Master of Technology

In

Mechanical Engineering (Energy Technology)

Course Structure & Syllabus

Department of Mechanical Engineering

National Institute of Technology Hamirpur

Hamirpur (HP) – 177005, India

Course Structure of M. Tech. Mechanical Engineering (Energy Technology)

SEMESTER-I

Sr. No.	Course No.	Course Name	Teaching Schedule			Hours/ Week	Credit
			L	T	P		
1.	ME-671	Materials & Fabrication Techniques for Energy Systems	4	0	0	4	4
2.	ME-672	Solar Energy Technology & Systems	4	0	0	4	4
3.	ME-673	Hydrogen Energy & Fuel Cells	4	0	0	4	4
4.	ME-7MN	Programme Elective I	4	0	0	4	4
5.	ME-7MN	Programme Elective II	4	0	0	4	4
6.	ME-674	Energy Lab-I	0	0	4	4	2
Total			**20**	**0**	**4**	**24**	**22**

Programme Elective-I & II: List of Programme Electives is given in the Annexure.

SEMESTER-II

Sr. No.	Course No.	Course Name	Teaching Schedule			Hours/ Week	Credit
			L	T	P		
1.	ME-681	Wind & Small Hydro Energy Systems	4	0	0	4	4
2.	EE-682	Grid Integration of Renewable Energy	4	0	0	4	4
3.	ME-683	Bio-Energy Technology & Systems	4	0	0	4	4
4.	ME-7MN	Programme Elective III	4	0	0	4	4
5.	ME-7MN	Programme Elective IV	4	0	0	4	4
6.	ME-684	Energy Lab-II	0	0	4	4	2
Total			**20**	**0**	**4**	**24**	**22**

Programme Elective-III & IV: List of Programme Electives is given in the Annexure.

SEMESTER-III

Sr. No.	Course No.	Course Name	Hours/Week	Credit
1.	ME- 800	M. Tech. Dissertation	--	20
Total			**--**	**20**

SEMESTER-IV

Sr. No.	Course No.	Course Name	Hours/Week	Credit
1.	ME- 800	M. Tech. Dissertation	--	20
Total			**--**	**20**

Total Credit of the Programme = 84

Annexure

List of Programme Electives

Programme Elective-I

ME-771	Instrumentation & Control for Energy Systems
ME-772	Modeling & Simulation of Energy Systems
ME-773	Optimization Techniques for Energy Systems

Programme Elective-II

ME-776	Energy Efficiency, Audit & Management
ME-777	Energy Policy Analysis
ME-778	Economics & Planning of Energy Systems

Programme Elective-III

ME-781	Fuels & Combustion
ME-782	Energy Conservation & Waste Heat Recovery
ME-783	Nuclear Energy Systems

Programme Elective-IV

ME- 786	Integrated Energy Systems
ME- 787	Energy Storage Systems
ME- 788	Solar Architecture

Course Name: **Materials & Fabrication Techniques for Energy Systems**
Course Code: **ME-671**
Course type: **Core**

Contact Hours/Week: **4L** | Course Credits: **04**

Course Objectives

- To understand the concept of materials for energy harvesting.
- To analyse the material design, related to photovoltaic cell and energy storage
- To understand fabrication techniques of materials used in energy applications.

COURSE CONTENT

Material Properties: Properties and characteristics of materials, Mechanical properties, Electrical properties, Optical properties, Luminescence, Photoconductivity, Selective surfaces, Glazing materials, Types of insulation and properties, Reflecting surfaces and transparent materials, Microstructure.

Materials for Energy Harvesting: Solar cells, Nuclear materials, Composites for wind energy, Thermo-electrics, Piezo-electric materials, Ferro-electric materials, Smart materials.

Materials For Energy Transformation: Polymer membranes for fuel cells, PEM fuel cell, Acid/alkaline fuel cells, Light emitting diodes, Turbines.

Materials and Fabrication Techniques of Energy Storage: Characteristics and types of battery materials, Fabrication techniques for lead acid battery, Lithium ion battery, Metal hydride battery, Fabrication of carbon nano-tubes (CNT) and its application for hydrogen storage, CNT-polymer composites, Ultra-capacitors, Sensible storage material, Phase change material.

Fabrication Techniques: Refining of solar grade Si, Cell fabrication and metallization techniques, Electronic and Solar grade Silicon, Production of single crystal Silicon, Procedure of masking, Photolithography and etching, Method of doping and junction fabrication, Fabrication of GaAs (Gallium Arsenide) and In-P (Indium phosphide) solar cell.

Materials and Techniques of Deposition and Coating: Characteristics of materials used for deposition and coating, Deposition techniques, Physical vapour deposition (PVD), Chemical vapour deposition (CVD), Plasma enhanced CVD (PECVD), Hot wire CVD (HWCVD), Coating techniques, Diffusion, Oxidation, Photolithography, Sputtering.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Understand the materials used for energy appliances.

CO2: Apply the concepts of materials required for energy storage and energy generation.

Text/Reference Books

1. Materials Science and Engineering: An Introduction by W Callister, John Wiley & Sons
2. Solar Photovoltaics, Fundamentals, Technologies and Applications by C. S. Solanki, PHI.
3. Chemical and Electrochemical Energy System by R. Narayan and B. Viswanathan, Universities Press
4. Energy Storage Systems by B. Kilkis and S. Kakac, K. A. P. London.
5. Fundamentals of Materials for Energy and Environmental Sustainability by D S Ginley and D Cahen, Cambridge University Press

Course Name: **Solar Energy Technology & Systems**
Course Code: **ME-672**
Course Type: **Core**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To impart knowledge about the concepts of Photovoltaic system.
- To impart knowledge on solar collector system.
- To impart knowledge on different solar thermal systems.

COURSE CONTENT

Introduction and Solar Radiation: Methodologies for solar thermal conversion system, Solar thermal power plant, Economics of solar processes, Solar radiation, Radiation geometry, Solar time, Sun earth angles, Sun path diagram, Sunshine hours, Measurement of solar diffuse, Global and direct solar radiation, Equipment's, Estimation of solar radiation on horizontal and tilted surfaces, Solar radiation data analysis.

