



Overview of Solar Energy

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PDH: 6

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Module 3: Direct Solar Energy

Learning Objectives

By the end of this section, you will be able to:

- **Evaluate** the global and regional technical potential of various solar energy technologies for climate change mitigation.
- **Select** appropriate solar technologies—including PV, CSP, and thermal systems—based on specific energy service needs and environmental constraints.
- **Analyze** the integration challenges and opportunities for incorporating variable solar energy into existing power grids and industrial processes.

Executive Summary: Solar energy is the most abundant energy resource on Earth, with an intercept rate approximately 10,000 times greater than current global human energy consumption. While historically underutilized, rapid cost reductions and technological advancements in photovoltaics (PV) and concentrating solar power (CSP) are positioning direct solar energy as a primary driver for 2050 climate change mitigation scenarios.

Introduction to Solar Energy Applications

Solar energy conversion comprises a large family of technologies capable of delivering heat, cooling, natural lighting, electricity, and fuels.

Primary Energy Service Categories

- **Thermal Conversion:** Direct heating for domestic hot water (DHW), space heating, and industrial processes.
- **Electricity Generation:** Direct conversion via **Photovoltaic (PV)** cells or thermal-to-electric conversion via **Concentrating Solar Power (CSP)** plants.
- **Solar Fuels:** Production of energy carriers such as hydrogen or hydrocarbon fuels for transport and industry.
- **Passive Design:** Exploiting solar irradiance through architectural features to manage building temperature and lighting without mechanical assistance.

Assessment of Resource Potential

The solar resource is virtually inexhaustible and available in all regions, though local factors like land availability and meteorology dictate technical potential.

Design Fundamentals

- **Theoretical Potential:** Estimated at $3.9 * 10^6$ EJ/yr.

- **Global Irradiance Components:** The sum of **beam solar irradiance** (direct from the sun) and **diffuse irradiance** (scattered by the sky/clouds).
- **Solar Constant:** The irradiance outside the atmosphere is approximately $1,367 \text{ W/m}^2$; on a clear day at the Earth's surface, this is roughly $1,000 \text{ W/m}^2$.

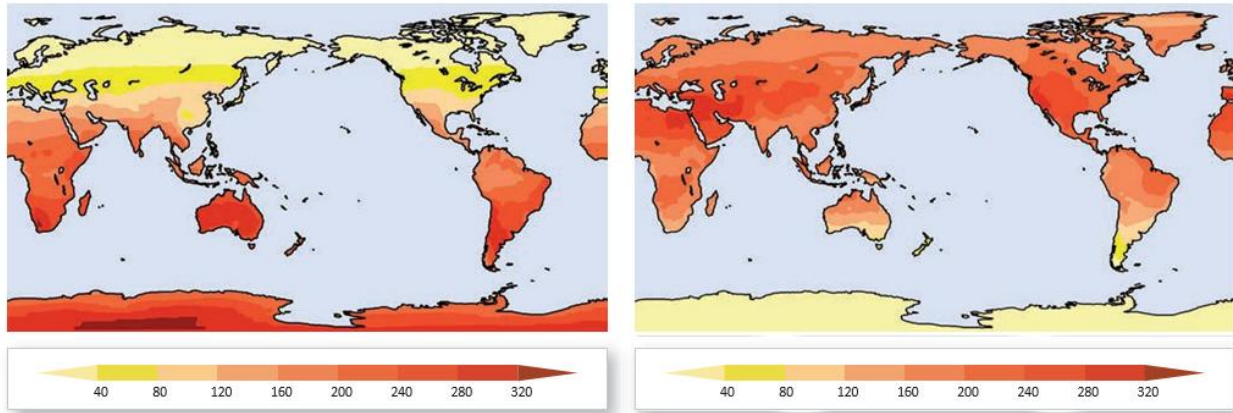


Figure 3.1: The global solar irradiance (W/m^2) at the Earth's surface obtained from satellite imaging radiometers and averaged over the period 1983 to 2006. Left panel: December, January, February. Right panel: June, July, August (ISCCP Data Products, 2006).

