ANNA UNIVERSITY, CHENNAI

UNIVERSITY DEPARTMENTS

REGULATIONS - 2023

CHOICE BASED CREDIT SYSTEM

M.E. THERMAL ENGINEERING (WITH SPECIALISATION IN REFRIGERATION & AIR-CONDITIONING)

VISION STATEMENT

Department of Mechanical Engineering strives to be recognized globally for excelling in Engineering education and research leading to innovative, entrepreneurial and competent graduates in Mechanical Engineering and allied disciplines.

MISSION STATEMENT

- To provide world class education through the conduct of pioneering and cutting–edge research for students and faculty to make impactful contribution to the society.
- To expand the frontiers of engineering and science in technological innovation while fostering academic excellence and scholarly learning in a collegial environment.
- To attract highly motivated students with enthusiasm, aptitude and interest in the field of Mechanical and allied Engineering.
- To excel in industrial collaboration and research leading to innovative technology development and transfer.
- To serve the society with Innovative and entrepreneurially competent graduates for the national and international community towards achieving the sustainable development goals.

PROGRAMME EDUCATIONAL OBJECTIVES (PEOs):

This Master programme, Thermal Engineering (with specialisation in Refrigeration & Air-Conditioning) strives to produce graduates with the knowledge and skills to excel in the field of Thermal sciences.

PEO	Programme Educational Objectives
1.	Postgraduates will demonstrate technical competency and leadership leading to a excellence in diverse careers.
2.	Postgraduates will pursue curiously with commitment towards sustainable development solutions for the betterment of society.
3.	Postgraduates will pursue lifelong learning through solutions with the ability to act in the face of complexity and novelty.

PROGRAMME OUTCOMES (POs):

PO	Programme Outcomes
1.	Ability to independently carry out research/investigations & solve practical problems.
2.	Ability to write and present a substantial technical report(s)/document(s).
3.	Ability to design and conduct experiments, as well as to analyse and interpret data in a real time system and function on multidisciplinary teams.
4.	To produce industry ready post-graduates in the field of thermal sciences particularly in Refrigeration & Air-Conditioning.
5.	Ability to design a thermal system to meet the desired constraints such as economic, environment and sustainability.
6.	Ability to acquire and apply knowledge as needed, using appropriate learning strategies.

PEO/PO Mapping:

PEO	PO					
	1	**2**	**3**	**4**	**5**	**6**
1	2	1	2	3	2	2
2	2	2	3	3	3	2
3	3	1	2	2	2	3

PROGRAM ARTICULATION MATRIX

		COURSE NAME	PO1	PO2	PO3	PO4	PO5	PO6
YEAR I	SEM I	Advanced Mathematical Methods	3	-	-	1	2	-
YEAR I	SEM I	Advanced Thermodynamics	2	2	3	2	2	2
YEAR I	SEM I	Advanced Heat Transfer	2.2	1.2	2	2.4	2	1.25
YEAR I	SEM I	Refrigeration Systems	3		1		3	3
YEAR I	SEM I	Instrumentation and Control for Thermal Systems	1.25	1.5	2	1.2	2	2
YEAR I	SEM I	Research Methodology and IPR	3	3	2	-	-	-
YEAR I	SEM I	Technical Seminar						
YEAR I	SEM II	Design of Heat Exchangers for HVAC Systems	1.25	1	1.8	3	2.33	1.25
YEAR I	SEM II	Air Conditioning and Ventilation	3		1		3	3
YEAR I	SEM II	Computational Fluid Dynamics for Thermal Systems	1.25	-	-	2	1.6	2.5
YEAR I	SEM II	Processing and Preservation of Perishables	2.6	1	2.2	2.8	2.8	3
YEAR I	SEM II	Professional Elective I						
YEAR I	SEM II	Thermal Simulation Laboratory	1.67	2	-	2	-	1.5
YEAR I	SEM II	Refrigeration and Air-Conditioning Laboratory	2	2	2	1.67	1	1
YEAR I	SEM II	Summer Internship#*						
YEAR II	SEM III	Professional Elective II						
YEAR II	SEM III	Professional Elective III						
YEAR II	SEM III	Professional Elective IV						
YEAR II	SEM III	Project Work I	3	3	3	3	3	3
YEAR II	SEM III	Advanced Thermal Virtual Laboratory	1.67	-	-	2.33	2	1
YEAR II	SEM IV	Project Work II	3	3	3	3	3	3

