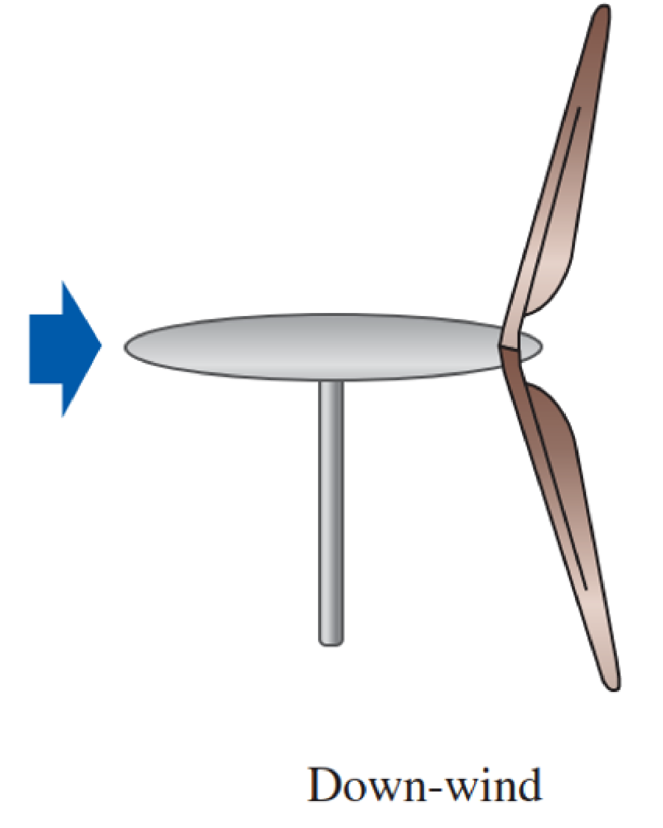
According to the location of the rotor with respect to the tower, the HAWT can be classified into two types:

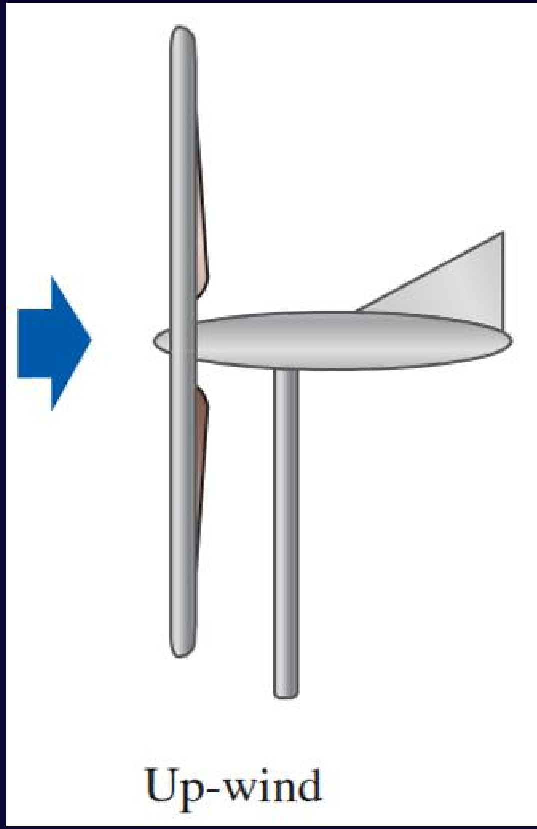
A- Upwind turbine:

- In upwind wind turbines, the rotor is positioned upwind of the tower, meaning the wind hits the blades before it hits the tower.
- The turbine must orient the rotor (via the yaw system) to face into the wind to maximize energy capture.

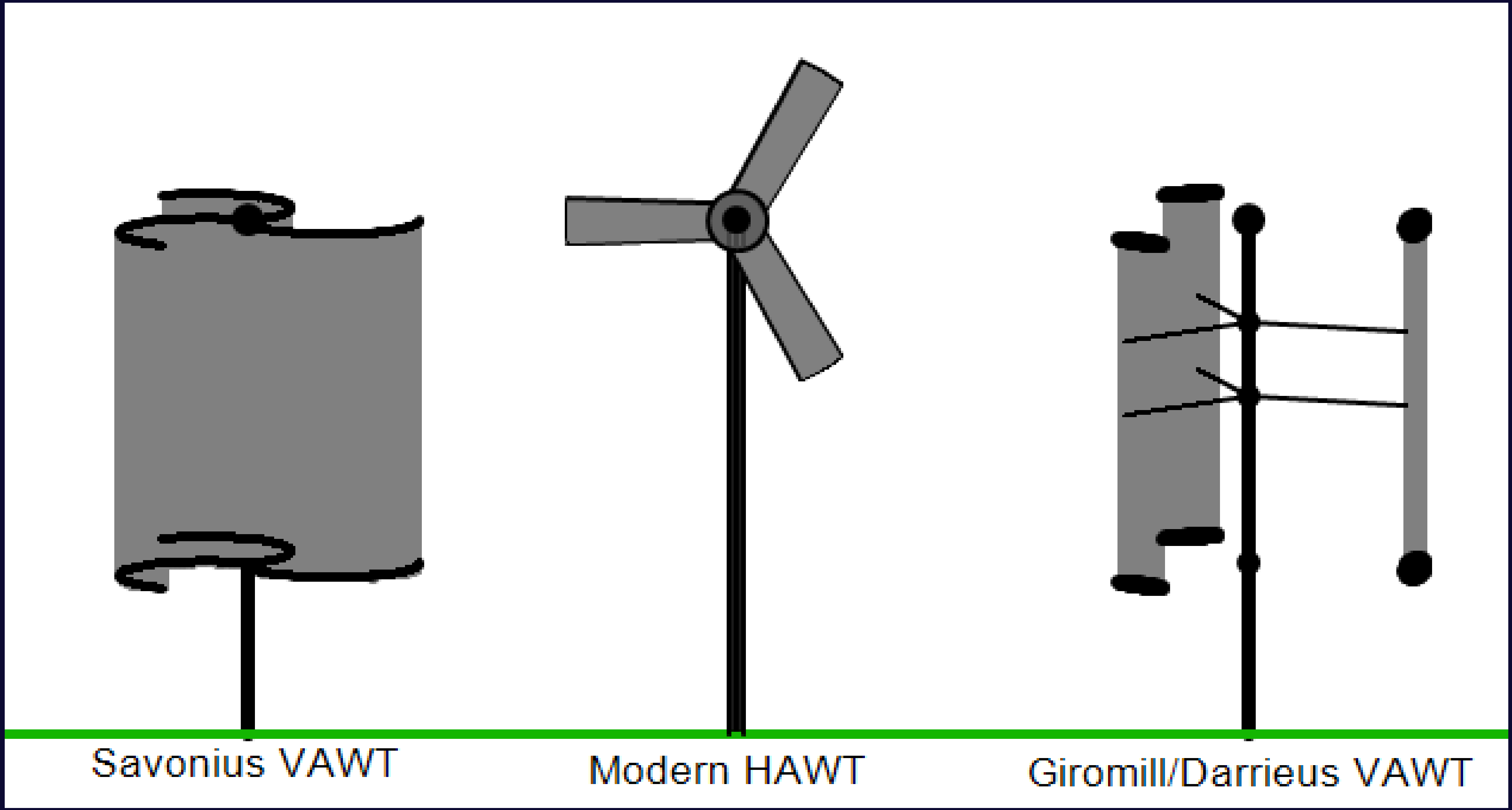
B- Downwind turbine:

- In downwind wind turbines, the rotor is positioned downwind of the tower, meaning the wind hits the tower first and then flows to the blades.
- In these turbines, the rotor doesn't require a yaw mechanism because the blades naturally align with the wind direction due to the tower's position.





Different Types of Wind Turbines



CONSIDERATIONS IN WIND POWER APPLICATIONS

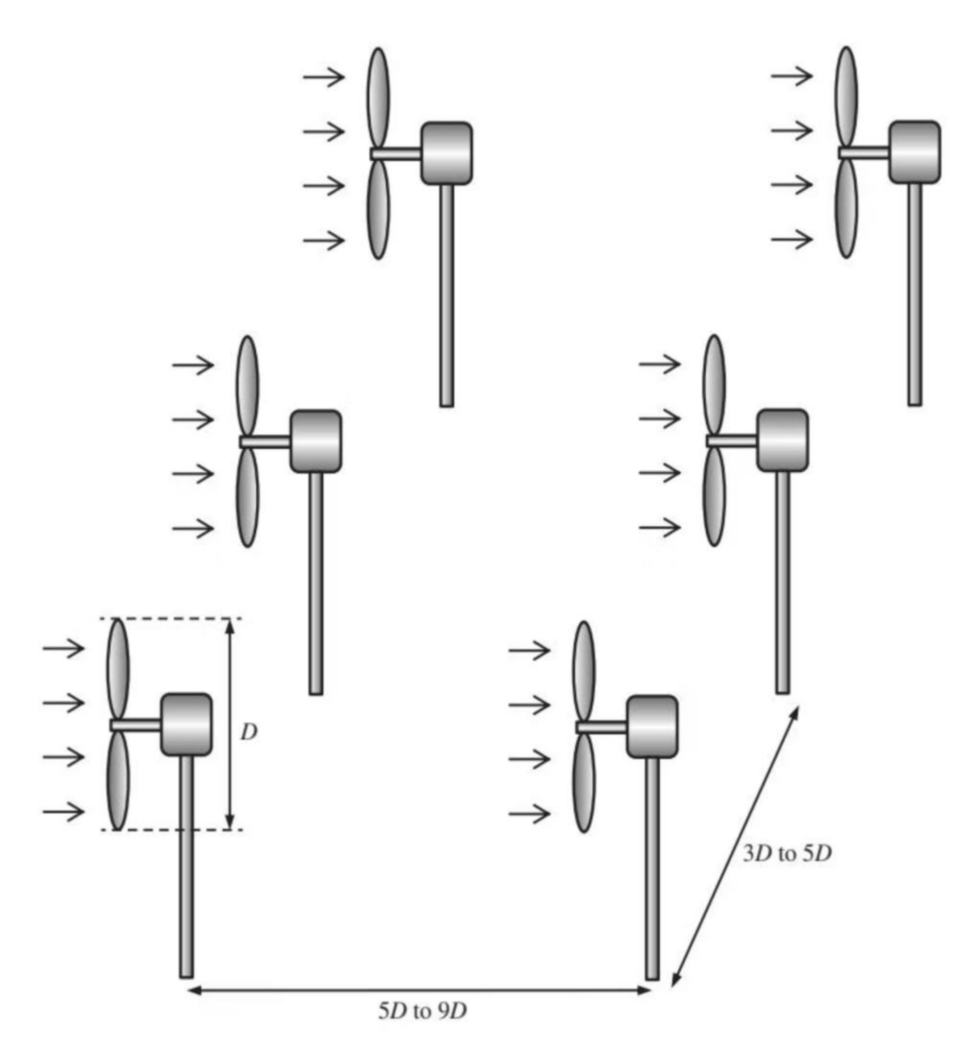
Key Design Factors for Wind Power

- Optimum Spacing Between Turbines
- Turbine Blade Diameter and Generator Selection

1. Optimum Spacing Between Turbines

The number of wind turbines at a given site depends on the spacing between them. If the turbines are spaced too close to each other, the flow through one turbine affects the flow through the next turbine, and this reduces the turbine performance. If the turbines are far from each other, this means a poor use of the site, as the potential for the installation of additional turbines for greater power outputs is not realized.

It turns out that there is optimum spacing between the turbines, and it is estimated to be 3–5 blade diameters between the turbines in a row and 5–9 blade diameters between rows.



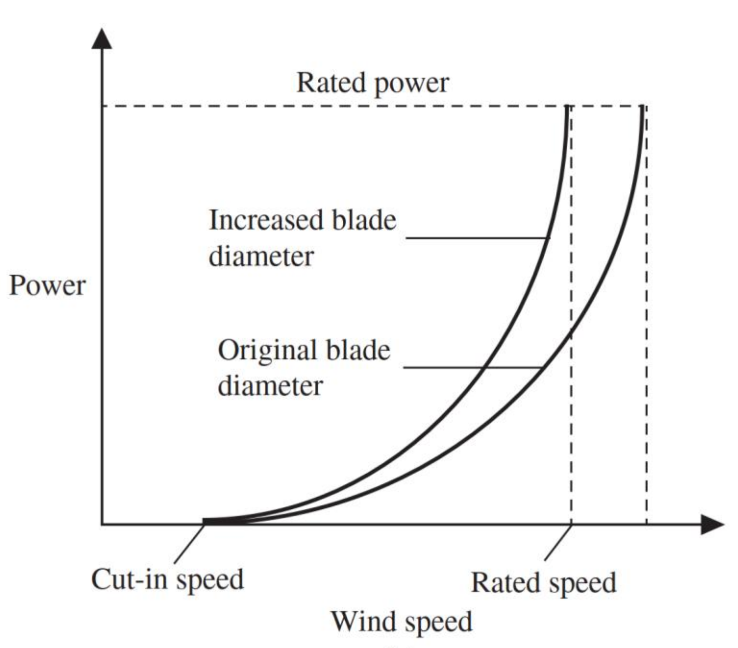
2. Turbine Blade Diameter and Generator Selection

Impact of Increased Blade Diameter

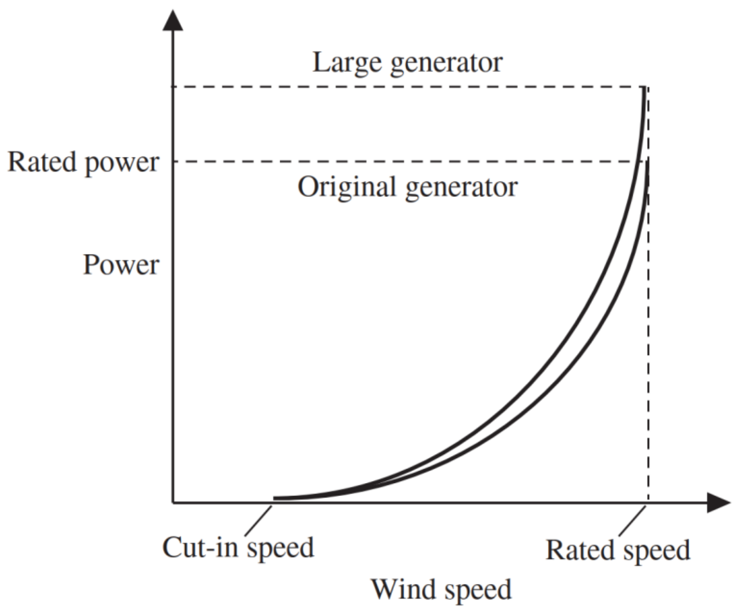
When the blade diameter is increased at the same generator rating, the power curve will move left, as shown in Fig. a. Then, the rated power can be realized at a lower wind speed.

