Course title: Solar technologies			
Course code: ENR 151	**No. of credits:** 4	**L-T-P:** 55-2-6	**Learning hours:** 63
Pre-requisite course code and title (if any): NA			
Department: Department of Energy and Environment			
Course coordinator: Dr. Som Mondal	**Course instructor(s):** Dr. Som Mondal / Dr. Aviruch Bhatia / Prof. S. C. Mullick		
Contact details: som.mondal@terisas.ac.in			
Course type: Core	**Course offered in:** Semester 2		

Course description

Solar energy, most abundant and freely available natural energy resources, is used for various applications including space heating, cooling, lighting, process heat for industrial purposes and also electricity generation through PV system and steam power plant. This course covers the basics of conversion technologies, system designing techniques and the methods of direct use of solar energy in daily life. The course has three parts. Part A deals with physics and technology of PV materials, devices, systems design and applications. Part B deals with Solar Thermal collector technologies, storage and applications. Finally, under Part C, the method for harnessing solar energy through passive architecture is covered.

Course objectives

The objective of the course is to develop in-depth understanding of various technologies and applications to harness solar energy through active conversion methods such as photovoltaic & thermal and integration of passive architectures in building.

Course contents

Module	Topic	L	T	P
	Part-A: Solar Photovoltaic Technology (1.5 Credit)			
1	**Physics of solar cells** Crystal structure, band theory, energy band diagrams, Fermi level, intrinsic and extrinsic semiconductor, doping, n-type and p-type silicon, p-n junctions, drift and diffusion current, absorption of radiation and excess minority carriers, generation, recombination and carrier separation Standard solar cell structure, I-V characteristics, FF, Voc, Isc, Pmax, conversion efficiency, losses in solar cell, Rs, Rsh, impact of radiation and temperature, PC1D simulation of industrial solar cell structure Concepts of heterojunctions, multi junction and concentrated solar cell, Introduction to advanced softwares used in solar cell simulation	5	2	0
2	**Solar PV module technologies** ***First generation: Silicon wafer based technology:*** Materials and process requirements for solar cell fabrication, process flow, process control measures, quality control techniques Single and poly crystalline silicon solar cells, Materials and process requirements for module assembly, routine and type tests, qualification test standards, types of degradation. ***Second generation: Thin film technologies:*** Merits and demerits of thin film technologies, amorphous-Si, CdTe and CIGS solar cell module, manufacturing steps ***Third generation/emerging PV technologies:***Organic PV, Dye sensitized PV, Quantum-dot, Hot-carrier, Up conversion and down conversion Latest benchmark efficiencies – laboratory and manufacturing, New technologies in market – PERC, Bifacial, TOPCON, Half-cut cell etc.	7	0	2
3	**Solar PV systems** Balance of System (BoS) components: battery, PCU (charge controller, inverter, data logger), transformer, cables and connectors, switches/circuit breakers, energy meters, bypass and blocking diodes Types of PV systems: Standalone, grid-connected, hybrid, rooftop business models – CAPEX and RESCO, canal top, floating PV system	4	0	4

	System design: SPV system design guideline and methodologies, introduction to PVSyst, designing of standalone/grid-connected PV systems for domestic/commercial use			
4	**Solar PV applications** Lighting, agriculture, refrigeration, telecommunications, space, BIPV, fencing, water purification, navigation, defence, offshore, etc.	2	0	0
	Part –B: Solar Thermal Technology (1.5 Credit)			
5	**Solar Radiation review** Solar radiation on the collector, Liu & Jordan relation	2	0	0
6	**Solar Thermal collectors** ***Non concentrating collectors*** Flat plate collectors: general design features and characteristics, materials. Unglazed, Single and double glazed solar collectors, Optical losses and thermal losses, thermal analysis and performance characteristics. Design of water and air heating collectors: their specific features. Short term and long term performance (utilizability) Evacuated tube collectors: general design features, characteristics, materials, thermal analysis Thermo siphon system and forced convection system, Concentrating solar collectors: General description; concentrators, receivers, Orienting/tracking requirements, Materials General characteristics Optical features of solar concentrators: II Law of thermodynamics for solar concentrators. Optical and thermal losses, Thermal performance characteristics parabolic trough collectors (PTC), Parabolloid dish collectors, Scheffler dish, Linear Fresnel Reflector Collector	12	0	0
7	**Application** Solar hot water/steam systems, Solar cookers: box type, dish type and others; dryers; desalination systems; absorption cooling; furnace, Process heating systems, community cooking system Power generation: Concentrator based system, Fresnel system, central tower, distributed line focus and point focus systems, Hybrid solar thermal	4	0	0
8	**Energy Storage** Sensible heat storage, latent heat storage (PCM), thermo-chemical storage Organic & inorganic PCMs, properties, characterization Applications in power generation, green building, cooking, cold storage, transportation, district heating & cooling, salinity gradient solar pond	3	0	0
	Part –C: Passive Architecture (1 Credit)			
9	**Climate and human thermal comfort** Factors affecting climate; climatic zones and their characteristics; urban climate; microclimate; implications of climate on building design; principles of energy conscious design, Building materials, embodied energy of building materials, alternative building materials	5	0	0
10	**Thermal performance of buildings** ***Heat Transfer*** Conduction, convection, radiation; evaporation; solar radiation; radiation on tilted surfaces; unshaded surface; shaded surface; simplified method for performance estimation	3	0	0
11	**Passive concepts for heating and cooling** ***Passive heating:*** direct gain, indirect gain, thermal storage wall, roof top collectors, isolated gain, solarium	4	0	0