Solar Cells: Fundamentals of semiconductor physics, Doping, Interaction of light and semiconductors, P-N junction, Function of solar cell, Equivalent circuit of solar cell, Analysis of PV cells, Dark and illumination characteristics, Efficiency limits, Variation of efficiency with band-gap and temperature, Efficiency measurements, High efficiency cells, Recent developments in solar cells, Solar modules, Photo-voltaic system technology.

Solar photovoltaic system: PV system design, Array design, PV system installation, Operation and maintenance, Balance of PV system (BOS), Issues and challenges of PV system operation and maintenance, Factor affecting the PV system performance, Performance measurements and characterization of PV power plant, Stand alone, Hybrid and grid connected system, Grid connected PV system design and optimization, Rooftop PV systems, Net and Feed-in- tariff mechanism, Energy generation analysis, Power control and management systems for grid integration, Issues and challenges of grid integrated PV system, PV system simulation tools, National solar energy mission.

Solar Thermal Collectors: Liquid flat collector, Energy balance for flat plate collectors, Overall heat loss coefficient, Heat transfer between parallel surfaces, Testing methods, Types of flat plate collectors, Liquid and air flat plate collectors, Focusing collectors, Types of focusing collectors, Thermal analysis, Evacuated tube collectors, Tracking system, Design of solar heating system.

Solar Thermal Systems and Design: Solar Refrigeration system, Solar air-conditioning system, Solar cookers, Solar pond, Solar drying, Solar desalination, Solar greenhouse technology, Design and sizing of solar heating systems, F–chart method.

Course Outcomes

Upon successful completion of course, the students will be able to
CO1: Apply the concepts of photovoltaics for solar energy applications.
CO2: Estimate the choice of solar collector for a given application.
CO3: Evaluate and analyze the performance of solar thermal system by utilizing suitable method.

Text/Reference Books

1. Solar Energy: Fundamentals and Applications by Garg, J Prakash, Tata McGraw Hill, New Delhi.
2. Solar Photovoltaics. Fundamental Technologies and Application by Chetan Singh Solanki, PHI Publication.
3. Solar Engineering of Thermal Processes by JA Duffie and WA Beckman, John Wiley.
4. Solar Energy Engineering by S. A. Kalogirou, Academic Press.
5. Principles of Solar Engineering by D Yogi Goswami, CRC Press.

Course Name: **Hydrogen Energy & Fuel Cells**
Course Code: **ME-673**
Course Type: **Core**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To impart comprehensive and logical knowledge of hydrogen production, storage and utilization.
- To impart the knowledge of various fuel cell technologies.

COURSE CONTENT

Introduction: Properties of hydrogen as fuel, General introduction to infrastructure requirement for hydrogen production, Storage, Dispensing and utilization, Fundamentals and classification of fuel cells, Thermodynamic efficiency.

Hydrogen Energy Production: Thermal-steam reformation, Thermo-chemical water splitting, Gasification-pyrolysis, Nuclear thermal catalytic, Partial oxidation methods, Electrochemical-Electrolysis, Photo electro chemical, Biological-anaerobic digestion, Fermentation micro-organism, PEM based electrolysis.

Hydrogen Storage, Utilization and Safety: Physical and chemical properties, General storage methods, Compressed storage-composite cylinders, Glass micro sphere storage, Zeolites, Metal hydride storage, Chemical hydride storage, Cryogenic storage, Carbon based materials for hydrogen storage, Overview of hydrogen utilization, Hydrogen burners, Power plant, Marine applications, Hydrogen dual fuel engines, Hydrogen safety aspects, Backfire, Pre-ignition, Hydrogen emission, NOx control techniques and strategies, Hydrogen powered vehicles.

Fuel cells: Working principle, Thermodynamics and kinetics of fuel cell process, Performance evaluation of fuel cell, Comparison on battery vs fuel cell, Types of fuel cells: AFC, PAFC, SOFC, MCFC, DMFC, PEMFC, Microbial fuel cells, Relative merits and demerits.

Fuel Cell Operation & Application of Systems: Supply of fuel, Electrical arrangement, Removal of products, Materials for battery construction, Production and purification of fuels. Large scale power generation, Power plant for vehicles, Domestic power, Fuel cell economics, Future trends in fuel cells.

Course Outcomes

Upon successful completion of course, the students will be able to
CO1: To evaluate the performance of fuel cells under different operating conditions.
CO2: Design and develop suitable hydrogen storage system to be used along with fuel cell system.
CO3: To understand environmental hazards associated with the use of hydrogen energy technology.

Text/Reference Books

1. Hydrogen and Fuel Cells: Emerging Technologies and Applications by Bent Sorenson, Academic Press.
2. Hydrogen and Fuel Cells: Advances in Transportation and Power by MF Hordeski, The Fairmont Press.
3. Hydrogen Fuel: Production, Transport, and Storage by Ram B. Gupta, CRC Press.
4. Hydrogen and Fuel Cell: Technologies and Market Perspectives by Johannes Topler**,** Jochen Lehmann, Springer**.**
5. Hydrogen and Fuel Cells: A Comprehensive Guide by RL Busby, Penn Well Books.

Course Name: **Energy Lab-I**
Course Code: **ME-674**
Course Type: **Practical**

Contact Hours/Week: **4P** Course Credits: **02**

Course Objectives

- To learn the practical applicability of the theoretical concepts of Solar Energy.
- To understand various types of properties of materials used for energy applications.

COURSE CONTENT

List of Experiments:

1. To investigate the current-voltage and power-voltage characteristics of solar PV module for series and parallel combination of PV modules using module testing kit.
2. To examine the effect of variation in the tilt angle of PV module on power generation.
3. Evaluation of thermal performance of solar water heater with flat plate collector in thermo-syphon mode of flow with fixed input parameters.
4. Evaluation of thermal performance of solar water heater at different radiation levels with fixed other input parameters.
5. To study the characteristics of solar PV module under standard test condition using Sun Simulator.
6. Measurement of solar radiation and sunshine hours in terms of hourly value of global and diffuse radiation incident on a horizontal surface on a clear day using shaded and unshaded pyranometers/energy meters.
7. Calibration of given thermocouple / RTD with the help of reference Platinum Resistance Thermometer (PRT) and dry calibration bath.
8. To estimate solar thermal efficiency of parabolic dish collector.
9. Study of concentrated solar power (CSP) plant using thermal energy storage.
10. Study of solar assisted solid and liquid desiccant cooling system.
11. Experimental study of mechanical property of material used for energy application.
12. Experimental study of electrical property of material used for energy application.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: To carry out performance analysis of solar thermal system at different input parameters.
CO2: To understand the working principle of solar photovoltaic cell / module.
CO3: To understand the mechanical and electrical properties of material used for energy application.