Impact of Larger Generator

When a larger generator is used, the rated power increases (Fig. b). This is particularly advantageous at high wind speeds. Therefore, the generator size can be increased to maximize turbine power output if the turbine mostly operates at high wind speeds



(a)



(b)

3.9 Power coefficient and Betz Limit

Energy from wind stream is extracted by a wind turbine, by *converting the kinetic energy (K.E.) of the wind to rotational motion required to operate an electric generate*.

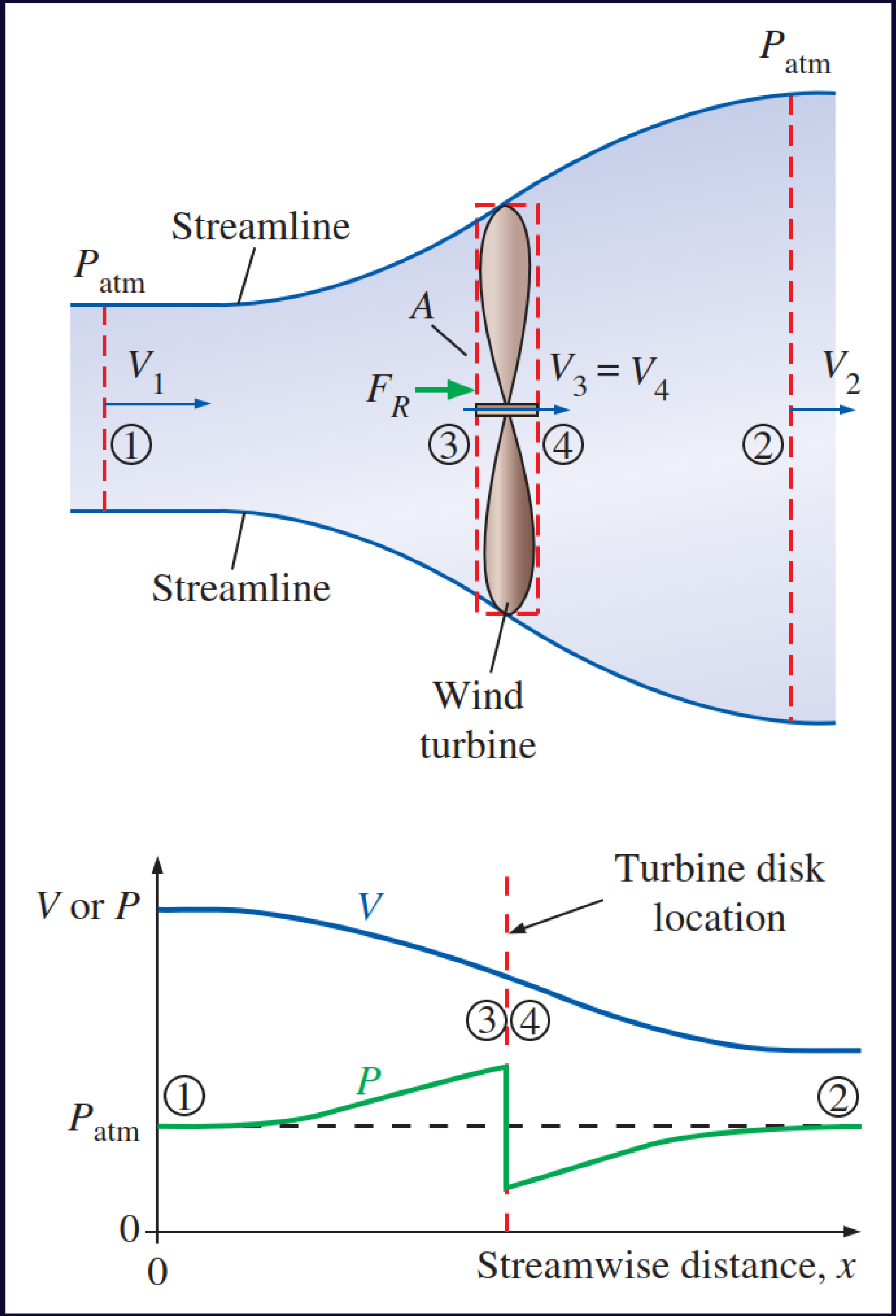
- The Betz limit is a theoretical maximum efficiency for converting the kinetic energy of wind into mechanical energy using a wind turbine.
- It states that a turbine can capture at most 59.3% of the wind's kinetic energy. This limit is derived from the principles of conservation of mass and momentum in fluid dynamics and was formulated by the German physicist Albert Betz in 1919.
- To extract energy from the wind, the turbine slows down the airflow as it passes through the rotor.
- If the turbine extracted 100% of the wind's kinetic energy, the air would stop completely behind the rotor, creating a blockage. This would prevent more wind from flowing through, making the turbine ineffective.
- The Betz limit balances the amount of energy extracted while allowing sufficient airflow to continue moving through the turbine.
- Power coefficient : it is the ratio of the power produced by the rotor to the power extracted form the wind.

$$C_p = \frac{Power\ Produced\ by\ the\ Rotor}{Power\ Extracted\ from\ the\ Wind} = \frac{P_r}{P_w} = \frac{P_r}{\frac{1}{2}\rho \times A \times v^3}$$

In order to compute the mathematical relationships, let us make the following assumptions:

1. The *flow of wind is 'incompressible'*, and hence the air stream *diverges* as it passes through the turbines

2. The *mass flow rate of wind is 'constant'* at *far upstream, at the rotor and at far down stream*



Power Equations

$$E = \frac{1}{2}\dot{m} \times v^2$$

$$\dot{m} = \rho \times A \times v$$

$$E = \frac{1}{2}\rho \times A \times v \times v^2$$

$$E = \frac{1}{2}\rho \times A \times v^3$$

$$P_{max} = E \times C_p$$

$$P_{max} = \frac{1}{2}\rho \times A \times v^3 \times C_p$$

Where:

P_{max} = Betz's law of Wind maximum power

A = the swiped area by the turbine blades, m^2

ρ = the air density, kg/m^3

v = wind speed, m/s

C_p = Maximum power coefficient, (0.593)

Power Equations

The swiped area can be found using the following:

$$A = \pi R^2$$

Where:

R = the radius of the rotor, in meters.

The air density can be calculated by:

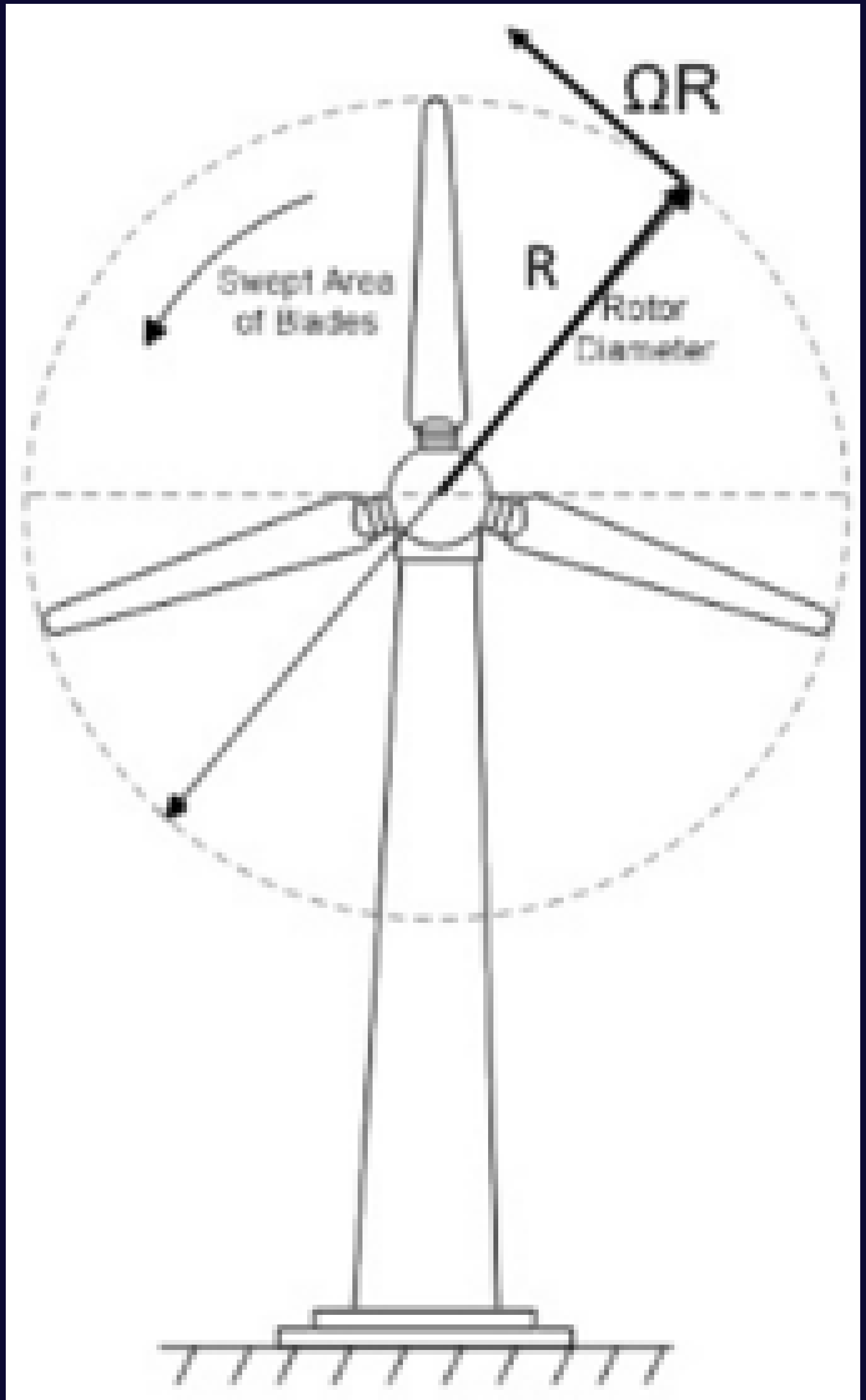
$$\rho = \frac{P_{atm}}{R \times T}$$

Where:

P_{atm} = the atmospheric pressure, pa;

R = specific gas constant of air which is equal to 287 J/kg.°K

T = air temperature, K.



Example 2. **What is the maximum power that can be generated by a wind turbine having blade radius of 18 m and receives wind that has a speed of 12 m/s, the turbine operates at 30°C temperature and atmospheric pressure of 680 mmHg? Take density of the mercury 13600 kg/m^3**

Given:

- Blade radius, R=18 m
- Wind speed, V=12 m/s
- Temperature, T=30 °C
- Maximum power coefficient, Cp=0.593.
- The density of the mercury, which is 13600 kg/m^3
- h = is the elevation of the mercury = 0.68 m

Solution:

$$T = 30 + 273 = 303\,°K$$

$$P_{atm} = \rho_{Hg} \times g \times h$$

$$P_{atm} = 13600 \times 9.81 \times 0.68$$

$$P_{atm} = 90722.88\,Pa$$

$$\rho = \frac{P_{atm}}{R \times T} = \frac{90722.88}{287 \times 303} = 1.0432\,Kg/m^3$$

$$A = \pi R^2 = \pi(18)^2 = 1017.876\,m^2$$

$$P_{max} = \frac{1}{2}\,\rho \times A \times v^3 \times C_p$$

$$P_{max} = \frac{1}{2} \times 1.0432 \times 1017.876 \times (12)^3 \times 0.593$$

$$P_{max} = 544040.07\,W$$

1.10 Exercises

1. List the advantages and disadvantages of wind power plants.
2. List how wind turbine impacts the environment?
3. List the components of wind power plant and explain two of them briefly.
4. What are the major components of wind turbine?
5. Explain briefly the power curve for wind turbine.
6. Explain briefly the two main types of wind turbines?