Table 3.1: Annual total technical potential of solar energy for various regions of the world, not differentiated by conversion technology (Rogner et al., 2000; their Table 5.19).

REGIONS	Range of Estimates	
	Minimum, EJ	Maximum, EJ
North America	181	7,410
Latin America and Caribbean	113	3,385
Western Europe	25	914
Central and Eastern Europe	4	154
Former Soviet Union	199	8,655
Middle East and North Africa	412	11,060
Sub-Saharan Africa	372	9,528
Pacific Asia	41	994
South Asia	39	1,339
Centrally planned Asia	116	4,135
Pacific OECD	73	2,263
TOTAL	1,575	49,837
<i>Ratio of technical potential to primary energy supply in 2008 (492 EJ)</i>	3.2	101

Note: Basic assumptions used in assessing minimum and maximum technical potentials of solar energy are given in Rogner et al. (2000):

- Annual minimum clear-sky irradiance relates to horizontal collector plane, and annual maximum clear-sky irradiance relates to two-axis-tracking collector plane; see Table 2.2 in WEC (1994). Maximum and minimum annual sky clearance assumed for the relevant latitudes; see Table 2.2 in WEC (1994).

💡 Design Tip: For CSP systems, select sites with a minimum Direct-Normal Irradiance (DNI) of $2,000 \text{ kWh/m}^2/\text{yr}$ to ensure technical and economic viability.

Table 3.2: International and national projects that collect, process and archive information on solar irradiance resources at the Earth’s surface

Available Data Sets	Responsible Institution/Agency
<i>Ground-based solar irradiance</i> from 1,280 sites for 1964 to 2009 provided by national meteorological services around the world.	World Radiation Data Centre, Saint Petersburg, Russian Federation (wrdc.mgo.rssi.ru)
<i>National Solar Radiation Database</i> that includes 1,454 ground locations for 1991 to 2005. The satellite-modelled solar data for 1998 to 2005 provided on 10-km grid. The hourly values of solar data can be used to determine solar resources for collectors.	National Renewable Energy Laboratory, USA (www.nrel.gov)
<i>European Solar Radiation Database</i> that includes measured solar radiation complemented with other meteorological data necessary for solar engineering. Satellite images from METEOSAT help in improving accuracy in spatial interpolation. Test Reference Years were also included.	Supported by Commission of the European Communities, National Weather Services and scientific institutions of the European countries
<i>The Solar Radiation Atlas of Africa</i> contains information on surface radiation over Europe, Asia Minor and Africa. Data covering 1985 to 1986 were derived from measurements by METEOSAT 2.	Supported by the Commission of the European Communities
<i>The solar data set for Africa</i> based on images from METEOSAT processed with the Heliosat-2 method covers the period 1985 to 2004 and is supplemented with ground-based solar irradiance.	Ecole des Mines de Paris, France
<i>Typical Meteorological Year (Test Reference Year)</i> data sets of hourly values of solar radiation and meteorological parameters derived from individual weather observations in long-term (up to 30 years) data sets to establish a typical year of hourly data. Used by designers of heating and cooling systems and large-scale solar thermal power plants.	National Renewable Energy Laboratory, USA. National Climatic Data Center, National Oceanic and Atmospheric Administration, USA. (www.ncdc.noaa.gov)
<i>The solar radiation data for solar energy applications.</i> IEA/SHC Task36 provides a wide range of users with information on solar radiation resources at Earth’s surface in easily accessible formats with understandable quality metrics. The task focuses on development, validation and access to solar resource information derived from surface- and satellite-based platforms.	International Energy Agency (IEA) Solar Heating and Cooling Programme (SHC). (swera.unep.net)
<i>Solar and Wind Energy Resource Assessment (SWERA)</i> project aimed at developing information tools to simulate RE development. SWERA provides easy access to high-quality RE resource information and data for users. Covered major areas of 13 developing countries in Latin America, the Caribbean, Africa and Asia. SWERA produced a range of solar data sets and maps at better spatial scales of resolution than previously available using satellite- and ground-based observations.	Global Environment Facility-sponsored project. United Nations Environment Programme (swera.unep.net)

Technology and Applications

Passive Solar and Daylighting

Passive technologies redistribute absorbed solar gains through radiation, conduction, and convection without mechanical elements like fans.