Books and References

1. Principles of Solar Energy Collection and Storage by S. P. Sukhatme, Tata McGraw Hill Pub.
2. Solar Photovoltaics: Fundamentals, Technologies and applications by C. S. Solanki, PHI Pub.
3. Solar Engineering of Thermal Processes by JA Duffie and WA Beckman, John Wiley.

Course Name: **Wind & Small Hydro Energy Systems**
Course Code: **ME-681**
Course Type: **Core**

Contact Hours/Week: **4L** | Course Credits: **04**

Course Objectives

- To impart knowledge about the concept and basics of wind energy.
- To impart knowledge of aerodynamic theories and design considerations of wind turbine.
- To impart knowledge on small hydro power systems.

COURSE CONTENT

Wind Energy Basics: Potential of wind power in India**,** Atmospheric circulations, Classifications, Factors influencing wind, Wind shear, Turbulence, Wind resource assessment, Weibull distribution, Wind energy conversion systems, Classification, HAWT, VAWT, Components of wind turbine, Controlling of wind turbine, Wind turbine electric generator.

Aerodynamic Theories of Wind Turbine: Axial momentum theory, Power coefficient, Axial momentum theory considering wake rotation, Blade element theory, Combined blade element momentum theory.

Wind Turbine Design Considerations: Overview, Design procedure, Wind turbine topologies, Machine elements, Wind turbine loads, Wind turbine subsystems and components, Design evaluation, Power curve prediction.

Small Hydro Power Systems: Essential elements of hydroelectric power plant, Environmental issues related to large hydro projects, Potential of hydropower in India, Site selection for small hydro power, Classification of Small hydro power.

Hydraulic Component Design: Impact of jet, Classification of hydraulic turbines, Velocity triangles, Euler's equation of turbomachine, Similarity laws of hydraulic turbines, Design calculation of Francis, Kaplan and Pelton turbines, Performance characteristics of impulse and reaction turbines, Turbines for small hydro power, Types of gate, Gate design, Governors.

Course Outcomes

Upon successful completion of the course, the student will be able to

CO1: Students will be able to understand the basic of wind energy conversion systems.

CO2: Students will be able to understand the principle of aerodynamic theories and design consideration of wind turbine.

CO3: Students will be able to understand the overview of small hydro power systems.

CO4: Students will be able to understand the principle of hydraulic turbine for small hydro application.

Text/Reference Books

1. Wind Energy Explained – Theory, Design and Application by J. F. Manwell, J. G. McGowan and A. L. Rogers, John Wiley & Sons.
2. Guide on How to Develop a Small Hydropower Plant by M. Laguna, ESHA.
3. Hydraulic Machines by K. Subramanya, TMH.
4. Introduction to Hydro Energy Systems: Basics, Technology and Operation by H. Wagner and J. Mathur, Springer.
5. Micro-Hydro Design Manual: A Guide to Small-Scale Water Power Schemes by A. Harvey, A. Brown and P. Hettiarachi, ITDG.

Course Name: **Grid Integration of Renewable Energy**
Course Code: **EE-682**
Course Type: **Core**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To understand the requirements for the correct integration of renewable energies into the power grid.
- To understand power electronic components necessary for energy production.
- To study the distributed generation systems.

COURSE CONTENT

Power system operation: Introduction on electric grid, Supply guarantees, Power quality and stability, Introduction to renewable energy grid integration, Concept of mini/micro grids and smart grids, Wind, Solar, Biomass, Power generation profiles, Load scheduling.

Power Electronics: Introduction to basic analysis and operation techniques on power electronic systems, Functional analysis of power converters, Power conversion schemes between electric machines and the grid, Power systems control using power converters, Electronic conversion systems application to renewable energy generation systems, Basic schemes and functional advantages, Wind power and photovoltaic power applications.

Power Quality Improvement in Grid Integration: Power control and management systems for grid integration, Detection systems, Synchronizing with the grid, Issues in integration of converter based sources, Network voltage management, Power quality management and frequency management, Influence of PV/WECS on system transient response.

Simulation tools: Simulation of grid connected / off grid renewable energy system (PV/WECS), Design of grid-interactive photovoltaic systems for house hold applications.

Course Outcomes

Upon successful completion of course, the students will be able to
CO1: Apply the concepts of grid integration using renewable energy sources.
CO2: Apply to use simulation tools in renewable energy system design.
CO3: Apply the concept of power electronics.

Text/Reference Books

1. Distribution System Modeling and Analysis by W H Kersting Second Edition, CRC Press
2. Grid Integration and Dynamic Impact of Wind Energy by V Vittal and R Ayyanar, Springer
3. Design of Smart Power Grid Renewable Energy Systems by A Keyhani Wiley–IEEE Press
4. Grid Converters for Photovoltaic and Wind Power Systems by R Teodorescu, M Liserre and P Rodriguez, Wiley-IEEE Press
5. Power Electronics: Circuits, Devices and Applications by H R Muhammad, Pearson

Course Name: **Bio-Energy Technology & Systems**
Course Code: **ME-683**
Course Type: **Core**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To impart the knowledge of the processes for converting biomass feed-stocks to fuels by various approaches.
- To impart technical and economic feasibility and sustainability of energy production from biomass.

COURSE CONTENT

Biomass resources and biomass properties: Biomass definition, Classification, Availability and estimation, Consumption and surplus biomass, Energy plantations, Potential of biomass and assessment.

Thermo-chemical conversion: Direct combustion, Incineration, Pyrolysis and gasification, Biomass stoves, Improved chulha and its design, Design, construction and operation of biomass combustors including incinerators, Biomass fired boilers and types, Biomass pyrolysis types, Manufacture of charcoal, Manufacture of pyrolytic oils and gases, Design, Construction and operation of pyrolysis units, Biomass gasification types, Gasifier burner arrangement for thermal heating, Gasifier engine arrangement for electrical power, Design, Construction and operation of gasifiers.