Q7) Choose the Correct Answer (MCQ for Wind Energy)

https://wayground.com/join?gc=48614322

7) Choose the Correct Answer (MCQ for Wind Energy)

1. **Which factor affects wind power generation most?**
   A) Wind direction B) Wind speed
   C) Number of clouds D) Soil quality

2. **What is the Betz limit for wind turbine efficiency?**
   A) 35% B) 50%
   C) 59.3% D) 75%

3. **The power in wind is proportional to:**
   A) Wind speed B) Wind speed squared
   C) Wind speed cubed D) Blade diameter

4. **Which wind turbine type is more common commercially?**
   A) Vertical axis B) Horizontal axis
   C) Radial axis D) Tangential axis

5. **VAWTs are preferred in areas with:**
   A) Steady wind direction B) Constant sunlight
   C) Rapidly changing wind direction D) Mountainous terrain

1. **What does the anemometer measure?**

   A) Wind direction B) Air temperature C) Wind speed D) Turbine RPM

2. **A yaw control system in wind turbines:**

   A) Measures temperature B) Starts the turbine

   C) Converts mechanical energy to electrical D) Faces the rotor into the wind

3. **The component that connects the low-speed shaft to the high-speed shaft in a wind turbine is called:**

   A) Rotor B) Gearbox C) Controller D) Nacelle

4. **The typical range of rotational speed for the low-speed shaft in a wind turbine is:**

   A) 1–5 rpm B) 15–30 rpm C) 100–500 rpm D) 1000–1800 rpm

5. **The wind turbine starts operating at approximately which wind speed?**

   A) 2 m/s B) 3.5 m/s C) 8 m/s D) 25 m/s

1. **The Savonius wind turbine is characterized by:**
   A) High efficiency at high wind speeds
   B) Self-starting and simple design
   C) Complex aerodynamic shape
   D) Horizontal axis configuration

2. **The Darrieus turbine is not self-starting because:**
   A) It has straight blades
   B) It operates only at low wind speeds
   C) It requires external force to begin rotation
   D) It faces downwind

3. **The theoretical maximum efficiency of a wind turbine was formulated by:**
   A) Albert Einstein
   B) Nikola Tesla
   C) Albert Betz
   D) James Watt

4. **Which of the following is a disadvantage of wind energy?**
   A) Produces harmful emissions
   B) Requires large installation area
   C) Depends on fossil fuels
   D) Creates greenhouse gases

5. **The main reason for limiting wind turbine operation at high speeds (cut-out speed) is:**
   A) To save electrical energy
   B) To prevent mechanical damage
   C) To reduce aerodynamic noise
   D) To avoid overheating of generator

وزارة التعليم العالي والبحث العلمي

الجامعة التقنية الشمالية

الكلية التقنية الهندسية / الموصل

قسم هندسة تقنيات ميكانيك القوى

اسم المادة : الطاقة المتجددة

محاضرة بعنوان

Geothermal Energy

مدرس المادة:

محمد طه محمد

Introduction

Geothermal energy utilizes the Earth's immense and constant internal heat as a reliable, renewable resource for electricity generation and direct heating. This lecture explores the geological origins of this energy, classifies the various types of geothermal resources, and examines the key technologies used to harness it. We will cover the operation of large-scale geothermal power plants, from Dry Steam to Binary Cycle systems, as well as small-scale applications like ground-source heat pumps. Understanding these fundamentals is key to evaluating geothermal energy's role in a sustainable energy future.

General Objective of the Lecture:

To provide a comprehensive understanding of the principles, resources, and technologies associated with geothermal energy extraction and utilization.

Specific Objectives of the Lecture:

1

Describe the geological structure of the Earth and identify the origins of geothermal heat, listing and defining the four main types of geothermal resources with at least 90% accuracy.

2

Compare and contrast the three main types of geothermal power plants (Dry Steam, Flash Steam, and Binary Cycle) by explaining their operational principles, required resource conditions, and key advantages.

3

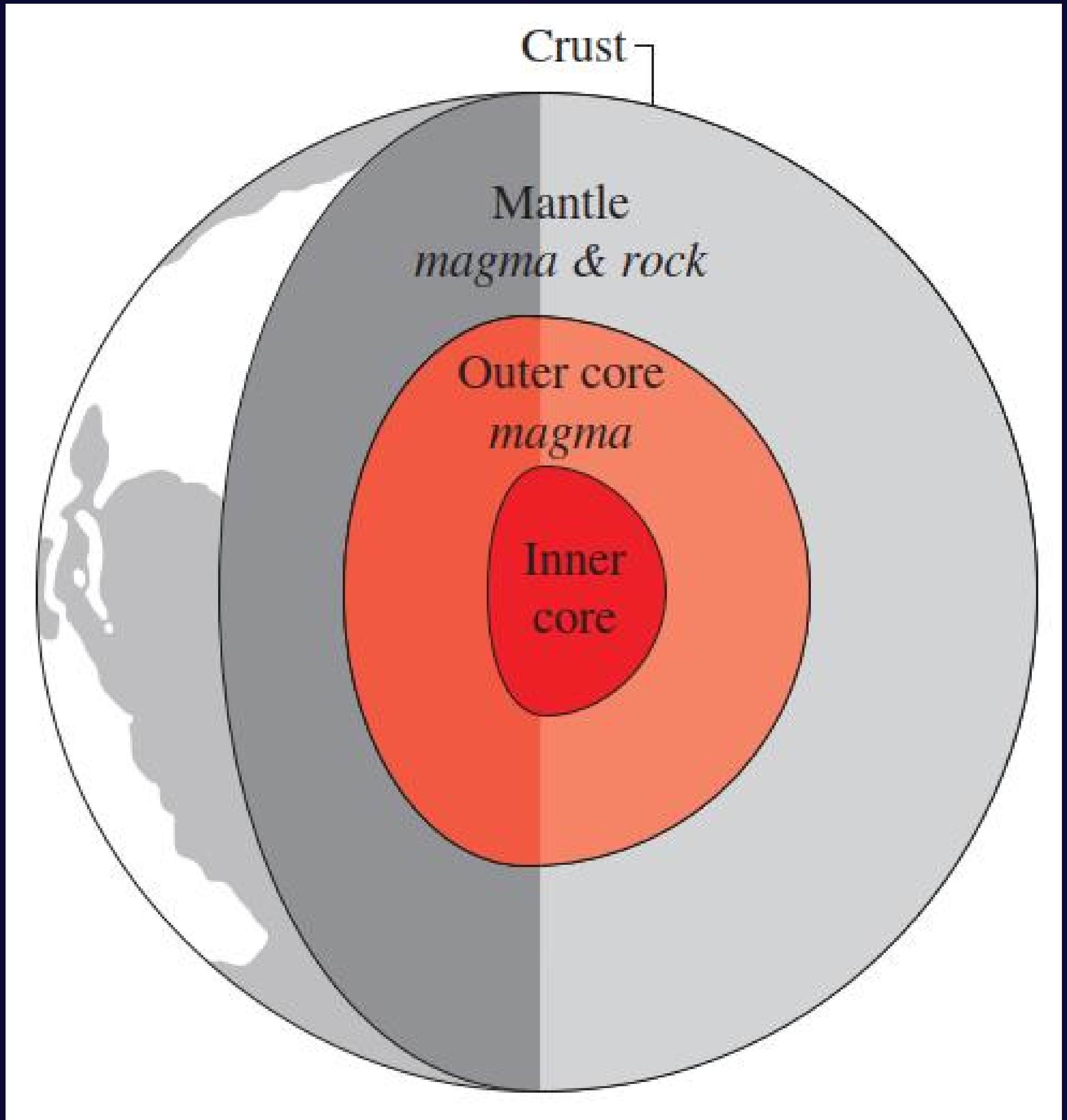
Explain the operational principle of a ground-source heat pump in both heating and cooling modes and calculate its potential efficiency advantage over an air-source heat pump using the Coefficient of Performance (COP) metric.

Geothermal Energy

Geothermal energy is the thermal energy within the earth’s interior

It is a renewable energy source because heat is continuously transferred from within the earth to the water recycled by rainfall

- The origin of geothermal energy is earth's core, and it is about 6500 km deep. The core is made up of an inner core (iron center) and an outer core made up of very hot magma.
- The temperature in the magma remains very high due to decay of radioactive Particles.
- The outer core is surrounded by the mantle whose thickness is about 3000 km. The mantle is made of magma and rock.
- The layer of the earth housing continents and ocean floors is called the crust. The thickness of the crust is 25 to 55 km on the continents and 5 to 8 km under the oceans. The crust is made up of tectonic plates.
- Volcanoes occur near the edges of these plates due to magma getting close to it.
- At some reasonable depths, the rocks and water absorb heat from this magma. These sites are characterized as geothermal resources. By digging wells and pumping the hot water to the surface, we make use of geothermal energy.



Geothermal resources can be classified based on their thermal and compositional characteristics:

Hydrothermal These are known geothermal fields containing high temperature water in steam, mixture, or liquid phases.

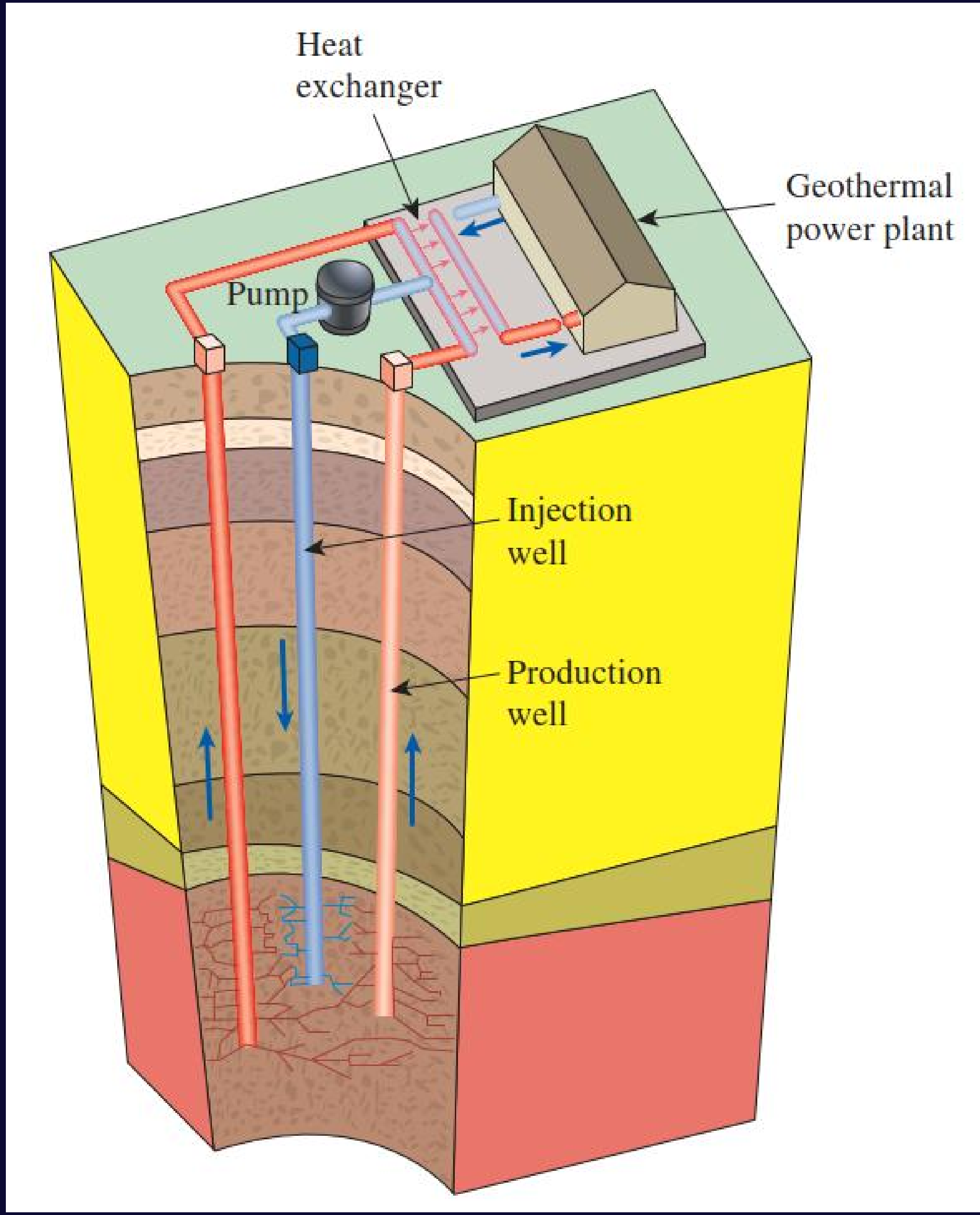
Geopressurized These resources contain hot liquid water at 150°C to 180°C at very high pressures (up to 600 bar). The fluid in these deposit-filled reservoirs also contains methane and high levels of dissolved solids. The fluid is highly corrosive and thus very difficult to harvest and handle.

Magma They are also called molten rock, and typically contained under active volcanoes at temperatures above 650°C.

Enhanced They are also called hot, dry rock geothermal systems. These are not natural geothermal resources. The idea is that water is injected into the hot rock formation at high pressure, and then the resulting hot steam is brought back to the surface. The system involves drilling of injection and production wells to a depth of 3 to 5 km. The temperature of the hot rock in this depth can be around 250°C.

Among these four geothermal resource categories, only hydrothermal resources are currently being exploited. The other three are estimated to have enormous energy potentials but current technologies do not allow feasible energy production from these resources.

Operation of enhanced geothermal systems.



A geothermal resource contains geothermal water at a temperature higher than that of the environment. One common classification of geothermal resources is based on the resource temperature.