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M.E. THERMAL ENGINEERING (WITH SPECIALISATION IN REFRIGERATION & AIR-CONDITIONING)
CURRICULUM AND SYLLABI FOR SEMESTER I TO IV

SEMESTER I

S. No.	Course Code	Course Title	Category	Periods L	Periods T	Periods P	Total Contact Periods	Credits
THEORY								
1.	MA3153	Advanced Mathematical Methods	FC	4	0	0	4	4
2.	IC3151	Advanced Thermodynamics	FC	3	1	0	4	4
3.	RA3151	Advanced Heat Transfer	PCC	3	0	2	5	4
4.	RA3101	Refrigeration Systems	PCC	4	0	0	4	4
5.	RA3152	Instrumentation and Control for Thermal Systems	PCC	3	0	0	3	3
6.	RM3151	Research Methodology and IPR	RMC	2	1	0	3	3
PRACTICALS								
7.	RA3111	Technical Seminar	EEC	0	0	2	2	1
			TOTAL	**19**	**2**	**4**	**25**	**23**

SEMESTER II

S. No.	Course Code	Course Title	Category	Periods L	Periods T	Periods P	Total Contact Periods	Credits
THEORY								
1.	RA3201	Design of Heat Exchangers for HVAC Systems	PCC	3	0	2	5	4
2.	RA3202	Air Conditioning and Ventilation	PCC	3	0	0	3	3
3.	RA3203	Computational Fluid Dynamics for Thermal Systems	PCC	3	0	2	5	4
4.	RA3204	Processing and Preservation of Perishables	PCC	3	0	0	3	3
5.		Professional Elective I	PEC	3	0	0	3	3
PRACTICALS								
6.	RA3261	Thermal Simulation Laboratory	PCC	0	0	4	4	2
7.	RA3211	Refrigeration and Air-Conditioning Laboratory	PCC	0	0	4	4	2
8.	RA3212	Summer Internship#*	EEC	---	---	---	---	2
			TOTAL	**15**	**0**	**12**	**27**	**23**

SEMESTER III

S. No.	Course Code	Course Title	Category	Periods			Total Contact Periods	Credits
				L	T	P		
THEORY								
1.		Professional Elective II	PEC	3	0	0	3	3
2.		Professional Elective III	PEC	3	0	0	3	3
3.		Professional Elective IV	PEC	3	0	0	3	3
PRACTICALS								
4.	RA3311	Project Work I	EEC	0	0	12	12	6
5.	RA3312	Advanced Thermal Virtual Laboratory	PCC	0	0	4	4	2
			TOTAL	**9**	**0**	**16**	**25**	**17**

SEMESTER IV

S. No.	Course Code	Course Title	Category	Periods			Total Contact Periods	Credits
				L	T	P		
PRACTICALS								
1.	RA3411	Project Work II	EEC	0	0	24	24	12
			TOTAL	**0**	**0**	**24**	**24**	**12**

*Summer Internship & Semester Internship is for 4-weeks duration.

Summer Internship will be evaluated in third semester.

Total Credits for the Programme = 23 + 23 + 17 +12 = 75

FOUNDATION COURSES (FC)

S. No.	Course Code	Course Title	Periods per week			Credits	Sem
			L	T	P		
1.	MA3153	Advanced Mathematical Methods	4	0	0	4	I

PROGRAM CORE COURSES (PCC)