Biological & Chemical conversion: Biodegradation and biodegradability of substrate, Biochemistry and process parameters of bio-methanation, Biogas digester types, Digester design and biogas utilization, Chemical kinetics and mathematical modeling of bio-methanation process, Economics of biogas plant with their environmental and social impacts, Bioconversion of substrates into alcohol, Production of methanol & ethanol, Organic acids, Solvents, Amino acids, Hydrolysis and hydrogenation, Solvent extraction of hydrocarbons, Bioethanol, Chemicals from biomass.

Biodiesel: History, Production methods of Biodiesel, Transesterification, Fuel quality, Standards and properties, Availability of raw materials for biodiesel, Applications, Biodiesel potential in India.

Waste to Energy: Introduction to Energy from waste, Classification of waste as fuel, Agro based, Forest residue, Industrial waste, Conversion devices, Incinerators, Gasifiers, Digesters, Environmental monitoring system for land fill gases, Environmental impacts, Measures to mitigate environmental effects due to

Course Outcomes

Upon successful completion of course, the students will be able to

CO1: To understand and assess the biomass resource, appropriate conversion technology for the given biomass resource and its use.

CO2: To evaluate the cost-benefit of various biomass energy conversion processes.

CO3: To identify remedies / potential solutions to the supply and environmental issues associated with biomass based energy resources.

Text/Reference Books

1. Introduction to Biomass Energy Conversion by S Capareda, CRC Press.
2. Solar Thermal and Biomass Energy by G Lorenzini and C Biserni, WIT Press.
3. Thermo-Chemical Processing of Biomass: Conversion into Fuels, Chemicals and Power by RC Brown and C Stevens, Wiley and Sons.
4. Bioenergy Technology and Engineering by Zhang Bailiang, ASI Ltd.
5. Biofuel and Bioenergy Technology by Wei-Hsin Chen, Keat Teong Lee, MDPI AG.

Course Name: **Energy Lab-II**
Course Code: **ME-684**
Course Type: **Practical**

Contact Hours/Week: **4P** | Course Credits: **02**

Course Objectives

- To develop experimental skills for energy related measurements and experiments.
- To understand the practical utilities of the different theories of energy components and system.
- To develop the skill for using different simulation software for energy system performance analysis.

COURSE CONTENT

List of Experiments:

1. To study the performance and working of Solar-Wind hybrid system.
2. Wind shear analysis for electrical power generation by a wind turbine.
3. To study the performance of Hydrogen Fuel Cell.
4. To calculate the moisture percentage and ash percentage in a sample of biomass.
5. To measure the properties of fuel.
6. Overview and system designing of hybrid system in HOMER software
7. Renewable resource assessment (Wind, Solar) and analysis of data for different locations.
8. Study and demonstration of hybrid wind turbine photovoltaic system.
9. To study the production of Biodiesel.
10. Experimentally investigate the performance characteristics of Francis Turbine.
11. Experimentally investigate the performance characteristic of Kaplan Turbine.
12. Study of Micro-hydel pumped storage system.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Able to produce Biodiesel.

CO2: To study Solar-Wind hybrid system in order to carry out system designing of hybrid system.

CO3: To measure the different properties of fuel.

Books and References

1. Wind Energy Explained – Theory, Design and Application by J.F. Manwell, J.G. McGowan and A.L. Rogers, John Wiley & Sons, Ltd., 2002.
2. Micro-Hydro Design Manual: A Guide to Small-Scale Water Power Schemes by A. Harvey, A. Brown and P. Hettiarachi, ITDG, 1993.
3. Bio-fuels: Biotechnology, Chemistry and Sustainable Development by DM Mousdale, CRC Press.

Course Name: **Instrumentation & Control for Energy Systems**
Course Code: **ME-771**
Course type: **Programme Elective-I**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To give an overview of measurements principles as well as requirements and functioning of sensors, signal conditioning and data acquisition systems.
- To illustrate the basics control system principles and components, application of microcontroller in monitoring and control of process / parameters and hardware and software interfacing.
- To explain the working of typical monitoring and control instruments / devices used in energy system studies.

COURSE CONTENT

Overview of Instruments and Measurement Systems: Principles of measurements and measurement errors, Classification of instruments, Static and dynamic characteristics, Input output configurations of measurement system.

Sensor and Transducers: Classification of transducer, Characteristics and applications of mechanical and electrical transducers, Difference between sensors and actuators, Principles of modern sensors and typical applications, Piezoelectric type sensors.

Introduction to Control Systems: Overview of control systems, Types and components of control system, Feedback and non-feedback systems and their applications, Transfer function, Block diagram representation and reduction techniques.

Signal Conditioning: Operational amplifier types and characteristics, Application circuits- inverter, Adder, Subtractor, Multiplier and divider, Analog to digital and digital to analog conversion techniques, Filters, Types of filters.

Data Acquisition Systems: Types of instrumentation systems and components, Working principle of analog DAS, Digitiser, Multiplexer, Digital data processing and display.

Microcontrollers and Compilers: Overview of microprocessor and microcontroller, Difference between 80286 and 80386 microprocessors, Microcontroller types and architecture, Use of compilers for data acquisition, Processing and display, Typical microcontroller, Applications for monitoring and control of electrical and non–electrical parameters/processes.

Course Outcomes

Upon successful completion of course, the students will be able to
CO1: To understand the concept of measurement system.
CO2: To understand principle of sensors and control systems.
CO2: To evaluate the phenomenon of signal conditioning and data acquisition system.

Text/ Reference Books

1. Principles of Measurements and Instrumentation by Morris A. S. Prentice Hall of India
2. A Course in Electrical and Electronics Measurements and Instrumentation by Sawhney A. K., Sahney, Dhanpat Rai and Sons.
3. Principles of Measurement Systems by Bentley J. P., Pearson Prentice Hall.
4. Automatic Control Systems by B C Kuo, Wiley.
5. Instrumentation Devices and systems by Raman C. S., Sharma G. R., and Mani V. S. V., Tata McGraw Hill.

Course Name: **Modelling & Simulation of Energy Systems**
Course Code: **ME-772**
Course type: **Program Elective-I**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To explain various modelling and simulation techniques used in energy applications.
- To impart knowledge of obtained data interpretation and validation.