High temperature resource: $T > 150°C$

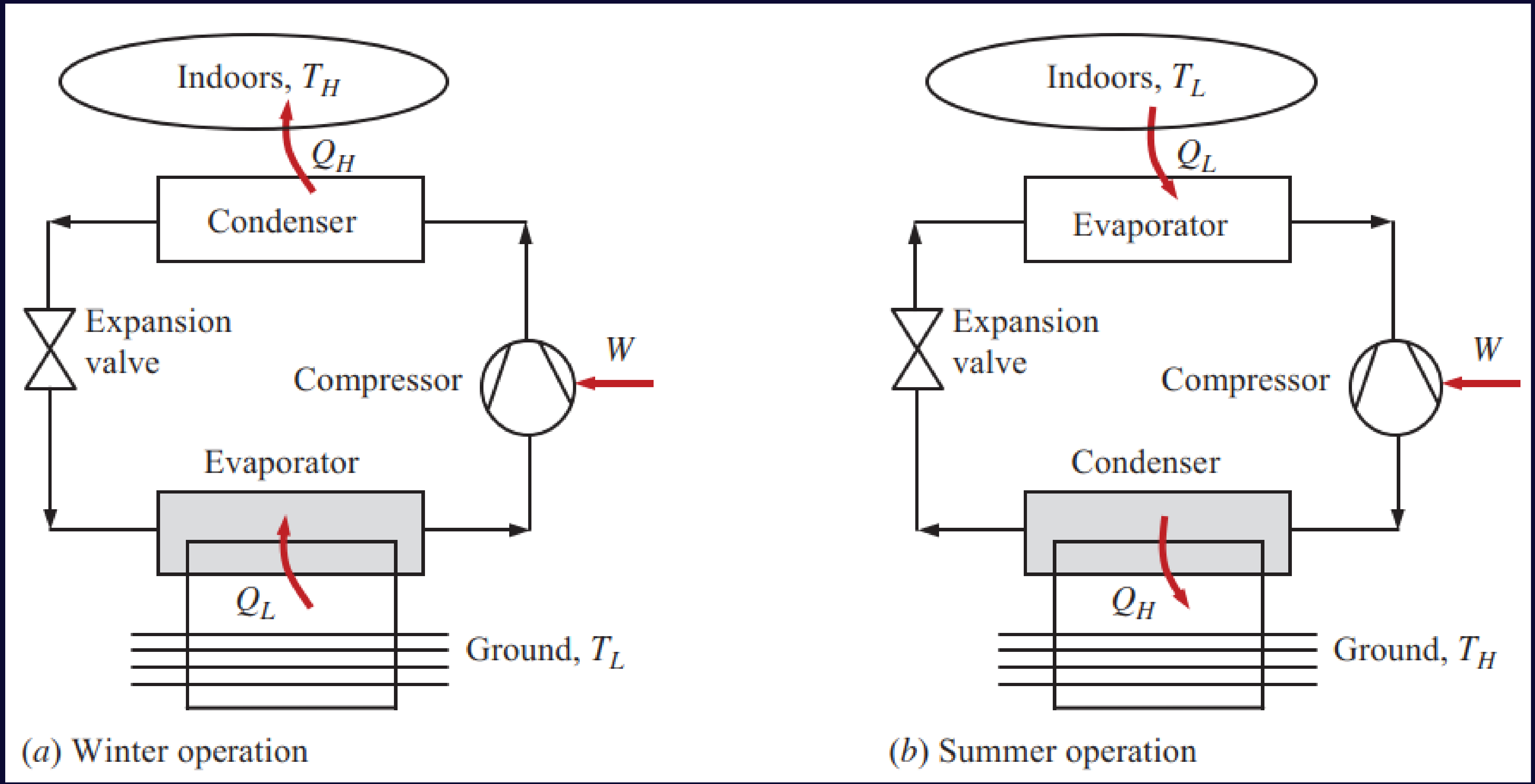
Medium temperature resource: $90°C < T < 150°C$

Low temperature resource: $T < 90°C$

The state of geothermal water in the reservoir may be superheated or saturated steam (dry steam), saturated steam-liquid mixture, or liquid (usually compressed liquid). Steam-dominated resources are of the higher quality than liquid-dominated resources due to higher enthalpy and exergy (work potential) values. However, most of the world’s geothermal resources are liquid dominated.

Ground-Source Heat Pump Systems

Ground-source heat pump systems are also known as geothermal heat pumps as they use the heat of earth in its operation. They have higher COPs than ordinary air-source heat pumps because ground is at a higher temperature than ambient air in winter (heating mode) and at a lower temperature than ambient air in summer (cooling mode).

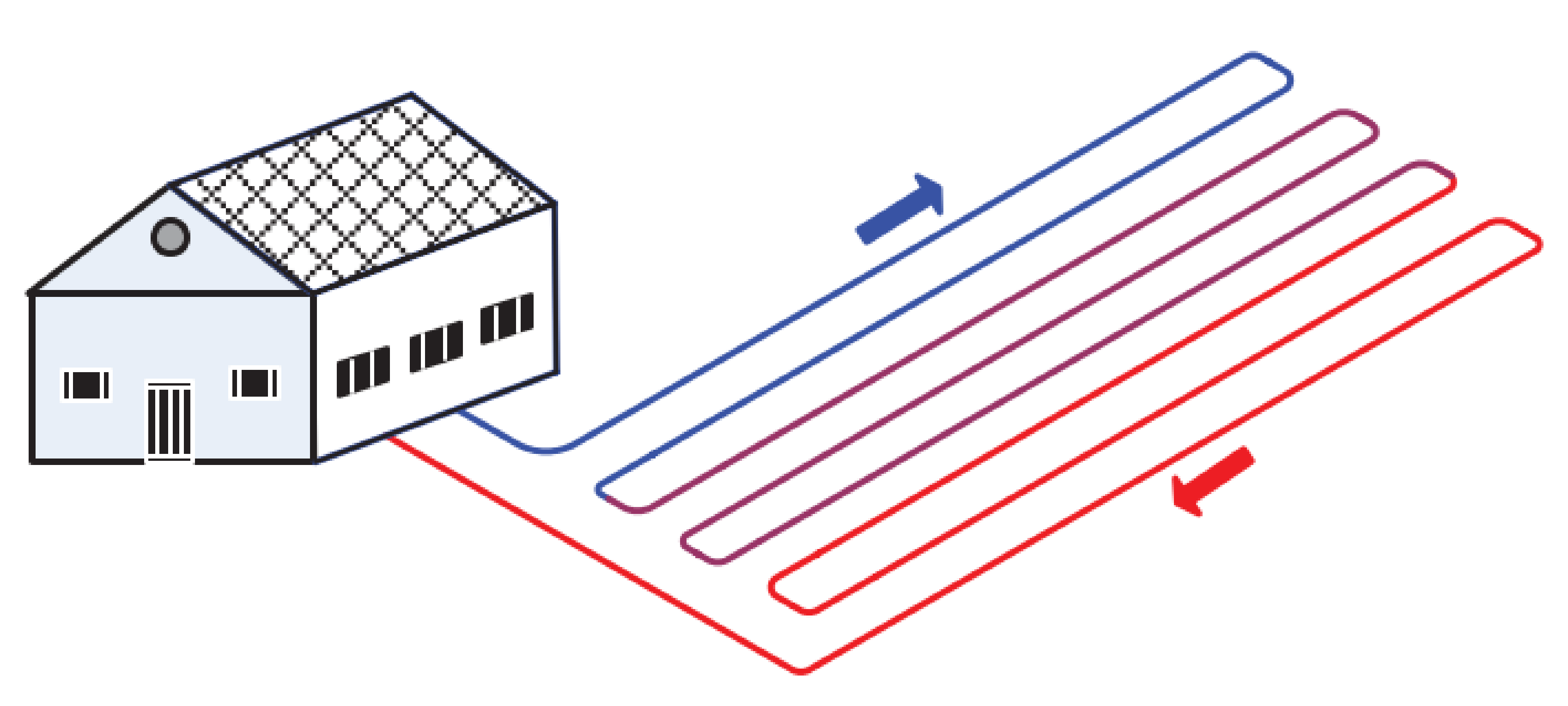


Actual COP of ground-source heat pumps ranges between about 3 and 5 while actual COP of air-source heat pumps ranges between about 1.5 and 3.

Ground-source heat pumps can be classified according to the configuration of piping and heat source as follows:

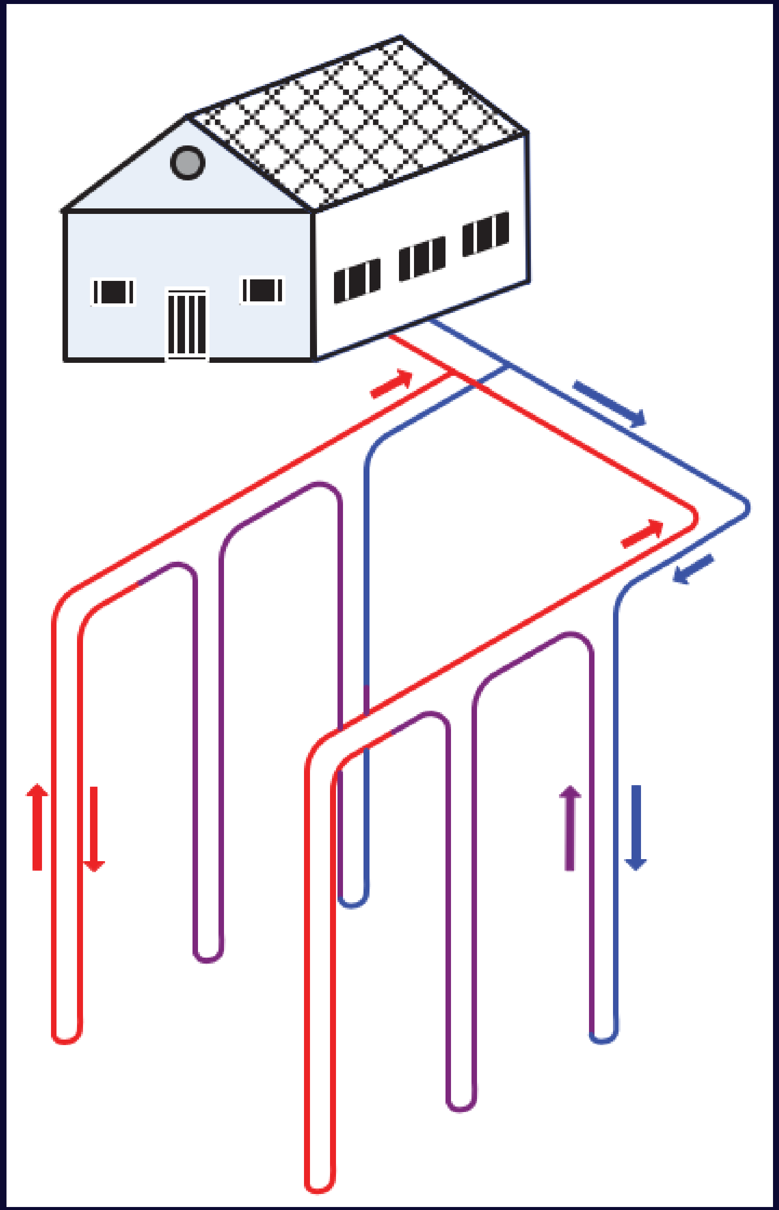
Horizontal loop heat pump

It involves horizontal underground piping in 1.2 to 2.0 m depths. It is suitable when there is sufficient area for pipe burial such as the relatively large backyard of a house.



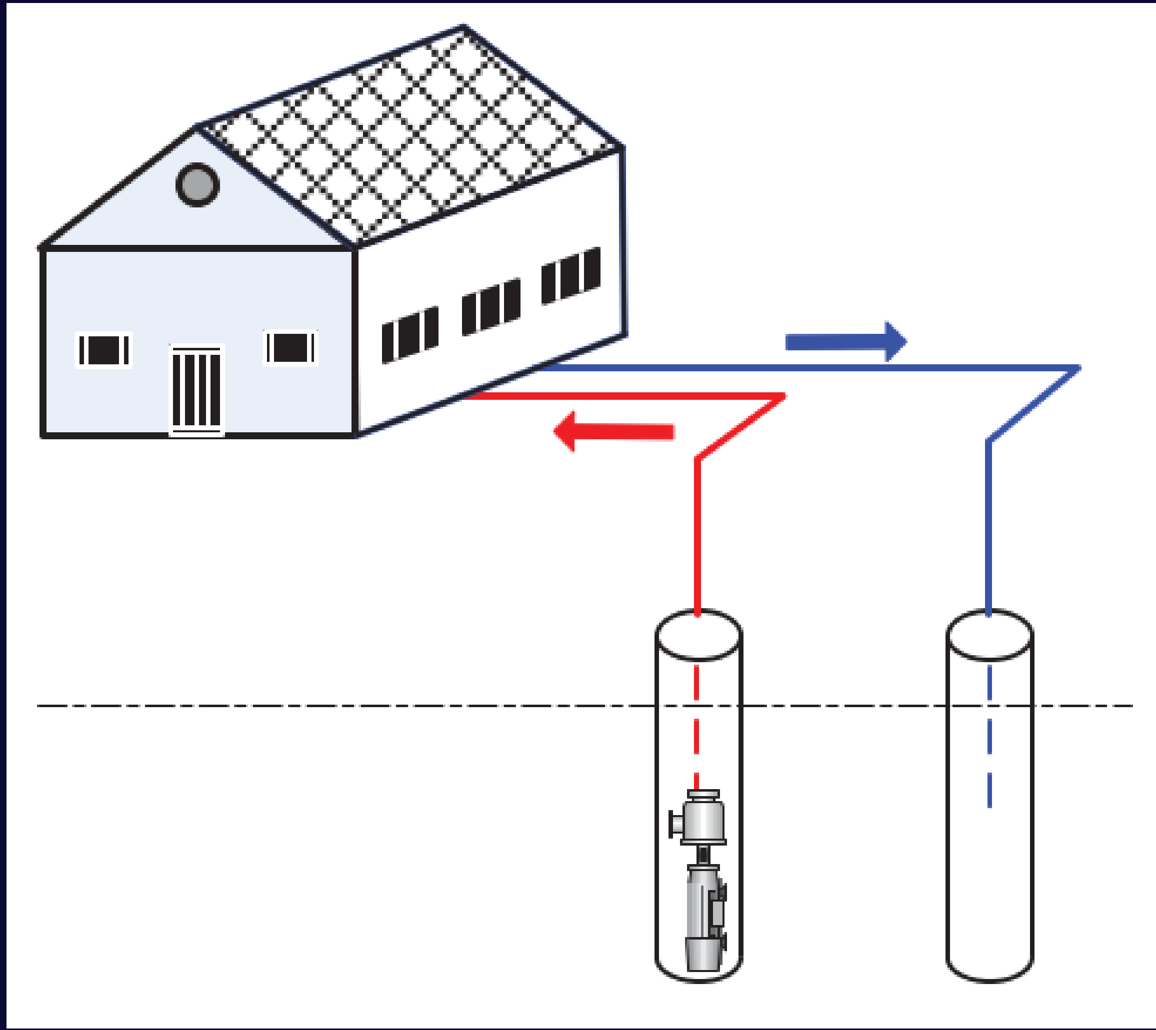
Vertical loop heat pump

- It is also called borehole loop heat pump. Vertical piping in 10 to 250 m depths is used. It can be installed everywhere as a small field allowing vertical drilling is sufficient. This type of heat pump is selected for meeting heating and cooling requirement of a medium-size university campus with several buildings.
- Vertical piping is more expensive than horizontal piping for a given heat transfer surface area. These systems require virtually no regular maintenance and they are safe. However, the capacity is limited per borehole and the ground temperature is relatively low.