S. No.	Course Code	Course Title	Periods per week			Total Contact Periods	Credits	Sem
			L	T	P			
1.	IC3151	Advanced Thermodynamics	3	1	0	4	4	I
2.	RA3101	Refrigeration Systems	4	0	0	4	4	I
3.	RA3152	Instrumentation and Control for Thermal Systems	3	0	0	3	3	I
4.	RA3151	Advanced Heat Transfer	3	0	2	5	4	I
5.	RA3202	Air Conditioning and Ventilation	3	0	0	3	3	II
6.	RA3204	Processing and Preservation of Perishables	3	0	0	3	3	II
7.	RA3261	Thermal Simulation Laboratory	0	0	4	4	2	II
8.	RA3211	Refrigeration and Air-Conditioning Laboratory	0	0	4	4	2	II
9.	RA3201	Design of Heat Exchangers for HVAC Systems	3	0	2	5	4	II
10.	RA3203	Computational Fluid Dynamics for Thermal Systems	3	0	2	5	4	II
11.	RA3312	Advanced Thermal Virtual Laboratory	0	0	4	4	2	III

PROFESSIONAL ELECTIVE COURSES (PEC)

S. No.	Course Code	Course Title	Category	Periods			Total Contact Periods	Credits
				L	T	P		
1.	RA3001	HVAC Machinery and Components	PEC	3	0	0	3	3
2.	RA3053	Thermal Management of Electronics and Batteries	PEC	3	0	0	3	3
3.	RA3054	Sorption Heating and Cooling Systems	PEC	3	0	0	3	3
4.	RA3055	Low Temperature Refrigeration and Cryogenics	PEC	3	0	0	3	3
5.	RA3051	Chilled Water and Air Handling systems	PEC	3	0	0	3	3
6.	RA3052	Cold Chain Systems and Management	PEC	3	0	0	3	3
7.	RA3002	Clean Room and Design Practices	PEC	3	0	0	3	3

S. No.	Course Code	Course Title	Category	Periods			Total Contact Periods	Credits
				L	T	P		
8.	RA3003	Sustainability for Buildings	PEC	3	0	0	3	3
9.	EY3061	Energy Storage Technologies	PEC	3	0	0	3	3
10.	SY3051	Solar Refrigeration and Air Conditioning	PEC	3	0	0	3	3
11.	RA3004	Functional Materials	PEC	3	0	0	3	3
12.	RA3056	Energy Audit for HVAC Systems	PEC	3	0	0	3	3
13.	RA3005	Turbomachinery for HVAC Systems	PEC	3	0	0	3	3

EMPLOYABILITY ENHANCEMENT COURSES (EEC)

S. No.	Course Code	Course Title	Category	Periods			Total Contact Periods	Credits	Sem
				L	T	P			
1.	RA3111	Technical Seminar	EEC	0	0	2	2	1	I
2.	RA3212	Summer Internship[#*]	EEC	---	---	---	---	2	II
3.	RA3311	Project Work I	EEC	0	0	12	10	6	III
4.	RA3411	Project Work II	EEC	0	0	24	24	12	IV

RESEARCH METHODOLOGY AND IPR COURSES (RMC)

S. No.	Course Code	Course Title	Category	Periods			Total Contact Periods	Credits	Sem
				L	T	P			
1.	RM3151	Research Methodology and IPR	RMC	2	1	0	3	3	I

SUMMARY

S. No.	M.E. THERMAL ENGINEERING (WITH SPECIALISATION IN REFRIGERATION AND AIR-CONDITIONING)					
	Course Category	Credits per Semester				Credits Total
		I	II	III	IV	
1.	FC	4	---	---	---	4
2.	PCC	11	10	2	---	23
3.	PCC	4	8	---	---	12
4.	PEC	---	3	9	---	12
5.	RMC	3	---	---	---	3
6.	EEC	1	2	6	12	21
	Total	**23**	**23**	**17**	**12**	**75**

MA3153 ADVANCED MATHEMATICAL METHODS

L T P C
4 0 0 4

OBJECTIVES:

- To familiarize the students in the field of differential equations.
- To enable them to solve boundary value problems associated with engineering applications using transform methods.
- To expose the students to the concepts of calculus of variations.
- To introduce conformal mappings and their applications to fluid flows and heat flows.
- To give the students a complete picture of tensor analysis.