Course Contents

Introduction: Modelling, Steps involved in its development, Simulation, Advantages and disadvantages of simulation, Tools of simulation, Approaches of simulation, Areas of application, Discrete and continuous systems, Various energy systems and its components.

Modelling and Validation: Models, Need of models and their classification, Mathematical modeling, Physical modeling and dimensional analysis, Dimensionless grouping of input and output variables to find empirical relations, Similarity criteria and its application to physical models, Solution procedure, Merging of different models. Accuracy and validation, Model development, Data collection, Parameter estimation, Goodness of fit tests, Need for regression in simulation.

Modelling of Energy Systems: Review of conservation laws and governing equations of heat, mass and momentum transfer, Deterministic model, Distributed parameter models in terms of partial identification and their solutions, Lumped parameter models in terms of differential and difference equations, State space model, Transfer functions, Block diagrams and sub-systems, Stability of transfer functions.

System Simulation: Monte-Carlo simulation, Normally distributed random numbers, 'Monte Carlo' vs 'stochastic simulation', Simulation of continuous and discrete processes with suitable examples from energy system engineering. Simulation Models: Terminology and concepts, Statistical models, Discrete distributions, Bernoulli distribution, Binomial distribution, Geometric distribution, Continuous distribution: Uniform distribution; Exponential distribution; Gamma distribution; Normal distribution; Weibull distribution; Triangular Distribution; Lognormal distribution, Poisson process, Classification of methods of numerical simulation, Numerical simulation versus real systems, Successive substitution method with examples, Newton Raphson method with one unknown examples, Newton-Raphson method with multiple unknowns examples, Gauss-Seidel method with examples, Rudiments of finite difference method for partial differential equations with examples.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Apply concepts of modelling and simulation techniques to energy relevant applications.
CO2: Apply various techniques for experimental or numerical data interpretation.
CO3: Learn to simulate the models for the purpose of optimum control.

Text Books

1. Design of Thermal Systems by W. F. Stoecker, McGraw Hill
2. Simulation Modelling and Analysis by Law and Kelton, McGraw Hill
3. Simulation Model Design & Execution by Fishwich, Prentice Hall
4. Elements of Thermal Fluid System Design by L. C. Burmeister, Prentice Hall
5. Discrete Event System Simulation by Banks, Carson, Nelson and Nicol, Pearson Int

Course Name: **Optimization Techniques for Energy Systems**
Course Code: **ME-773**
Course type: **Programme Elective-I**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To learn efficient computational procedures for solving optimization problems.
- To use programming languages for executing important optimization methods.

COURSE CONTENT

Introduction to Optimization: Formulation of optimization problems, Classical optimization techniques, Linear and non-linear programming, Single variable, Multi-variable and constrained optimization, Specialised algorithms for integer-programming and geometric programming, Non-traditional optimization algorithms, Calculus techniques - Lagrange multiplier method, Search methods, Geometric programming, Dynamic programming, Examples applied to heat transfer problems and energy systems such as gas and steam power plants, Refrigeration systems, Heat pumps.

Optimization Problem Formulation: Design variables, Constraints, Objective function and variable bounds, Single variable.

Single Variable Optimization Algorithms: Bracketing, Melliotls exhaustive search method, Bounding Phase Method.

Region Elimination Methods: Fibonacci search method, Golden section search method, Gradient based methods, Newton -Raphson method, Bisection method, Secant method, Cubic search method, Computer programs for bounding phase method.

Multivariable Optimization Algorithms: Simplex search method, Hooke-Jeeves pattern search method, Gradient based methods - Cauchy's (steepest descent) method, Newton's method, Constrained optimization algorithms, Kuhn Tucker conditions, Penalty function method, Method of multipliers, Cutting plane method, Generalized reduced gradient method, Computer program for penalty function method, Integer programming penalty function method, Global optimization using the steepest descent method, Genetic algorithms, Simulated annealing.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: To gain confidence in applying optimization techniques in energy based applications.

CO2: To obtain optimized solution of the energy system problems.

Text/ Reference Books

1. Optimization in Engineering Design Algorithms and Examples by Kalyanmoy Deb, PHI learning.
2. Optimization Methods by S. S. Rao, PHI learning.
3. Introduction to Optimum Design by J. S. Arora, McGraw Hill.
4. Optimization Methods for Engineering Design by R. L. Fox, Addison Wesley
5. Engineering Optimization Methods and Applications by G. V. Reklaitis, A. Ravindran and K. M. Ragsdell, Wiley.

Course Name: **Energy Efficiency, Audit & Management**
Course Code: **ME- 776**
Course Type: **Programme Elective-II**

Contact Hours/Week: **4L** | Course Credits: **04**

Course Objectives

- To impart basic knowledge to the students about energy audit and management.
- To give systematic knowledge and skill about assessing the energy efficiency.

COURSE CONTENT

Energy Efficiency in Thermal Utilities and systems: Energy efficiency in thermal utilities like boilers, Furnaces, Pumps and fans, Compressors, Efficient compressor operation, Leakage test, Factors affecting the performance, Energy savings. Co-generation (steam and gas turbines), Heat exchangers, Lighting system, Motors belts and drives, Refrigeration system.

Energy Efficiency Improvement in Electrical Systems: Improving energy efficiency in electrical systems, Electrical load management, Maximum demand control, Power factor, Power factor correction, Selection and location of capacitors, Performance assessment of PF capacitors and energy conservation opportunities, Motor efficiency, Factors affecting motor performance, Energy saving opportunities in motors, Energy efficient motors, Soft starter with energy savers, Energy efficient transformers, Factors affecting the performance of transformer, Cables and switch gears.

Energy Management & Audit: Definition, Energy audit, Need, Types of energy audit, Energy management bench marking, Energy performance, Matching energy use to requirement, Maximizing system efficiencies, Optimizing the input energy requirements, Energy audit instruments and metering, Duties and responsibilities of energy managers and auditors, Case studies of energy auditing.

Financial Management: Investment-need, Financial analysis techniques, Simple payback period, Return on investment, Net present value, Internal rate of return, Cash flows, Risk and sensitivity analysis, Financing options, Energy performance contracts.