Ground water wells heat pump

Underground water is circulated through the evaporator of the heat pump unit. Heat is transferred from the water to the refrigerant flowing in the evaporator. The cooler water leaving the evaporator is dumped back to the ground at a different location. The water well is located in 5 to 50 m depths. These systems can provide high capacities with relatively low cost. The temperature of water is relatively high as compared to horizontal loop and borehole heat pumps. An aquifer is needed for sufficient water yield. The wells need to be maintained and water quality should be monitored.



GEOTHERMAL POWER PRODUCTION

Only a fraction of geothermal resources have relatively high temperatures making them suitable for electricity production. Geothermal power plants have been in operation for decades in many parts of the world

- First geothermal power plant was built in Italy in 1904.
- First geothermal plant was built in 1960 in the Geysers in northern California.
- There are dozens of geothermal power plants in the United States located in California, Nevada, Utah, Idaho, Oregon, and Hawaii.
- About 14,300 MW of geothermal electricity are produced in 24 countries as of 2018, and 28 percent of this is generated in the United States with 3550 MW.

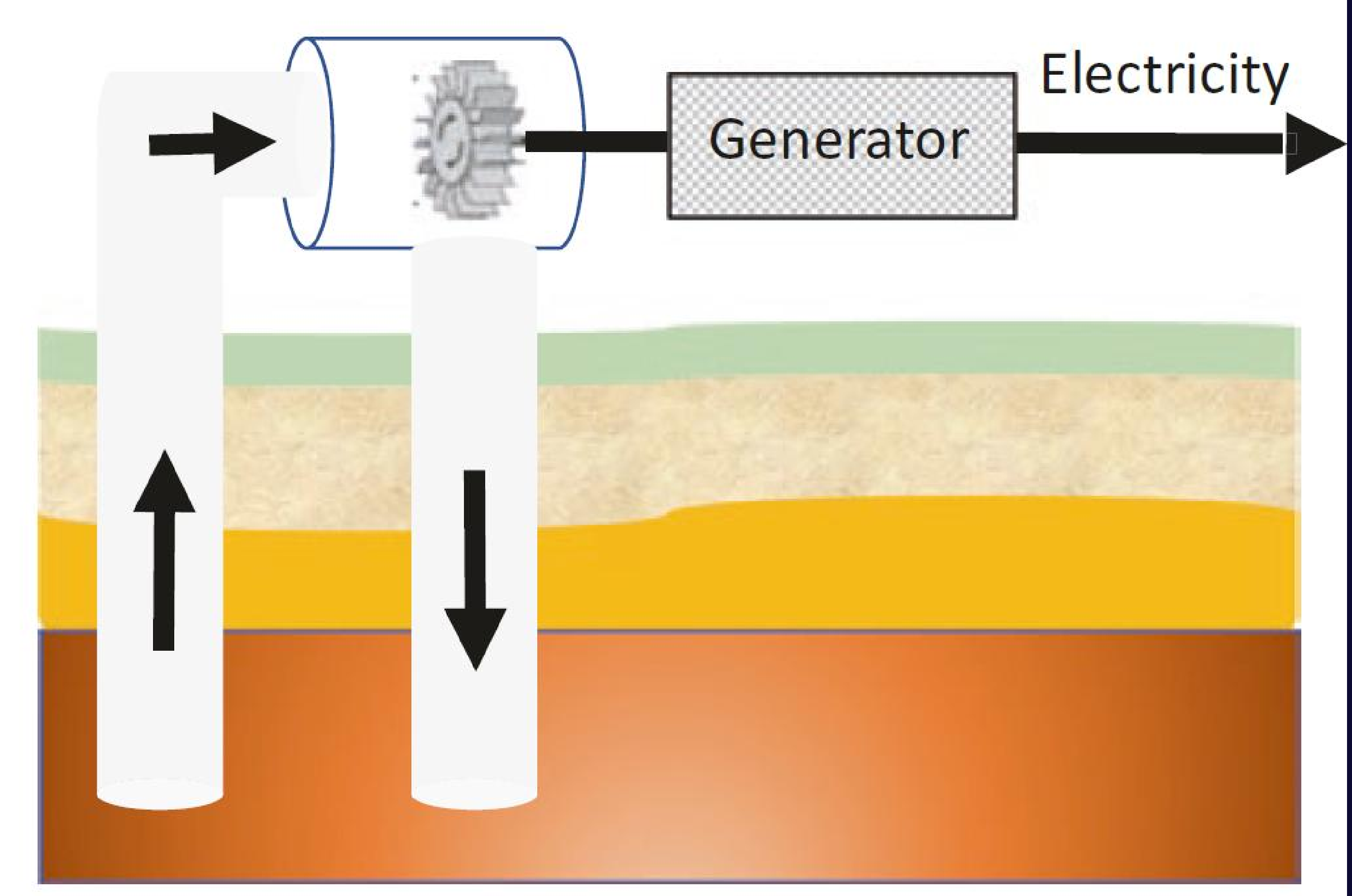
Geothermal Power Plant Technologies:

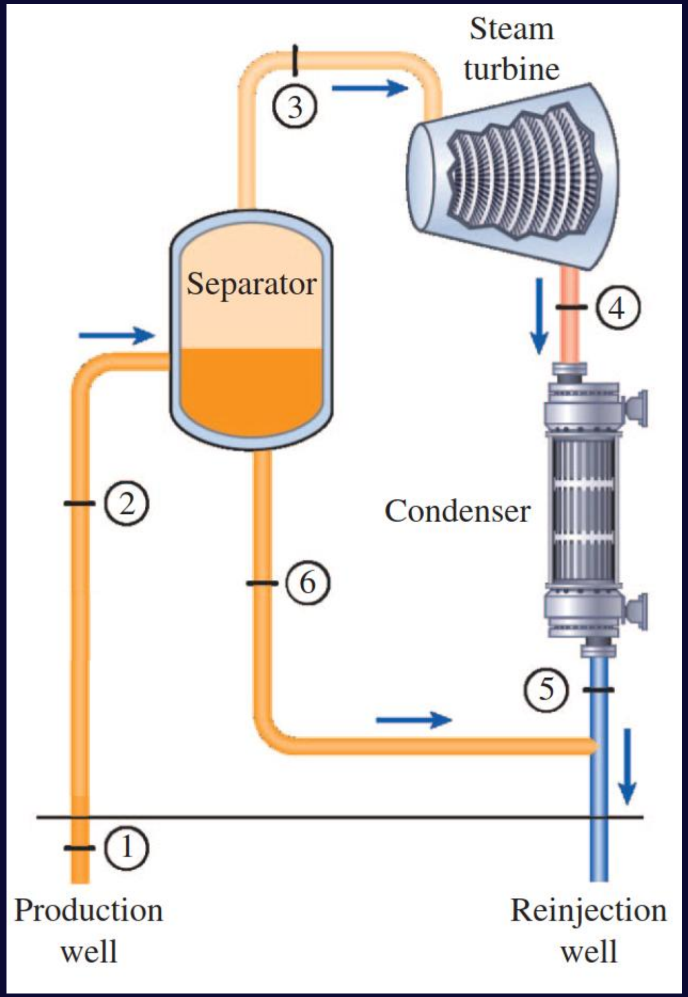
There are three commercial types of conventional geothermal power plants:

1. Dry Steam Geothermal Power Plant.
2. Flash Steam Geothermal Power Plant.
3. Binary Geothermal Power Plant.

Dry Steam Geothermal Power Plant.

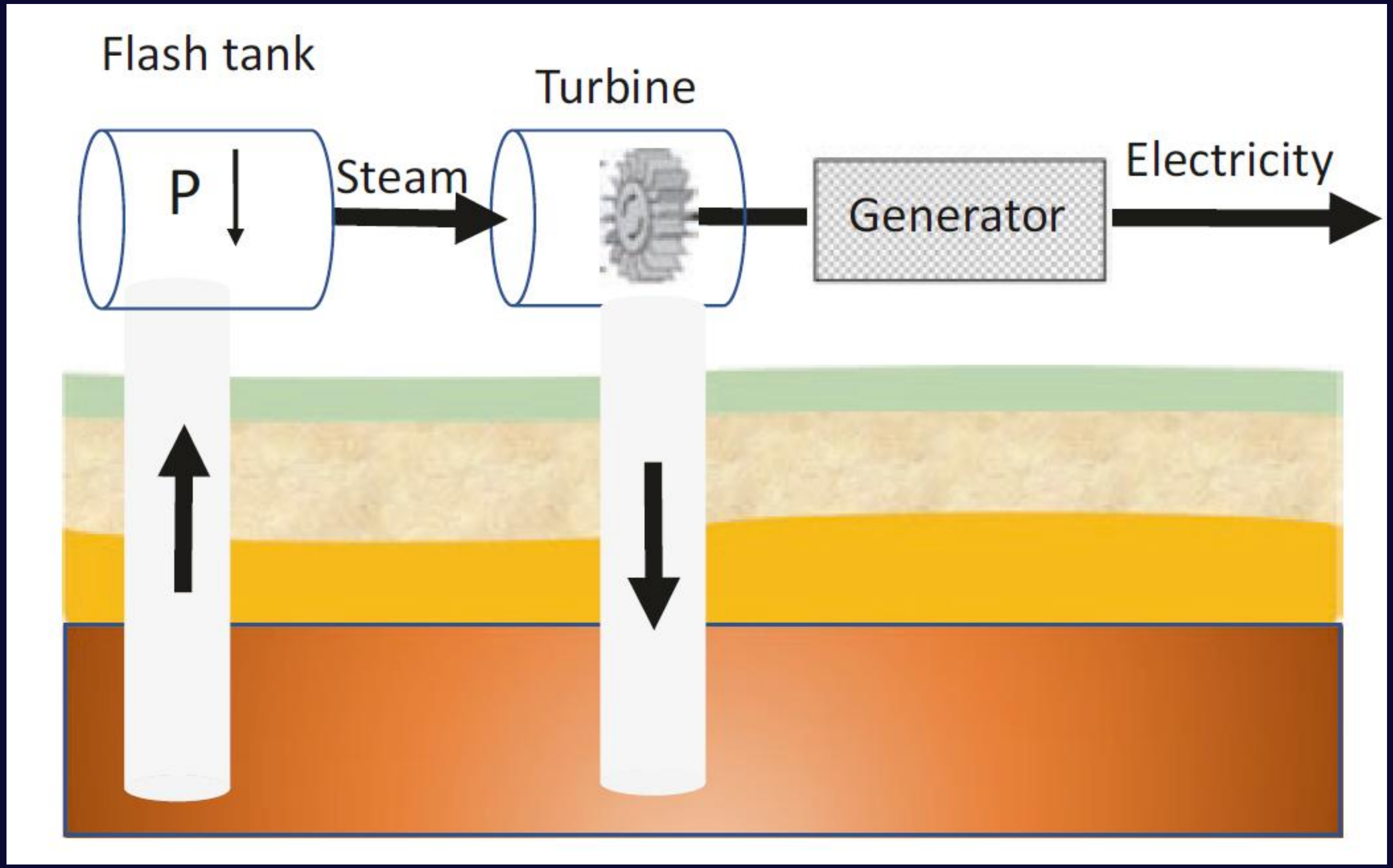
The majority of geothermal resources have only dry heat that can be used. The heat is exploited from these sites by injecting water deep below the surface into the high-temperature rock where it is heated to steam and brought back to the surface to power a turbine. The condensed water that exits the turbine is injected back into the rock. The water is heated again and available for the next cycle