UNIT I ALGEBRAIC EQUATIONS 12

Systems of linear equations: Gauss Elimination method, pivoting techniques, Thomas algorithm for tridiagonal system – Jacobi, Gauss Seidel, SOR iteration methods - Systems of nonlinear equations: Fixed point iterations, Newton Method, Eigenvalue problems: power method, Faddeev – Leverrier Method

UNIT II LAPLACE TRANSFORM TECHNIQUES FOR PARTIAL DIFFERENTIAL EQUATIONS 12

Laplace transform: Definitions, properties -Transform of error function, Bessel's function, Dirac Delta function, Unit Step functions – Convolution theorem – Inverse Laplace Transform: Complex inversion formula – Solutions to partial differential equations: Heat equation, Wave equation

UNIT III FOURIER TRANSFORM TECHNIQUES FOR PARTIAL DIFFERENTIAL EQUATIONS 12

Fourier transform: Definitions, properties – Transform of elementary functions, Dirac Delta function– Convolution theorem – Parseval's identity – Solutions to partial differential equations: Heat equation, Wave equation, Laplace and Poison's equations.

UNIT I CALCULUS OF VARIATIONS 12

Concept of variation and its properties – Euler's equation – Functionals dependant on first and higher order derivatives – Functionals dependant on functions of several independent variables – Variational problems with moving boundaries -Direct methods – Ritz and Kantorovich methods.

UNIT V TENSOR ANALYSIS 12

Summation convention – Contravariant and covariant vectors – Contraction of tensors – Inner product – Quotient law – Metric tensor – Christoffel symbols – Covariant differentiation –Gradient, divergence and curl.

TOTAL: 60 PERIODS

OUTCOMES:

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

CO1 get familiarized with the methods which are required for solving system of linear, Non linear equations and eigenvalue problems.
CO2 develop the mathematical methods of applied mathematics and mathematical physics
CO3 solve boundary value problems using integral transform methods apply the concepts of calculus of variations in solving various boundary value problems
CO4 familiarize with the concepts of tensor analysis.

REFERENCES:

1. Andrew L.C. and Shivamoggi B.K., "Integral Transforms for Engineers", Prentice Hall of India Pvt. Ltd., New Delhi, 2003.
2. Elsgolts L., "Differential Equations and the Calculus of Variations", MIR Publishers, Moscow, 2003.
3. Grewal B.S., "Higher Engineering Mathematics", Khanna Publishers, 44^{th} Edition, New Delhi, 2017.

4. Gupta A.S., “Calculus of Variations with Applications”, Prentice Hall of India Pvt. Ltd., New Delhi, 2004.
5. James G., “Advanced Modern Engineering Mathematics”, Pearson Education, 4th Edition, Horlow, 2016.
6. Burden, R.L., and Faires, J.D., “Numerical Analysis – Theory and Applications”, Cengage Learning, India Edition, New Delhi, 2010.
7. O'Neil P.V., “Advanced Engineering Mathematics”, Thomson Asia Pvt. Ltd., 8th Edition, Singapore, 2017.
8. Ramanaiah, G.T., “Tensor Analysis”, S. Viswanathan Pvt. Ltd., Chennai, 1990.
9. Sankara Rao K., “Introduction to Partial Differential Equations”, Prentice Hall of India Pvt. Ltd., 3rd Edition, New Delhi, 2010.
10. Sastry S.S., "Introductory Methods of Numerical Analysis", Prentice - Hall of India Pvt. Limited, 5th Edition, New Delhi, 2012.

Mapping of CO with PO

CO	PO					
	1	**2**	**3**	**4**	**5**	**6**
1	3	3	3	3	2	2
2	3	3	3	3	2	2
3	3	3	3	3	2	2
4	3	3	3	3	2	2
5	3	3	3	3	2	2
Avg.	**3**	**3**	**3**	**3**	**2**	**2**

IC3151 **ADVANCED THERMODYNAMICS**

L	T	P	C
3	1	0	4

COURSE OBJECTIVES:

- To achieve an understanding of basic principle and scope of thermodynamics.
- To predict the availability and irreversibility associated with the thermodynamic processes and Chemical availability of reactive systems.
- To arrive at the adiabatic flame temperature during combustion of air-fuel mixture

UNIT I THERMODYNAMIC PROPERTY RELATIONS 12

Thermodynamic Potentials, Maxwell relations, Generalised relations for changes in Entropy, Internal Energy and Enthalpy, Generalised Relations for Cp and Cv, Clausius Clapeyron Equation, Joule Thomson Coefficient, Bridgeman Tables for Thermodynamic Relations.