Core Components

- **Direct-Gain Systems:** Utilizing windows and thermal mass (concrete, brick, or phase-change materials) to store energy.
- **Indirect-Gain Systems:** Such as **Trombe walls**, where thermal mass is placed directly behind glazing.
- **Daylighting:** Utilizing light wells, tall windows, and task lighting to reduce artificial lighting demand.

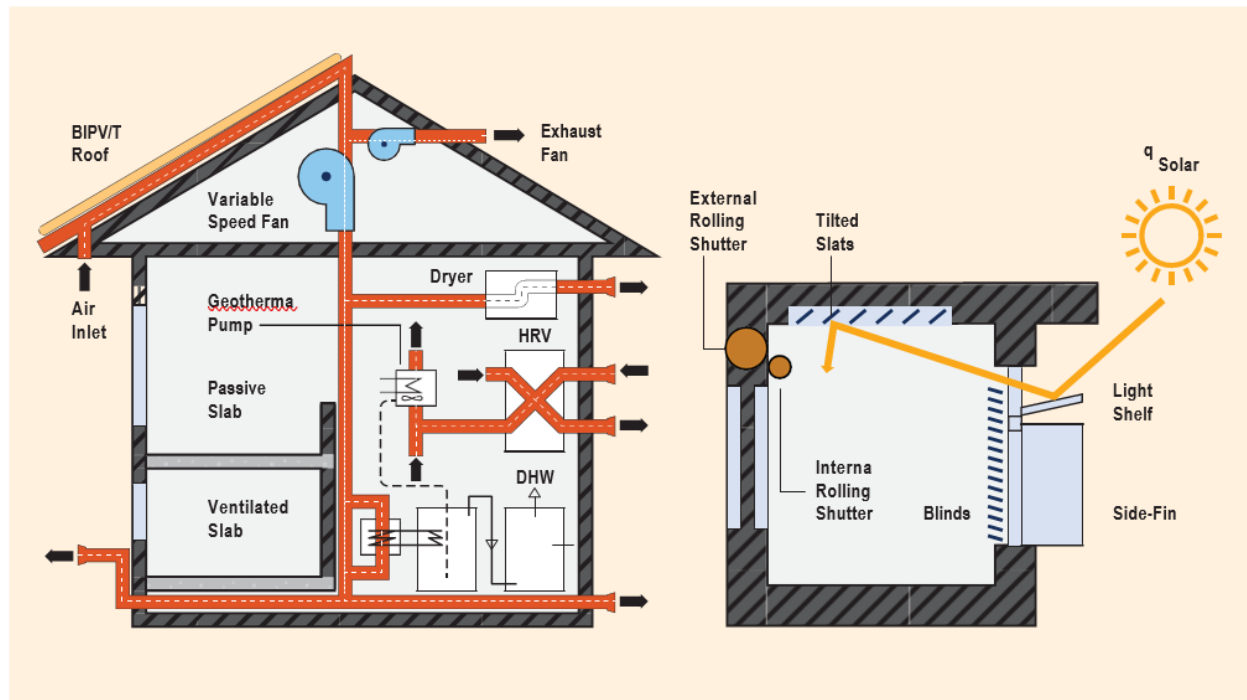


Figure 3.2: Left: Schematic of thermal mass placement and passive-active systems in a house; solar-heated air from building-integrated photovoltaic/thermal (BIPV/T) roof heats ventilated slab or domestic hot water (DHW) through heat exchanger; HRV is heat recovery ventilator. Right: Schematic of several daylighting concepts designed to redistribute daylight into the office interior space (Athienitis, 2008).