	Passive cooling**:** nocturnal cooling, evaporative cooling, roof surface evaporative cooling (RSEC), direct evaporative cooling using drip-type (desert) coolers, nocturnal radiation cooling, earth coupling, ***Daylighting:*** basic principles and systems			
12	**Rating systems of energy efficient buildings** LEED, GRIHA, IGBC rating system for existing and new building	4	0	0
		55	**2**	**6**

Evaluation criteria

- Assignments: 30% (after Module 2, module 7 and 12)
- Written Test 1: 15% (after completion of Module 1, 2, 9, 10)
- Written Test 2: 15% (after completion of Module 3, 5, 6 and 11)
- Written Test 3: 40% (after completion of module 4, 7, 8, 12)

Learning outcomes

After completing this course students will be able to:

- Understand the physics and technology of solar PV, solar thermal and passive architecture (Test 1,2)
- Apply system design approaches for various application of solar PV and thermal technologies (Test 2,3 and assignments)
- Design and integrate the concepts of passive architecture in existing and new buildings (Test 2 and 3)

Pedagogical approach

A combination of class-room interactions, practicals/simulation, assignments

Recommended readings

Text Books

Renewable Energy Engineering and Technology – A Knowledge Compendium, ed. VVN Kishore (TERI Press, 2008).
CS Solanki: Solar Photovotaics – Fundamentals, Technologies and Applications, Third Ed (PHI Learning, 2015)

Reference Books

SM Sze, Kwok K Ng: Physics of semiconductor devices, third edition (John Wiley & Sons, 2007)
MA Green: Solar Cells Operating Principles, Technology, and System Applications (Prentice-Hall, 1981)
MA Green:High Efficiency Silicon Solar Cells (Trans Tech Publications, 1987)
SJ Fonash: Solar Cell Device Physics (Academic Press, 1982)
Handbook of photovoltaic science and engineering, ed. Antonio Luque and Steven Hegedus (John Wiley and Sons, 2011)
Anna Mani, S Rangarajan: Handbook of Solar Radiation Data for India, (Allied Publishers, 1980)
Richard C Neville, RC Neville, Bas Van Der Hoek: Solar Energy Conversion: The Solar Cell (Elsevier Science & Technology, 1995)
Peter Würfel : Physics of Solar Cells: From Basic Principles to Advanced Concepts (Wiley-VCH, 2009)
JF Kreider and F Kreith: Solar Heating and Cooling: Active and Passive Design (Hemisphere Publishing Corporation, 1982)
Low Temperature Engineering Application of Solar Energy, ed. RC Jordan (ASHRAE, 2004)
HP Garg and J Prakash: Solar Energy: Fundamentals and Applications (Tata McGraw Hill, 1997)
AB Meinel & MP Meinel: Applied Solar Energy: An Introduction (Addison)1976
JA Duffie and WA Beckman: Solar Engineering of Thermal Processes, Third Edition (John Wiley & Sons, 2013)
S Sukhatme and J Nayak: Solar Energy: Principles of Thermal Collection and Storage, Third Edition (Tata McGraw Hill, 2008)

Additional information (if any)

Student responsibilities

Attendance, feedback, discipline: as per university rules.

Course reviewers

1. Dr. O S Sastry, Consultant, ISA, NISE Campus, Gurgaon
2. Dr. A K Saxena, Addl. GM & Head, BHEL Gwalpahari
3. Prof. J K Nayak, IIT Bombay
4. Mr. S K Singh, DG-NISE, Gurgaon