UNIT II REAL GAS BEHAVIOUR AND MULTI-COMPONENT SYSTEMS 12

Equations of State (mention three equations), Fugacity, Compressibility, Principle of Corresponding States, use of generalised charts for enthalpy and entropy departure, fugacity coefficient, Lee-Kesler generalised three parameter tables. Fundamental property relations for systems of variable composition, partial molar properties, Real gas mixtures, Ideal solution of real gases and liquids, Equilibrium in multi-phase systems, Gibb's phase rule for non-reactive components.

UNIT III AVAILABILITY ANALYSIS 12

Introduction, Reversible work, Availability, Irreversibility and Second - Law Efficiency for a closed System and Steady-State Control Volume. Availability Analysis of Simple Cycles. Chemical availability of closed and control volume. Fuel Chemical availability, Evaluation of the availability of hydrocarbon fuels.

UNIT IV PHASE EQUILIBRIUM OF MIXTURES 12

Phase equilibrium – Two phase system – Multiphase systems, Gibbs phase rule. Simplified criteria for phase equilibrium – General criteria of any solution, Ideal solution and Raoult's law, Vapour as Ideal gas mixture, Pressure and Temperature diagrams. Completely miscible mixtures – Liquid-vapour mixtures

UNIT V THERMO CHEMISTRY 12

Ideal gas laws and properties of Mixtures, Combustion Stoichiometry, Application of First Law of Thermodynamics – Heat of Reaction – Enthalpy of Formation – Adiabatic flame temperature. Second law of Thermodynamics applied to combustion – entropy, maximum work and efficiency Chemical equilibrium: - Equilibrium constant evaluation K_p & K_f, Equilibrium composition evaluation of ideal gas and real gas mixtures.

TOTAL : 60 PERIODS

COURSE OUTCOMES:

On successful completion of this course the student will be able to

1. Find thermodynamic properties using various thermodynamic relations.
2. Apply the law of thermodynamics to thermal systems.
3. Perform second law analysis to thermal systems
4. Design and analyse a multi component thermodynamic system
5. Understand and analyse the combustion of different fuels

REFERENCES:

1. Kenneth Wark., J.R, Advanced Thermodynamics for Engineers, McGraw-Hill Inc., 1995.
2. K.Annamalai, I.K.Puri, M.A.Jog, Advanced Thermodynamics Engineering, Second Edition, CRC Press, 2011.

3. Sonntag R.E. and Van Wylen, G., Introduction to Thermodynamics, Classical and Statistical Themodynamics, Third Edition, John Wiley and Sons, 1991.
4. S.S. Thipse, Advanced Thermodynamics, Narosa Publishing Home Pvt. Ltd., 2013
5. Yunus A. Cengel and Michael A. Boles, Thermodynamics, McGraw-Hill Inc., 2006.
6. Adrian Bejan, Advanced Engineering Thermodynamics, John Wiley & Sons, 4th Edition, 2016
7. Holman,J.P., Thermodynamics, Fourth Edition, McGraw-Hill Inc., 1988.

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	1	1	2	1	2	2
2	2	2	2	*2*	1	2
3	3	2	3	2	3	3
4	3	3	3	3	3	3
5	3	3	3	3	3	3
Avg.	2.4	2.2	2.6	2.2	2.4	2

RA3151 **ADVANCED HEAT TRANSFER**

L	T	P	C
3	0	2	4

COURSE OBJECTIVES:

- To teach the fundamentals and advancements of heat transfer and its applications with emphasis on numerical solutions to the students and prepare them for research.
- To offer hands-on training on measurement, analysis of heat transfer phenomena with emphasis on data analysis and report preparation.