⚠ **Safety Constraint:** Effective solar-gain control (shading) must be employed in solar buildings to prevent summer overheating and visual discomfort from glare.

Active Solar Heating and Cooling

Active systems use mechanical elements (pumps, fans) and collectors to transfer heat via carrier fluids (water, air, or glycol).

Collector Types

- **Flat-Plate Collectors:** Common for residential water and space heating.
- **Evacuated-Tube Collectors:** Achieve higher temperatures (up to industrial grades) by minimizing convection losses through a vacuum.
- **Unglazed Collectors:** Typically used for low-temperature applications like swimming pool heating.

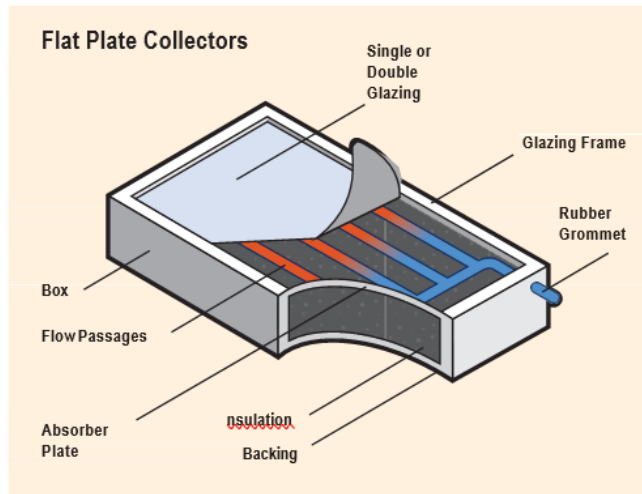


Figure 3.3a: Schematic diagram of thermal solar collectors: Glazed flat-plate.

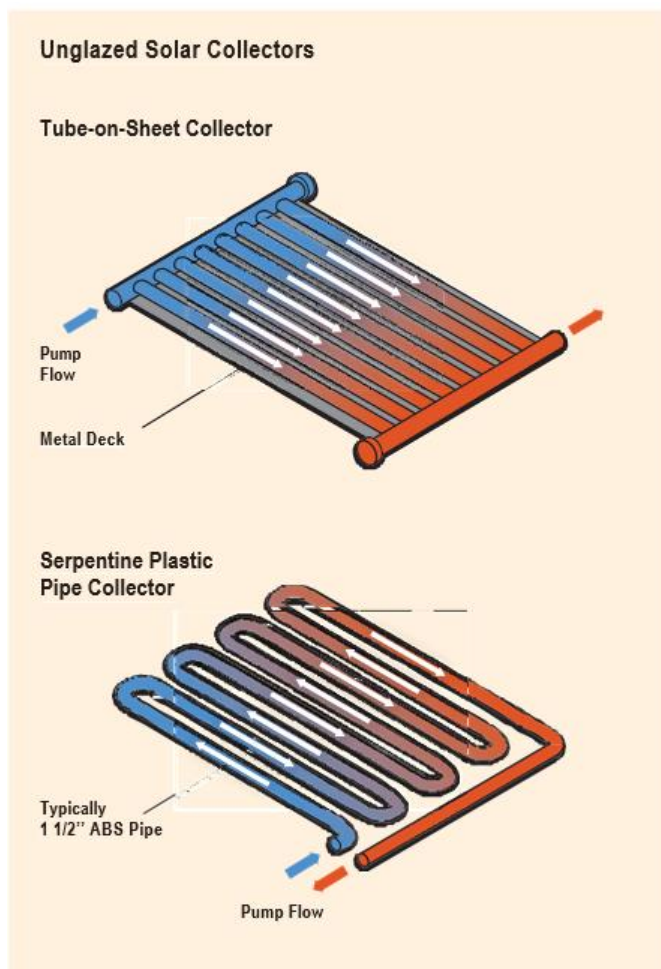


Figure 3.3b: Schematic diagram of thermal solar collectors: Unglazed tube-on-sheet and serpentine plastic pipe.



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