Course Outcomes

Upon successful completion of the course, the students will be able to
CO1: Students will be able to apply the knowledge of the subject to calculate the efficiency of various thermal utilities.
CO2: Students will be able to carry out the cost- benefit analysis.
CO3: Conduct energy audit and formulate and implement the energy conservation strategies.

Text/Reference Books

1. Handbook on Energy Audit and Environment Management by Y P Abbi and Shashank Jain, TERI, New Delhi
2. Industrial Energy Management and Utilization by LC Witte, PS Schmidt, DR Brown, Hemisphere Publication, Washington.
3. Financial Evaluation of Renewable Energy Technologies by T C Kandpal and H P Garg, Macmillan India Ltd.
4. Energy Conservation in Process Industry by W F Kenny, Academic Press.
5. Energy Management Principles by C Smith and K Parmenter, Academic Press.

Course Name: **Energy Policy Analysis**
Course Code: **ME-777**
Course Type: **Programme Elective-II**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To impart knowledge on Energy Policy.
- To impart knowledge on Energy-Economy-Environment interaction.
- To impart knowledge on Energy Policy Instruments.

COURSE CONTENT

Energy Policy: Energy policies in the country, Tariffs and subsidies, Energy utility interface, Private sector participation in power generation, State role and fiscal policy, Energy and development, National energy plan, International treaties, Role of modeling in energy policy analysis.

Energy Demand and Supply: Energy database, Energy balances, Flow diagrams, Energy demand analysis, Trend analysis, Econometric models, Elasticities approach, Input-output models, Simulation / process models, Energy supply analysis, Costs of exploration and economics of utilization of depletable and renewable resources, Scarcity rent, International energy supply, Energy demand supply balancing, Policy and planning implications of energy–environment interaction, Clean development mechanism, Energy policy related acts and regulations.

Energy Policy Instruments: Pricing, Regulation, Incentives, Subsidies, Framework for policy analysis, Stakeholders, Criteria for energy access, Security, Sustainability, Development, Case studies of a few energy policies – successes and failures, Free riders and rebound effect, Reference energy system, End use analysis.

Modelling: Energy, S-shaped logistic curves, Examples of accelerated diffusion, Factors affecting diffusion, Economy wide impacts, Input-output models, Optimization models, MARKAL, Scenario generation approach and examples, Energy policy analysis project.

Course Outcomes

Upon successful completion of the course, the students will be able to
CO1: Students will be able to draft a policy document.
CO2: Students will be able to understand Energy Policy Instruments.
CO3. Students will be able to carry out project on Energy Policy analysis.

Text/Reference Books

1. Energy Policy Analysis and Modelling by Mohan Munasinghe and Peter Meier, Cambridge University Press.
2. Energy Systems Analysis for Developing Countries by P Meier, Springer.
3. Energy Policies of the World by Gerand J. Mangone, Elsevier.
4. Energy Policy Analysis: A Conceptual Framework by M S Hamilton, CRC Press.
5. Introduction to Energy Analysis by K Blok and Evert Nieuwlaar, Routledge.

Course Name: **Economics & Planning of Energy System**
Course Code: **ME-778**
Course Type: **Programme Elective-II**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To enable students undertake financial feasibility evaluation studies of energy technologies.
- To impart knowledge about the techniques used in energy planning.

COURSE CONTENT

Economics of Energy System: Relevance of financial and economic feasibility, Evaluation of energy technologies and systems, Basics of engineering economics, Financial evaluation of energy technologies, Social cost benefit analysis, Energy demand analysis and forecasting, Economics of energy conservation and renewable energy technologies, Energy supply assessment and evaluation, Energy demand – supply balancing, Energy models, Carbon credits and trading opportunities, Case studies on financial and economic feasibility evaluation of renewable energy systems.

Energy Planning: Policy and Planning implications of energy-environment interaction, Energy investment planning and project formulation, Energy Pricing, Clean development mechanism, Generation system capacity adequacy planning, Probabilistic models of generating unit outage performance and system load, Evaluation of loss of load and loss of energy indices, Probabilistic production costing, Reliability analysis, Software for energy planning, Technology transfer and its financing, Energy policy related acts and regulations, Interconnected systems, Multi-area reliability analysis, Power pool operation and energy exchange contracts.

Energy Forecasting: Sector-wise peak demand and energy forecasting by trend and econometric projection methods, Optimal generation expansion planning, Formulation of least cost optimization problems, Problems involving all type of costs, Minimum assured reliability constraints, Optimization techniques for solution by linear, Nonlinear and dynamic programming approaches, Case studies.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Students will be able to apply the knowledge of the subject in financial estimation of renewable energy system.

CO2: Students will be able to carry out estimation of energy requirement using energy forecasting methods.

CO3: Students will be able to estimate energy pricing.

Text/Reference Books

1. Reliability Evaluation of Power Systems by R. Billinton & R.N. Allan, Plenum Press.
2. Energy Planning and Policy by Maxime Kleinpeter, Wiley.
3. Financial Evaluation of Renewable Energy Technologies by T C Kandpal and H P Garg, Macmillan India Ltd.
4. Contemporary Engineering Economics by C S Park, PHI.
5. Energy Planning by Ashok V. Desai (Editor), Wiley Eastern Ltd.

Course Name: **Fuels & Combustion**
Course Code: **ME-781**
Course Type: **Programme Elective-III**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To impart the knowledge about conventional and unconventional fuels.
- To impart the knowledge of combustion principle, flame propagation and thermodynamics of combustion.

COURSE CONTENT

Fuels: Detailed classification, Conventional and Unconventional Solid, Liquid, Gaseous fuels and Nuclear fuels, Origin of Coal, Analysis of coal. Coal, Carburization, Gasification and liquefaction, Lignite, Petroleum based fuels, Problems associated with very low calorific value gases, Coal gas, Blast furnace gas alcohols, Biogas.

Principles of Combustion: Chemical composition, Flue gas analysis, Combustion stoichiometry, Chemical kinetics, Rate of reaction, Reaction order, Molecularity, Zeroth, First, Second and third order reactions, Complex reactions, Chain reactions, Theories of reaction kinetics, General oxidation behaviour of HC's.

Thermodynamics of Combustion: Enthalpy of formation, Heating value of fuel, Adiabatic flame temperature, Equilibrium composition of gaseous mixtures.