UNIT – I CONDUCTION **9L, 6P**

Boundary Conditions, Thermal Conductivity, Conduction equation, Fin Design, analytical solutions – Multi-dimensional steady state heat conduction, Transient Heat conduction – Lumped Capacitance Method, Semi-Infinite Media Method

PRACTICALS:

Thermal conductivity of solids & liquids and effect of temperature, Thermal analysis of fins, Lumped heat method for analysis of different geometries

UNIT – II CONVECTION **9L, 6P**

Energy & Momentum equations, Laminar & Turbulent Boundary Layers, Entry length, Reynolds-Colburn Analogy, Heat transfer coefficient for flow over a flat surface, circular & non-circular ducts

PRACTICALS:

Thermal & hydraulic boundary layer development through fluid, Free & Forced convective heat transfer coefficient studies.

UNIT – III TWO-PHASE FLOW **9L, 6P**

Flow patterns, Void fraction, critical flow, Dispersed, slug, annular & stratified flow, Homogeneous, Drift & Separated flow model

PRACTICALS:

Temperature & Flow field visualisation

UNIT – IV TWO-PHASE HEAT TRANSFER **9L, 6P**

Pool & Convective boiling, critical heat flux, Dropwise & filmwise condensation, Melting & Solidification, Heat transfer enhancement methods.

PRACTICALS:

Plotting of boiling & condensation curves, T-t plots during melting & solidification

UNIT – V THRUST AREAS **9L, 6P**

Thermoregulation, Laser Generated Heat Transfer, Tissue Thermal Properties and Perfusion, Thermal Damage and Rate Processes in Biologic Tissues, Thermal Injury, Mathematical models of bio-heat transfer

Machine Learning in Heat Transfer – Linear regression and Neural networks, Practical considerations & Applications.

PRACTICALS:

Irradiation studies & heat generation from lasers

TOTAL: 45L + 30P = 75 PERIODS

COURSE OUTCOMES:

Upon completion of this course, the students will be able to:

1. Demonstrate the concepts of conduction and experimentation in the thermal systems.
2. Illustrate the concept of conservation of energy, solve problems and conduct experiments in convection heat transfer.

3. Categorise & examine the different two-phase flow models and evaluate the parameters of flow fields through experimentation.
4. Analyse the phase change heat transfer and formulate practical problems and interpret data of experimentation.
5. Use engineering tools and appraise the heat transfer in biological systems.

REFERENCES:

1. John H. Lienhard IV and John H. Lienhard V, A Heat Transfer Textbook, Phlogiston Press, 2020.
2. Adrian Bejan, Convection heat transfer, Wiley, 2013.
3. Holman.J.P, Heat Transfer, Tata McGraw Hill, 2002.
4. Yunus Cengel, Heat and Mass Transfer: Fundamentals and Applications, McGraw Hill, 2020.
5. Brennen, C.E., Fundamentals of Multiphase Flow, Cambridge University Press, 2005.
6. Collier, J. G. and Thome, J. R., Convective Boiling and Condensation, 3rd ed., Oxford University Press.
7. Incropera F.P. and DeWitt. D.P., Fundamentals of Heat & Mass Transfer, John Wiley & Sons, 2002.
8. Ashley J. Welch, Martin J.C. Gemert, Optical-Thermal Response of Laser-Irradiated Tissue, Springer Dordrecht, 2011.
9. Punit Prakash, Govindarajan Srimathveeravalli, Principles and Technologies for Electromagnetic Energy Based Therapies, Academic Press, 2021.

Mapping of CO with PO

CO	PO					
	1	**2**	**3**	**4**	**5**	**6**
1	2	1	2	2	1	-
2	2	1	2	3	2	1
3	3	1	2	3	2	1
4	2	1	2	2	2	1
5	2	2	2	2	3	2
Avg.	2.2	1.2	2	2.4	2	1.25

RA3101 REFRIGERATION SYSTEMS

L	T	P	C
4	0	0	4

COURSE OBJECTIVE

To impart knowledge on Refrigeration so that the students gain proficiency on Refrigeration systems and their various ingredients to the extent of conducting research independently.