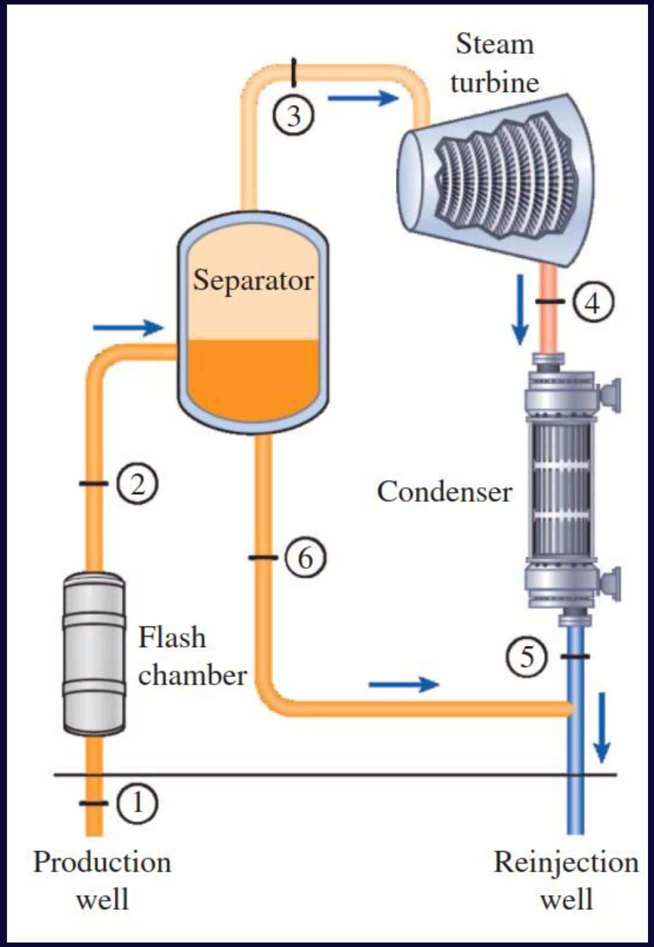


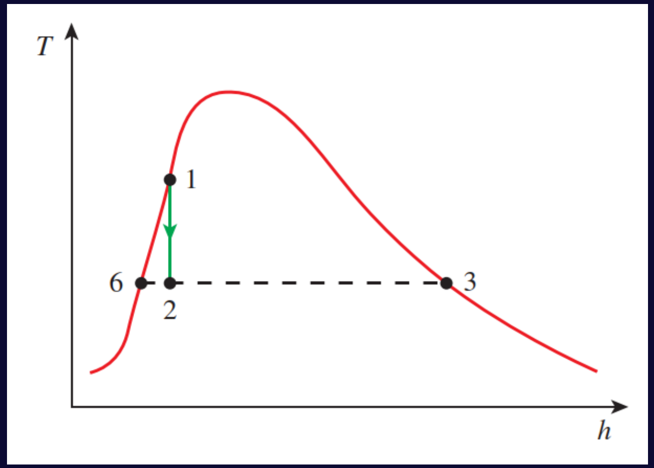


Flash Steam Geothermal Power Plant

Flash steam power plants are used when the geothermal resource is hot water (>180 °C) under pressure. Fluid is then pumped to the surface and into a tank at lower pressure, causing the fluid to rapidly vaporize (or flash) and turn a turbine, which drives a generator

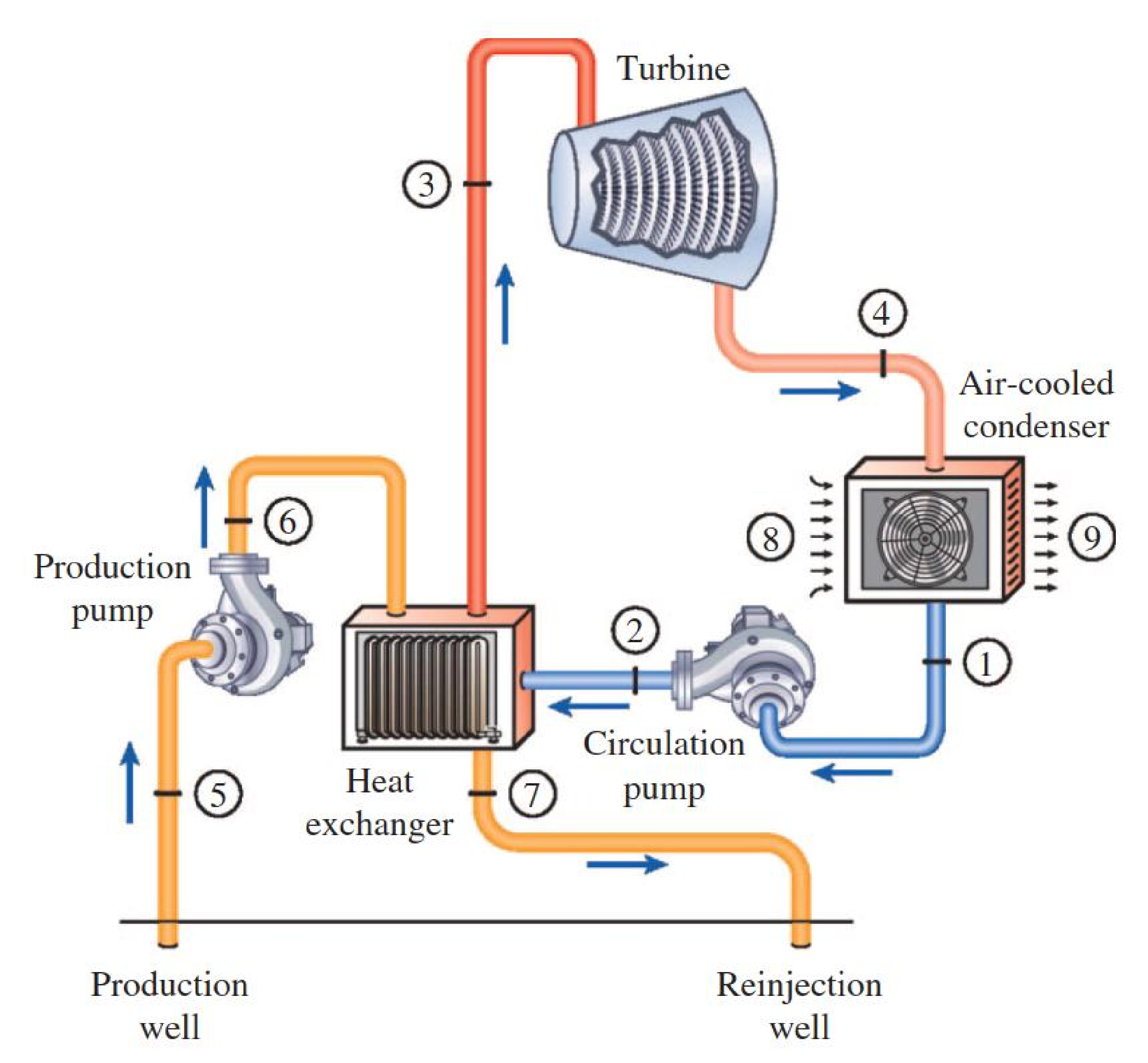






Binary Geothermal Power Plant

Most geothermal power plants are Binary Cycle type used when the geothermal resource is hot water at moderate temperatures (<180 °C). As the hot water enters the power plant, it passes through a heat exchanger together with a secondary fluid with a lower boiling point, causing it to rapidly vaporize and drive the turbine. In this process, the corrosive geothermal source water never comes in contact with the turbine components.



EXAMPLE

A geothermal site contains geothermal water available at wellhead at a rate of 100 kg/s. The geothermal water is at 180°C with a vapor fraction of 20 percent. The ambient conditions are 25°C and 1 atm.

- What is the maximum thermal efficiency of a geothermal power plant using this resource?
- What is the maximum amount of power that can be produced from this site?
- If a typical second-law efficiency for a geothermal power plant is 30 percent, predict the actual power output from a geothermal power plant at this site and its thermal efficiency.

SOLUTION

(a) We use properties of water for geothermal fluid. The maximum thermal efficiency can be determined from the Carnot efficiency relation using the geothermal source and ambient (dead state) temperatures:

$$\eta_{\text{th,max}} = 1 - \frac{T_L}{T_H} = 1 - \frac{(25+273)\text{ K}}{(180+273)\text{ K}} = 0.3422 \text{ or } \mathbf{34.2\ percent}$$

(b) The maximum power potential is equal to the exergy of the geothermal water available at the wellhead:

$$\dot{W}_{\max} = \dot{m}_1[h_1 - h_0 - T_0(s_1 - s_0)]$$

The enthalpy and entropy values of geothermal water at the wellhead state and dead state are obtained from steam tables:

$$\left.\begin{array}{r} T_1 = 179.9\ ^\circ\text{C} \\ x_1 = 0.20 \end{array}\right\} \begin{array}{l} h_1 = h_{f@179.9^\circ\text{C}} + x_1 h_{fg@179.9^\circ\text{C}} = 762 + (0.20)(2015) = 1165\ \text{kJ/kg} \\ s_1 = s_{f@179.9^\circ\text{C}} + x_1 s_{fg@179.9^\circ\text{C}} = 2.138 + (0.20)(4.448) = 3.0276\ \text{kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{r} T_0 = 25^\circ\text{C} \\ P_0 = 1\ \text{atm} \end{array}\right\} \begin{array}{l} h_0 \cong h_{f@25^\circ\text{C}} = 104.8\ \text{kJ/kg} \\ s_0 \cong s_{f@25^\circ\text{C}} = 0.367\ \text{kJ/kg}\cdot\text{K} \end{array}$$

$$\begin{aligned} \dot{W}_{\max} &= (100)[(1165 - 104.8) - (298)(3.0276 - 0.367)] \\ &= 26734\ \text{kW} \end{aligned}$$

(c) The second-law efficiency of a power plant is defined as the actual power output divided by the maximum power output. It is also defined as the actual thermal efficiency divided by the maximum (i.e., Carnot) thermal efficiency. Then, for a second-law efficiency of 30 percent, the actual power output and actual thermal efficiency are predicted to be

$$\eta_{II} = \frac{\dot{W}_{actual}}{\dot{W}_{max}} \longrightarrow \dot{W}_{actual} = \eta_{II}\dot{W}_{max} = (0.30)(26,734 \text{ kW}) = \mathbf{8020 \text{ kW}}$$

$$\eta_{II} = \frac{\eta_{th,actual}}{\eta_{th,max}} \longrightarrow \eta_{th,actual} = \eta_{II}\eta_{th,max} = (0.30)(0.3422) = 0.1027 \text{ or } \mathbf{10.3\%}$$

Exercises

1) List the types of conventional geothermal power plants.
2) Explain briefly the dry steam geothermal power plant.
3) Explain briefly the flash steam geothermal power plant.
4) Explain briefly the binary geothermal power plant.
5) Classify the ground-source heat pumps according to the configuration of piping and heat source.

Q6) Choose the Correct Answer (MCQ for Geothermal Energy)

1. **Geothermal energy originates from:**
   A) Solar heat
   B) Radioactive decay in Earth's core
   C) Ocean currents
   D) Atmospheric radiation
2. **Dry steam geothermal plants use:**
   A) Ocean water
   B) Direct steam from Earth
   C) Solar heating
   D) Fuel combustion
3. **Flash steam plants operate with geothermal fluid at:**
   A) Below 100°C
   B) Between 100–180°C
   C) Above 180°C
   D) Room temperature
4. **Binary geothermal plants use:**
   A) Direct steam
   B) No heat exchangers
   C) A secondary fluid with low boiling point
   D) No turbine
5. **Which energy source can be tapped using underground drilling?**
   A) Solar
   B) Wind
   C) Geothermal
   D) Hydropower

وزارة التعليم العالي والبحث العلمي

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اسم المادة : الطاقة المتجددة

محاضرة بعنوان

Hydraulic Energy

مدرس المادة:

محمد طه محمد

Hydraulic Energy

This comprehensive presentation covers the fundamentals of hydroelectric power generation, including advantages and disadvantages, site selection criteria, plant components, turbine types, and practical calculations for power output.

General Objective of the Lecture:

To provide students with a clear understanding of hydroelectric power systems, including their components, turbine types, advantages, disadvantages, and the principles required to analyze and evaluate hydropower plant performance.

Specific Objectives of the Lecture:

1

By the end of the lecture, students will be able to *identify and describe* at least five major components of a hydroelectric power plant (such as dam, reservoir, penstock, turbine, generator) with correct functions as presented in the lecture.

2

Within the same lecture session, students will be able to *classify hydraulic turbines* into impulse and reaction types and provide *one example and one design head range* for each turbine type (Pelton, Francis, Kaplan).

3

By the end of the class, students will be able to *apply the hydropower formula* $P = \rho g H \dot{V} \eta$ to calculating power output and annual energy generated.

1 Hydro Power Plant

In hydro-electric plants energy of water is utilized to move the turbines which in turn run the electric generators. The energy of water utilized for power generation may be kinetic or potential. The *kinetic energy* of water is its energy in motion and is a function of mass and velocity, while the *potential energy* is a function of the difference in level/head of water between two points.

1.1 Advantages of Hydro Power Plant

1 Maintenance and Operation

Maintenance and operation charges are very low.

2 Running Cost

Running cost of the plant is low.

3 Efficiency Over Time

The plant efficiency does not change with age.

4 Quick Startup

It takes a few minutes to run and synchronize the plant.

5 Long Lifespan

Such a plant has comparatively a long life (100-125 years as against 20-45 years of a thermal plant).

1.2 Disadvantages of Hydro Power Plant

High Initial Cost

The initial cost of the plant is very high.

Long Construction Time

It takes considerable long time for the erection of such plants.

Remote Location & Transmission

Such plants are usually located in hilly areas far away from the load center and as such they require long transmission lines to deliver power, subsequently the cost of transmission lines and losses in them will be more.

Rainfall Dependency

Power generation by the hydro-electric plant is only dependent on the quantity of water available which in turn depends on the natural phenomenon of rain. So, if the rainfall is in time and proper and the required amount of water can be collected, the plant will function satisfactorily otherwise not.