Laminar and Turbulent Flames Propagation and Structure: Flame stability, Burning velocity of fuels, Measurement of burning velocity, Factors affecting the burning velocity, Combustion of fuel, Droplets and sprays, Combustion systems, Pulverized fuel furnaces, Fixed entrained, Fluidized bed systems.

Environmental Considerations: Air pollution, Effects on environment, Human health, Principal

Course Outcomes

Upon successful completion of course, the students will be able to
CO1: To understand the basic principle & Thermodynamic of combustion.
CO2: To understand the phenomenon of laminar and turbulent flame propagation and structures.
CO3: To identify various effect on environment and find out the solutions to reduce the emissions.

Text/Reference Books

1. Combustion Fundamentals by Roger A. Strehlow, Mc Graw Hill.
2. Fuels and combustion by Chander Mohan, Tata Mc Graw Hill.
3. Principles of Combustion by K. Kuo Kanneth, Wiley and Sons.
4. Combustion Engineering and Fuel Technology by A K Shaha, Oxford and IBH.
5. Combustion Engineering by Gary L. Berman & Kenneth W. Ragland, Mc. Graw Hill.

Course Name: **Energy Conservation & Waste Heat Recovery**
Course Code: **ME-782**
Course Type: **Programme Elective-III**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To understand the design of waste heat recovery systems, efficient power cycles and power generation system.
- To identify sources of energy loss and power saving.

COURSE CONTENT

Introduction of Energy Conservation and Waste Heat Recovery: Pattern of energy use, Potential of waste heat recovery (WHR), Source of waste heat, Utilization and category of waste heat, Relationship of WHR with other energy issues, Thermodynamic principle of waste heat recovery, Exergy and second law efficiency.

Recapitulation of Common Power Cycles: Vapour power cycle, Gas turbine cycle, Combined cycle, Co-generation, Tri-generation, Poly-generation, Heat recovery steam generator, Thermodynamic cycle for low temperature application.

Heat Exchanger and Waste Heat Recovery Systems: Introduction and classification of heat exchanger, Methods and analysis of heat exchanger, Regenerators, Special recuperators, Heat exchanger network analysis by pinch technique, Heat pipe.

Thermoelectric Generators and Heat Pump: Introduction to direct energy conversion device, Thermoelectric generation (TEG) basics, Thermoelectric element, Application of TEG, TEG performance analysis, Performance optimization, Heat pump system and application, Industrial process heating heat pump.

Other Waste Heat Recovery Systems: Magneto hydro dynamic generation, Thermo-ionic generation, Thermo-photovoltaic generation, Waste heat recovery from incinerator plant, Prime mover exhausts, Case studies and energy economics.

Course Outcomes

Upon successful completion of the course, the students will be able to

CO1: Students will be able to understand the principles and methods of application of low temperature heat.

CO2: Students will be able to understand the principles of thermoelectric generators and other waste heat recovery system.

Text/Reference Books

1. Heat Recovery System by D. A. Reay, E & F. N. Span, London.
2. Waste Heat Recovery Methods and Technologies, C. C. S. Reddy and S. V. Naidu, National University of Singapore.
3. Organic Rankine Cycle Power Systems 1st Edition Technologies and Applications, Ennio Macchi Marco Astolf, Woodhead Publishing.
4. Fundamental of Heat Exchanger Design by Ramesh K. Sash and Dusan P. Sekulic, Wiley.
5. Thermoelectric Handbook by D. M. Rowe, CRC Press.

Course Name: **Nuclear Energy Systems**
Course Code: **ME-783**
Course Type: **Programme Elective-III**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To impart the knowledge about nuclear energy and how the power generation takes place by nuclear reactor.
- To impart the knowledge of various types of reactors, working principle and properties of reactor material.

COURSE CONTENT

Review of Nuclear Energy: Nuclear Fission, Types of nuclear fission reactors, nuclear fusion and its prospects, Radio topic generation and its applications, Nuclear power generation, Operation efficiency of steam cycles for nuclear power plants.

Nuclear Reactors: Boiling water reactors (BWR) Light water and heavy water pressurized water reactors (PWR) Light water heavy water, Gas cooled reactors, liquid cooled reactors.

Fast breeder (FBR): Fissile and fertile materials, Breeding process, Gas cooled (He or CO_2) FBR, Liquid metal cooled FBR (LMEBR), Scope of FBR in power generation.

Reactor material properties and requirements: Nuclear engineering design, Materials selection, Availability and cost, Computer programming for material election and reactor design.

Nuclear Waste Management: Scientific and engineering aspects of the management of spent fuel, Reprocessed high-level waste, Low-level wastes, Decommissioning wastes, Characteristics of nuclear wastes, Classification of nuclear wastes and waste forms, Discussion on performance assessment.ositories.

Course Outcomes

Upon successful completion of course, the students will be able to
CO1: To understand the principle of power generation from nuclear reactor.
CO2: To understand the working of various types of reactors and materials properties that are used in it.
CO3: To understand the optimization nuclear waste.

Text/Reference Books

1. Nuclear Energy: Principles, Practices, and Prospects by David Bodansky, AIP.
2. Introduction to Nuclear Engineering by John R. Lamarsh and Anthony J. Baratta, Prentice Hall.
3. Nuclear Fuel Management by H. W. Graves, John Wiley and Sons.
4. Nuclear Energy Conversion by M. M. El-Wakil, American Nuclear Society.
5. Nuclear Reactor Engg.: Reactor Design Basic by S. Glasstone, CBS Publishers & Distributors.

Course Name: **Integrated Energy Systems**
Course Code: **ME-786**
Course Type: **Programme Elective-IV**

Contact Hours/Week: **4L**	Course Credits: **04**

Course Objectives

- On successful completion of this course, a student will have detailed knowledge of various major renewable energy resources and their effect on power system.
- State of the art and emerging technologies for efficient penetration and integration of renewable energy resources on power system.

COURSE CONTENT

Introduction: Pattern of fuel consumption, Agricultural, Domestic, Industrial and community needs, Projection of energy demands, Substitution of conventional sources by alternative sources, More efficient modern technologies, Potential, Availability as well as capacity of Solar, Wind, Biogas, Natural gas, Forest produce, Tidal, Geothermal, Mini-hydro and other modern application, Hybrid and integrated energy systems, Total energy concept and waste heat utilization, Energy modeling to optimize different systems.