UNIT I BASIC CYCLES AND ACTUAL VCR CYCLES 12

Reversed Brayton, Carnot VCR cycle – Practical VCR cycle – Sub cooling, super heating, LSHX, Factors influencing performance, Multi pressure Cycles, Cascade Cycle

UNIT II REFRIGERANTS AND LUBRICANTS 12

History of Refrigerants, Refrigerant Designation, International protocols on Environmental impact of Refrigerants, Eco Friendly Refrigerants in different sectors, Safety standards, Refrigerant-oil relationship, Energy Efficiency of Refrigerants, Sustainable Refrigerants

UNIT III SYSTEM COMPONENTS 12

Classification and performance aspects of Compressors, Condensers, Expansion devices, Evaporators. Receivers, Driers, Accumulators, suction line risers

UNIT IV REFRIGERATION LOAD and BALANCING 12

Estimation of Cooling Load, Cold Storages, Cool Storages, System Balancing – GraphicalAnalysis, Capacity modulation and Cycling Controls

UNIT V NOT- IN- KIND SYSTEMS AND ELECTRICAL COMPONENTS 12

Introduction to super-critical CO2 refrigeration system, Vapour absorption systems, Steam-Jet, Thermoelectric Refrigeration, Vortex Refrigeration, Magnetic Refrigeration.

Types of Electric drives, Starting Relays, Overload protecting Relays, Electric Circuits for domestic and commercial appliances.

TOTAL: 60 PERIODS

COURSE OUTCOMES

On successful completion of the course the student will be able to

1. Examine and investigate the cycles in Refrigeration
2. Understand and Explain the Refrigerants and Oils used in Refrigeration systems
3. Understand and Evaluate the various components of Refrigeration systems.
4. Analyse and Design the system load in-order to evolve a balanced system.
5. Describe and Compare the different Refrigeration systems to make best use of the available ones as well as explain the associated Electrical components.

REFERENCES:

1. Arora, C.P., Refrigeration and Air conditioning, McGraw Hill, 3rd Ed., 2010.
2. Dossat R.J., Principles of refrigeration, John Wiley, S.I. Version, 2001.
3. Ibrahim Dincer, Refrigeration Systems and Applications, John Wiley & Sons, 2017.
4. Jordan and Priester, Refrigeration and Air conditioning 1985.
5. Langley, Billy C., ‘Solid state electronic controls for HVACR’ Prentice-Hall 1986.
6. Stoecker W.F., Refrigeration and Air conditioning, McGraw-Hill Book Company, 1989.
7. Rex Milter, Mark R.Miller., Air conditioning and Refrigeration, McGraw Hill, 2006.

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	3	-	1	-	3	3
2	3	-	1	-	3	3
3	3	-	1	-	3	3
4	3	-	1	-	3	3
5	3	-	1	-	3	3
Avg.	3	-	1	-	3	3

RA3152	INSTRUMENTATION AND CONTROL FOR THERMAL SYSTEMS	L	T	P	C
		3	0	0	3

COURSE OBJECTIVES:

- To impart students with the fundamental background as well as practical knowledge to precisely measure and quantify various parameters in thermal systems.

UNIT – I DATA ANALYSIS 9

Statistical analysis of data, Regression analysis, Uncertainty analysis, Data reduction, Design of Experiments – Experimental design factors and protocols, Introduction to Data Analytics and Machine Learning.

UNIT – II SENSORS AND CALIBRATION 9

Transducers – LVDT, Strain gauge, Capacitive, Piezoelectric, Photoelectric, Photoconductive, Photovoltaic, Ionization, Magnetometer Search Coil, Hall-Effect, Temperature Sensors – Thermocouple, RTD, Thermistor. Calibration of Temperature and pressure sensors.

UNIT – III MEASUREMENTS IN THERMAL SYSTEMS 9

Temperature, pressure and flow measurements. Thermal conductivity, Specific heat, viscosity, rheological analysis of Newtonian and non-Newtonian fluids, Humidity, Solar irradiation, Differential Scanning Calorimeter, Calorific values of Solid, liquid and gaseous fuels. Case Studies and Report preparation.