1.3 Selection Of Site for a Hydro Power Plant

The following *factors* should be considered while selecting the site for a hydro-electric plant:

Availability of Water

The most important aspect of hydro-electric plant is the availability of water at the site since all other designs are based on it. Therefore, the run-off data at the proposed site must be available beforehand. It may not be possible to have run-off data at the proposed site but data concerning the rainfall over the large catchment area is always available. Estimate should be made about the average quantity of water available throughout the year and also about maximum and minimum quantity of water available during the year. These details are necessary to: (a) decide the capacity of the hydro-electric plant, (b) setting up of peak load plant such as steam, diesel or gas turbine plant and to, (c) provide adequate spillways or gate relief during the flood period.

Water Storage

Since there is a wide variation in rainfall during the year, therefore, it is always necessary to store the water for continuous generation of power. The storage capacity can be calculated with the help of mass curve. Maximum storage should justify the expenditure on the project. The *two types of storages in use* are: (a) The storage is so constructed that it can make water available for power generation of one year only. In this case storage becomes full in the beginning of the year and becomes empty at the end of each year. (b) The storage is so constructed that water is available in sufficient quantity even during the worst dry periods.

Water Head

In order to generate a requisite quantity of power it is necessary that a large quantity of water at a *sufficient head* should be available. An increase in effective head, for a given output, reduces the quantity of water required to be supplied to the turbines.

Accessibility & Distance

The site where hydro-electric plant is to be constructed should be easily accessible. This is important if the electric power generated is to be utilized at or near the plant site. The site selected should have transportation facilities of rail and road. It is of paramount importance that the power plant should be set up *near the load center*; this will *reduce the cost of erection and maintenance of transmission line.*

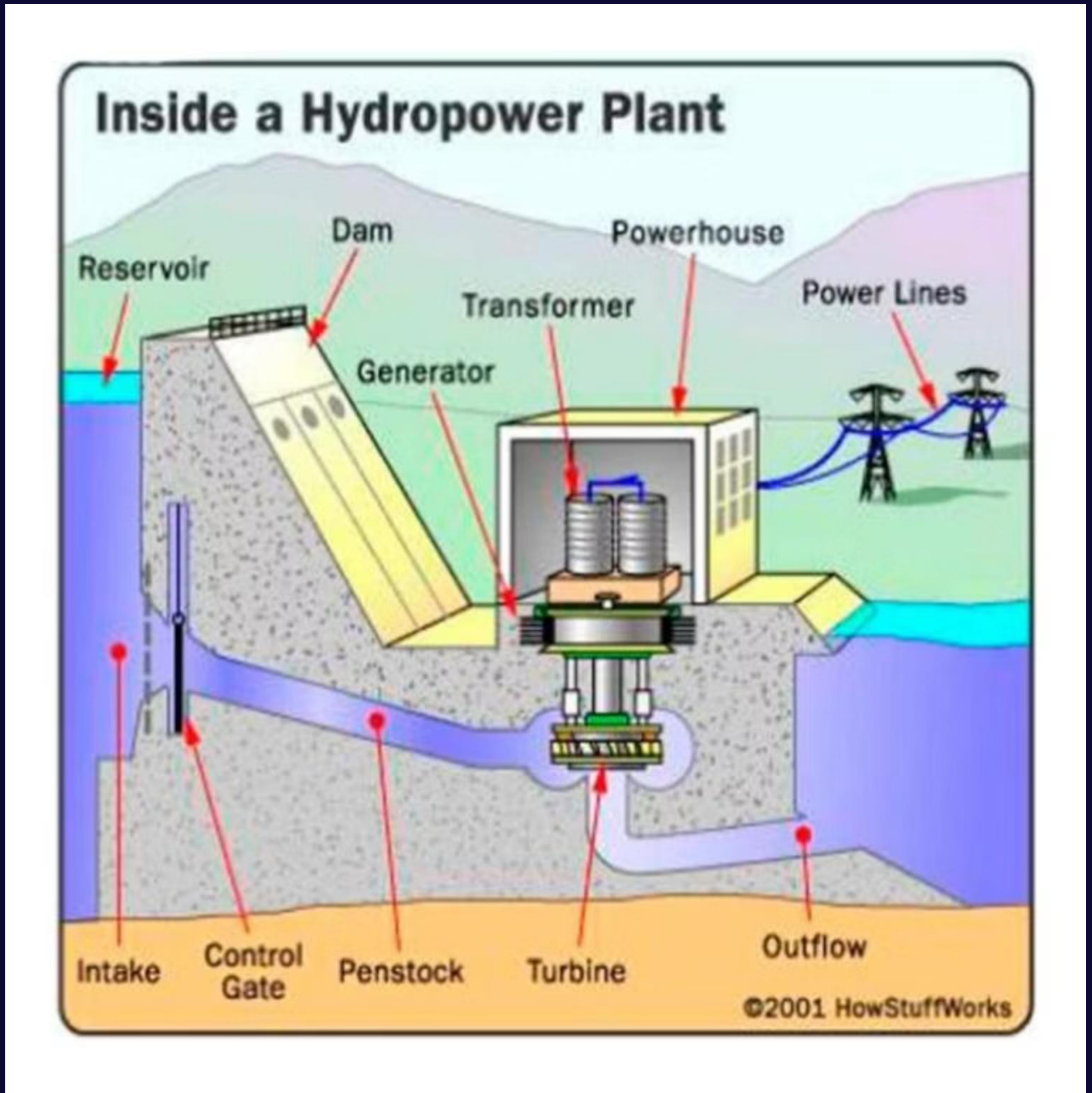
Type of Land

The land to be selected for the site should be cheap and rocky. The ideal site will be one where the dam will have largest catchment area to store water at high head and will be economical in construction. The necessary requirements of the foundation rocks for a masonry dam are as follows: (a) The rock should be strong enough to withstand the stresses transmitted from the dam structure as well as the thrust of the water when the reservoir is full. (b) The rock in the foundation of the dam should be reasonably impervious. (c) The rock should remain stable under all conditions.

1.4 Components of Hydroelectric Power Plant

The major components of a hydroelectric plant are as follows.

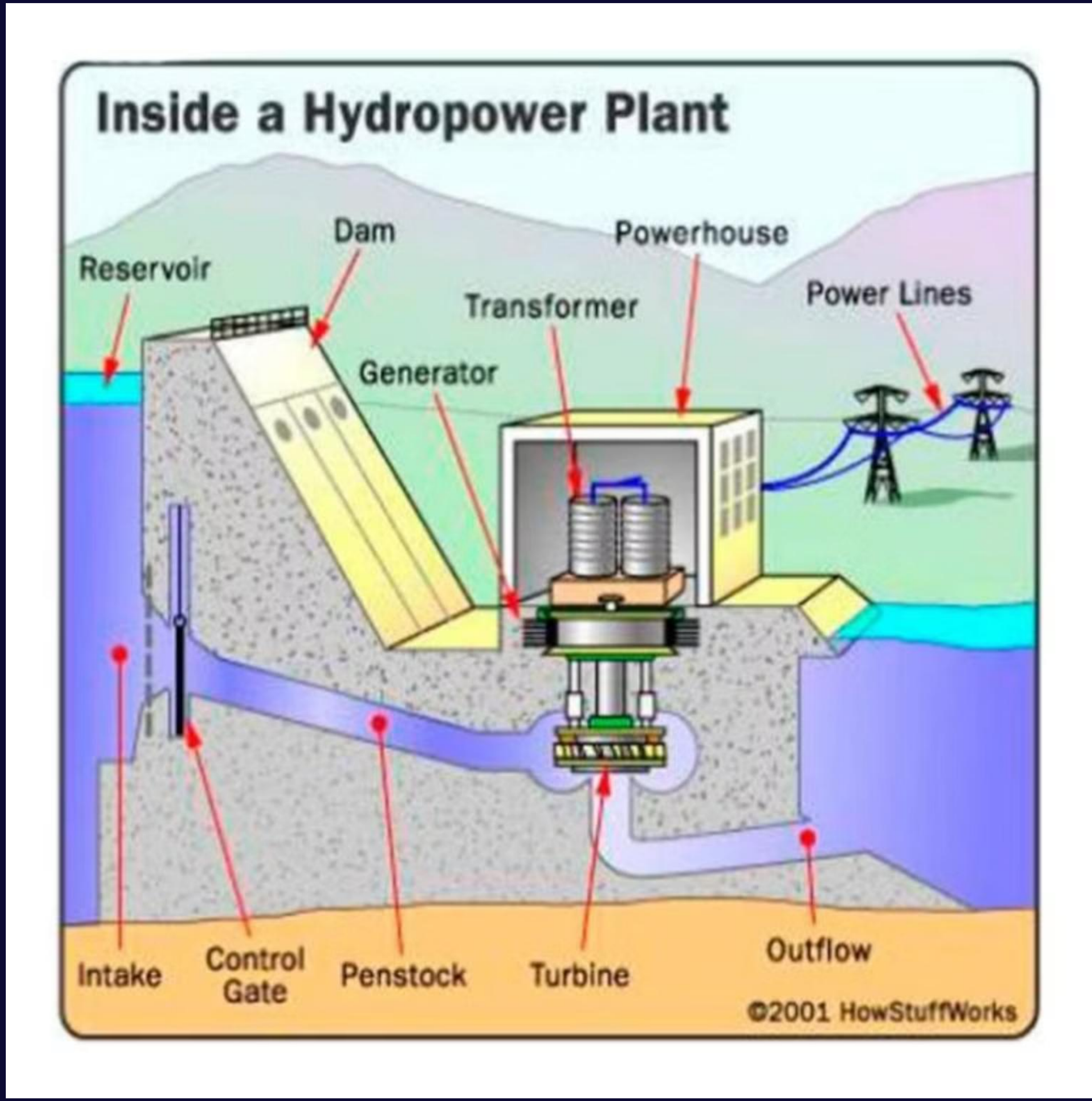
1. **Dam:** A structure built across a river to create a reservoir and control water flow.
2. **Reservoir:** A body of water created by the dam, storing water for later use.
3. **Intake Structure:** A structure that controls the flow of water from the reservoir into the penstock.
4. **Penstock:** A large pipe that carries water from the intake to the turbine.
5. **Turbine:** A machine with blades that rotate when struck by water, converting the water's kinetic energy into mechanical energy.
6. **Generator:** A machine that converts the mechanical energy from the turbine into electrical energy.
7. **Powerhouse:** The building that houses the turbine, generator, and other related equipment.
8. **Transformer**: The electricity produced by the generator is typically low voltage. Transformers "step up" the voltage to a much higher level, making it suitable for efficient transmission over long distances via transmission lines.
9. **Tailrace:** The channel that carries water away from the turbine after it has passed through.



1.4 Components of Hydroelectric Power Plant

The optional components of a hydroelectric plant are as follows:

1. **Draft Tube**: Connects the turbine outlet to the tailrace, helping to recover some of the water's kinetic energy.
2. **Surge Tank**: A safety device that protects the penstock from pressure surges caused by sudden changes in water flow.
3. **Forebay**: A small reservoir or pond located just before the intake structure.



1.5 Types of Hydraulic Turbines

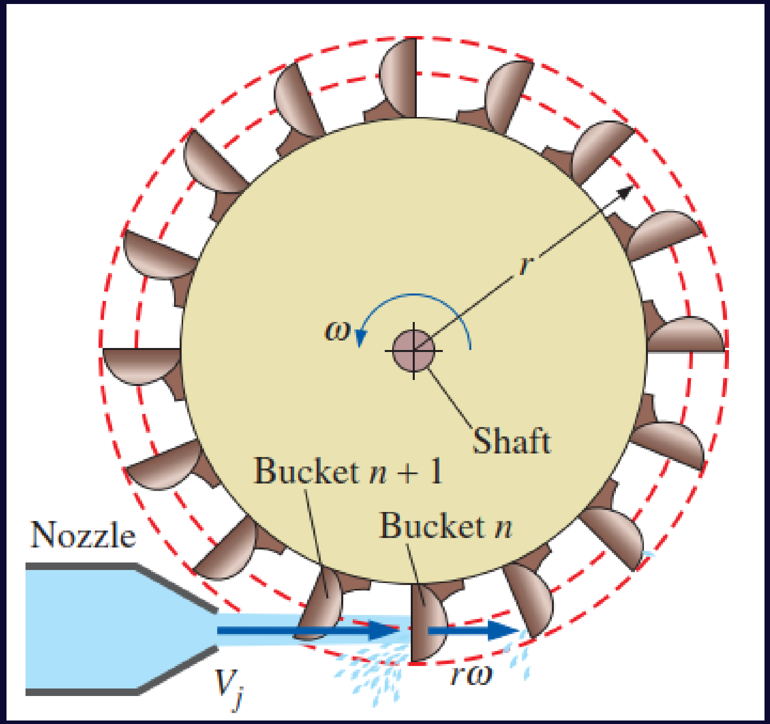
Hydraulic turbines are primarily categorized into two main types: impulse and reaction. Impulse turbines, like the Pelton wheel, use the kinetic energy of a high-speed water jet, while reaction turbines, such as the Francis and Kaplan turbines, utilize both the pressure and kinetic energy of the water as it passes through the runner.