System Aspects of Integration: Voltage effects, Thermal effects, Fault level, Islanding, Stand-alone systems, Network voltage and system efficiency, Case studies of stand-alone system.

Hybrid Energy Systems: Hybrid energy systems and its economic evaluation, Mathematical modeling of integrated energy systems, Technological aspects of power electronic systems connection to the grid, Hybrid and integrated energy systems, Total energy concept and waste heat utilization, Energy modeling to optimize different systems.

Course Outcomes

Upon successful completion of the course, the student will be able to
CO1: Students will be able to understand the different aspects of Integrated Energy Systems.
CO2: Students will be able to understand the concept of integrated renewable energy systems.
CO3: Students will be able to understand the concept of hybrid energy systems.

Text/Reference Books

1. Renewable Energy Sources for fuels and Electricity by L Barrtom, Island Press.
2. Energy Technology by T Ohta, Pergamon Press.
3. Renewable Energy Resources by J Twidell and T Weir, E&FN Spon.
4. Wind-Diesel Systems by R Hunter and G Elliot, Cambridge University Press.
5. Integrated Energy systems for Multigeneration by I. Dincer and Y. Bicer, Elsevier Science.

Course Name: **Energy Storage Systems**
Course Code: **ME-787**
Course Type: **Programme Elective-IV**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To study details of various energy storage systems along with applications.
- Enabling to identify the optimal solutions to a particular energy storage application / utility.

COURSE CONTENT

Introduction to Energy Storage Technology: Necessity of energy storage, Different types of energy storage, Pumped hydro, Flywheel, Compressed air, Electrostatic and electromagnetic storage, Thermo-chemical storage, Photo-chemical storage, Bio-chemical storage, Electro-chemical storage, Fossil fuels and synthetic fuel, Hydrogen for energy storage, Solar ponds for Energy storage, Comparison of energy storage technologies.

Electrochemical Energy Storage Systems: Fundamental concept and types of battery, Battery performance, Charging and discharging of batteries, Storage density, Energy density, Safety issues, Classical batteries, Solid-state and molten solvent batteries, Lead acid batteries, Nickel cadmium batteries, Zinc manganese dioxide, Modern batteries, Zinc-air, Nickel hydride, Lithium battery, Fuel cell.

Sensible Heat Thermal Energy Storage (SHTES) Systems: Introduction and types of thermal storage, Basics of sensible heat storage, Stratified storage, Rock bed storage, Thermal storage in building, Earth storage, Aquifers storage, Salt hydrates, Molten salts, Reversible chemical heat storage, Metal Hydride.

Latent Heat Thermal Energy Storage (LHTES) Systems: Phase change materials (PCMs), Selection criteria of PCMs, Stefan problem, Solar thermal LHTES systems, Energy conservation through LHTES systems, LHTES systems in refrigeration and air conditioning systems, Enthalpy formulation, Numerical heat transfer in melting and freezing process.

System Design & Applications: Battery sizing and standalone applications, Grid applications, Portable storage applications, Mobile storage applications, Hybrid systems for energy storage, Food preservation, Waste heat recovery, Solar energy storage, Greenhouse heating, Power plant applications, Drying and heating for process industries.

Course Outcomes

Upon successful completion of the course, the student will be able to
CO1: Understand the need of energy storage systems.
CO2: Understand the concept of electrochemical energy storage systems.
CO2: Acquire knowledge of thermal energy storage systems and its heat transfer mechanisms.
CO3: Understand the application of energy storage system.

Text/Reference Books

1. Fundamentals of Energy Storage by J. Jensen and B. Sorenson, Wiley-Interscience.
2. Thermal energy storage: Systems and Applications by I. Dincer and M. A. Rosen, Wiley pub.
3. Handbook of battery materials by C. Daniel, J. O. Besenhard, Wiley.
4. Chemical and Electrochemical Energy System by R. Narayan and B. Viswanathan, University Press.
5. Battery Systems Engineering by C. D. Rahn and C. Wang, Wiley Pub.

Course Name: **Solar Architecture**
Course Code: **ME-788**
Course Type: **Programme Elective-IV**

Contact Hours/Week: **4L** Course Credits: **04**

Course Objectives

- To impart the knowledge about the concept of thermal comfort requirements.
- To impart the knowledge about the concept of zero energy building.
- To impart the knowledge about the current trends in solar architecture.

COURSE CONTENT

Climate and Buildings: Factors affecting climate, Climatic zones and their characteristics, Implications of climate on building design**,** Microclimate**,** Building orientation and design, Building components, Site Planning, Sun motion, Solar radiation estimation on surfaces, Effect of shading.

Principles of Passive solar architecture: Passive heating concepts, Direct gain, Indirect gain, Thermal storage wall, Passive cooling concepts, Ventilation cooling, Thumb rules, Evaporative cooling, Roof surface evaporative cooling, Desiccant cooling, Earth air pipe system, Earth air tunnel and heat exchanger, Basic principles of day lighting, Importance of heat storage, Embodied energy of building materials, Alternative building materials, Design guidelines for commercial buildings, Residential building, Industrial building, Integration of solar systems, Case studies.

Thermal Performance of Buildings: Thermal comfort, Passive energy gain, Heat transfer in buildings, Thermal modeling of passive concepts, Energy efficient windows, Zero energy building, Building rating system, Energy conservation building codes, Software's for building simulation, Automation and energy management of buildings.

Course Outcomes

Upon successful completion of the course, the students will be able to
CO1: Understand the aspects of passive heating and cooling.
CO2: Solve the problem using building simulation tools.
CO3: Understand the aspect of energy rating systems.

Text/Reference Books

1. Passive Building Design by N K Bansal, G Hauser, G Minke, Elsevier.
2. Handbook on Energy Conscious Buildings by J K Nayak and J. A. Prajapati, MNRE, GoI.
3. Passive and low energy cooling of buildings by B Givoni, John Wiley.
4. Solar Energy: Fundamentals, Design, Modelling and Applications by G N Tiwari, CRC press.
5. Climate Responsive Architecture by A Krishan, N Baker, S Yannas, S Szokolay, McGraw Hill Edu.