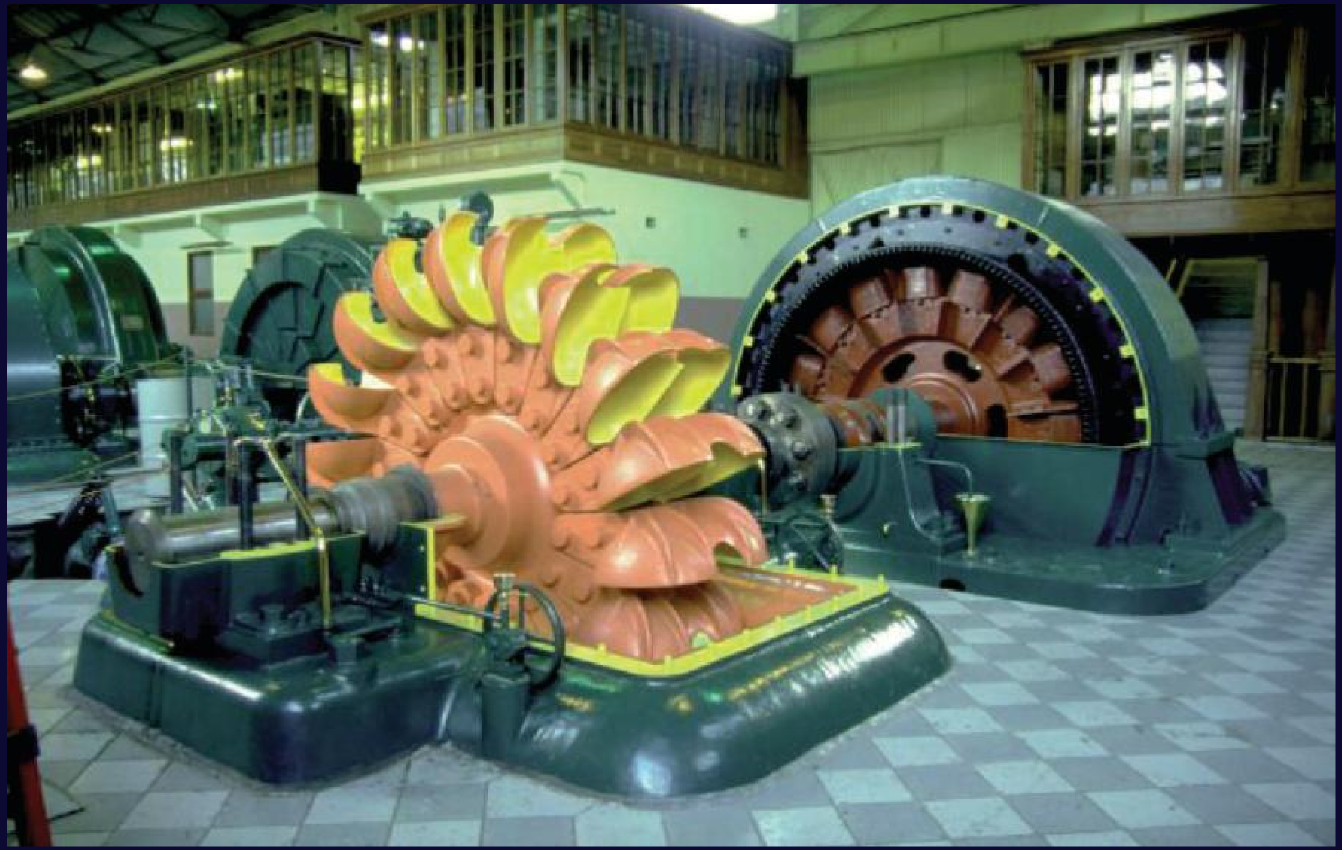
1.5.1 Impulse Turbines

Impulse turbines convert the **kinetic energy** of high-velocity water jets into mechanical rotation. Water pressure remains atmospheric before and after hitting the turbine.

a. Pelton Turbine

- Uses **one or more water jets** striking spoon-shaped buckets.
- Suitable for **high head** (H > 300 m) and **low discharge**.
- Common in mountain and high-dam regions.



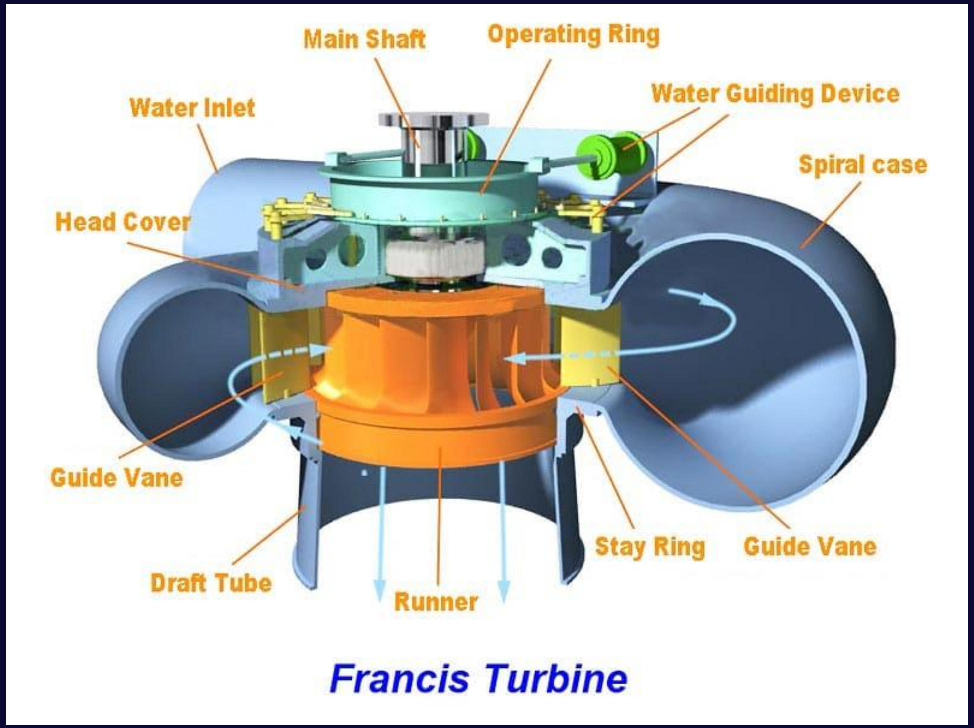


1.5.2 Reaction Turbines

Reaction turbines use both **pressure energy + kinetic energy**. Water flows through the turbine fully immersed and the pressure changes through the runner.

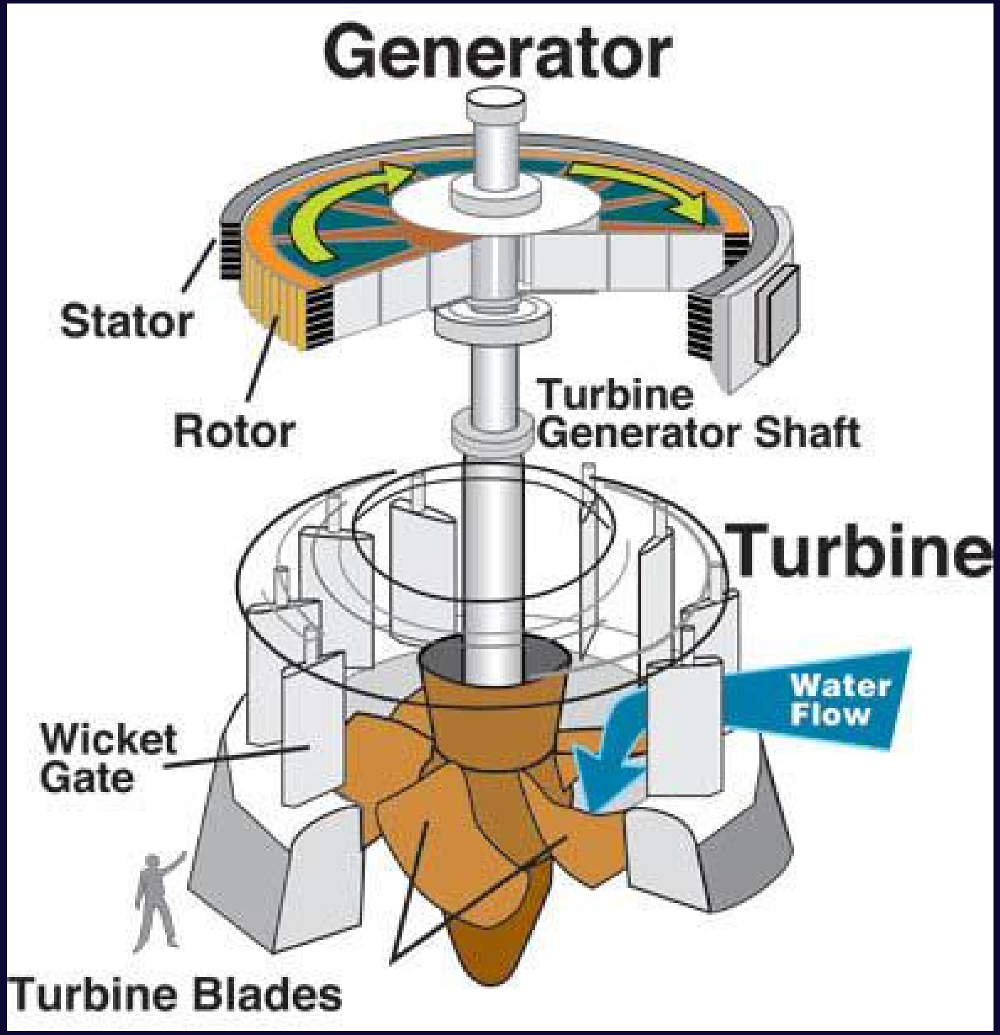
a. Francis Turbine

- Mixed-flow turbine (water enters radially and exits axially).
- Suitable for **medium head** (40–600 m).
- Most common turbine in hydropower plants.



b. Kaplan Turbine

- Axial-flow turbine with **adjustable blades**.
- Ideal for **low head** (H = 2–30 m) and **high discharge**.
- Very efficient over a wide range of flows.



1.6 Main hydroelectric power plant in Iraq

Station name	No. of Turbines	Manufacturer	Capacity (MW)	Turbine Type
Mosul (1986)	4x187.5MW	Toshiba - Japan	750	Frances
Haditha (1987)	6x110MW	Litostroj - Slovenia	660	Kaplan
Dokan (1979)	5x80MW	Power Machines - Russia	400	Frances
Darbandikhan (1961)	3x80MW	Mitsubishi - Japan	240	Frances

1.7 Turbine Design Ranges

Francis	Kaplan	Pelton
$40 < H < 600$	$2 < H < 30$	$50 < H < 1300$

H = head in meters

1.8 Hydro Power Calculations

Hydroelectric power plant is very efficient. It has overall efficiency ranges from 75-95%.

Typical losses are due to:

- Frictional drag and turbulence of flow
- Friction and magnetic losses in turbine & generator

The power developed by the plant is given by:

$$P = (g \times \rho \times H) \times \dot{V} \times \eta$$

Where:

- P = power in watts (W)
- g = gravitational acceleration (9.81 m/s^2)
- η = turbo-generator efficiency (0.75< η <0.95)
- $\dot{V}$ = quantity of water flowing (m^3/s)
- *H* = effective head (*m*)
- ρ=water density (1000 kg/m^3)

The Annual energy

$$E_{year} = P \times no\ of\ hours\ within\ one\ year$$

$$no\ of\ hours\ within\ one\ year = no\ of\ days\ in\ year \times no\ of\ hours\ in\ one\ day$$

$$no\ of\ hours\ within\ one\ year = 365 \times 24 = 8760$$

$$\therefore\ E_{year} = P \times 8760$$

Example

A mountain stream has an effective head of 26 m and a flow rate of 600 L/min. The hydroelectric plant that will harness this stream operates with an efficiency of 83%. Assume water density $\rho = 1000\ \text{kg/m}^3$ and gravitational acceleration $g = 9.81\ \text{m/s}^2$. Determine:

1. The electrical power output of the hydro plant.
2. The total electrical energy produced annually.
3. The approximate number of people whose annual energy needs (3000 kWh/person) can be met by this plant.

Given:

- Effective head H=26 m.
- Flow rate $\dot{V}$=600 L/min

$$\therefore\ \dot{V} = \frac{600}{1000} = 0.6\ m^3/min \ \ \rightarrow \dot{V} = \frac{0.6}{60} = 0.01\ m^3/s$$

- Efficiency η=83%.
- Density of water ρ=1000 kg/m^3
- Gravitational acceleration g=9.81 m/s^2
- Per person annual energy consumption = 3000 kWh/person

The Power generated

$$P = (\rho \times g \times H) \times \dot{V} \times \eta$$

$$P = (1000 \times 9.81 \times 26) \times 0.01 \times 0.83$$

$$P = 2117\ W \ \approx 2.117\ kW$$

Annual energy

$$E_{year} = P \times 8760$$

$$E_{year} = 2.117 \times 8760 = 18544.92\ kWh$$

Number of people supported

$$No\ of\ People = \frac{E_{year}}{E_{one\ people}} = \frac{18544.92}{3000} = 6.18 \approx 6\ People$$

1.9 Exercises

1

List the advantages and disadvantages of hydropower plants.

2

Explain briefly the factors which should be considered while selecting the site for hydropower plant.

3

List the essential elements of hydropower power plant.

4

What are the main types of hydraulic turbines? Briefly describe the working principle of each class and provide one example turbine for each.

Choose the Correct Answer (MCQ for Hydropower Plant)

1. Hydropower uses the energy of:

A) Steam
B) Oil
C) Water
D) Gas

2. Which of the following is an advantage of hydropower?

A) High maintenance cost
B) Short plant lifespan
C) Low operating cost
D) Fossil fuel dependency

3. The penstock in a hydro plant:

A) Houses the generator
B) Controls electricity flow
C) Carries water to the turbine
D) Measures rainfall

4. A surge tank is used to:

A) Increase generator efficiency
B) Cool the turbine
C) Prevent pressure surges
D) Store electricity

5. The ideal site for a hydro plant should have:

A) Forested land
B) Weak foundation rocks
C) Easy accessibility and high-water head
D) Remote deserts