UNIT – IV CONTROL SYSTEMS AND COMPONENTS 9

Open and closed loop control, Transfer function, Interfaces & Protocols. Types of feedback and feedback control system characteristics – Control system parameters, Signal conditioning and processing. Data Acquisition System

UNIT – V CONTROLLERS 9

PID Controllers, Programmable Logic Controllers, Telemetry, Transmitters – Electronic, Fibre-optic & Pneumatic, Regulators – Flow, Level, Pressure and Temperature, Thermostats and Humidistats, Variable-speed drive, Control & optimisation of operations – Cooling Tower, Clean Room, Furnace, pump and turbine, waste water treatment, SCADA, DCS, Industrial Internet of Things.

TOTAL: 45 PERIODS

COURSE OUTCOMES:

Upon completion of this course, the students will be able to:

1. Interpret the of sensitivity, resolution, random and bias error, and precision and accuracy in evaluating data.
2. Illustrate operating principles, calibration, and use of sensors for different measurements.
3. Classify the various measurement techniques, perform experiments and prepare technical reports.
4. Demonstrate the knowledge and understanding of data acquisition.
5. Outline and distinguish the various controllers suitable for thermal systems.

REFERENCES:

1. Holman, J.P., Experimental methods for Engineers, Tata McGraw-Hill, 7th Ed.2011.
2. Ernest O. Doebelin, Measurement Systems: Application and Design, McGraw-Hill, 2004.
3. Les Kirkup, Experimental Methods for Science and Engineering Students, Cambridge University Press, 2019.
4. Alan S. Morris, Reza Langari, Measurement and Instrumentation: Theory and Application, Elsevier, 2015.
5. Norman A. Anderson, Instrumentation for Process Measurement and Control, CRC Press,2017.
6. Aniruddha Datta, Pankaj Goel, Practical Guide to Instrumentation, Automation and Robotics, Elsevier, 2023.
7. Liptak, Instrument Engineers' Handbook, CRC Press, 2018

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	-	1	2	1	-	-
2	2	-	3	2	-	-
3	1	2	1	1	-	-
4	1	-	3	1	-	2
5	1	-	1	1	2	2
Avg.	1.25	1.5	2	1.2	2	2

RM3151 RESEARCH METHODOLOGY AND IPR **L T P C**
2 1 0 3

OBJECTIVES:

To impart knowledge on

- Formulation of research problems, design of experiment, collection of data, interpretation and presentation of result
- Intellectual property rights, patenting and licensing

UNIT I RESEARCH PROBLEM FORMULATION 9

Objectives of research, types of research, research process, approaches to research; conducting literature review- information sources, information retrieval, tools for identifying literature, Indexing and abstracting services, Citation indexes, summarizing the review, critical review, identifying research gap, conceptualizing and hypothesizing the research gap

UNIT II RESEARCH DESIGN AND DATA COLLECTION 9

Statistical design of experiments- types and principles; data types & classification; data collection - methods and tools

UNIT III DATA ANALYSIS, INTERPRETATION AND REPORTING 9

Sampling, sampling error, measures of central tendency and variation,; test of hypothesis- concepts; data presentation- types of tables and illustrations; guidelines for writing the abstract, introduction, methodology, results and discussion, conclusion sections of a manuscript; guidelines for writing thesis, research proposal; References – Styles and methods, Citation and listing system of documents; plagiarism, ethical considerations in research

UNIT IV INTELLECTUAL PROPERTY RIGHTS 9

Concept of IPR, types of IPR – Patent, Designs, Trademarks and Trade secrets, Geographical indications, Copy rights, applicability of these IPR; , IPR & biodiversity; IPR development process, role of WIPO and WTO in IPR establishments, common rules of IPR practices, types and features of IPR agreement, functions of UNESCO in IPR maintenance.

UNIT V PATENTS 9

Patents – objectives and benefits of patent, concept, features of patent, inventive steps, specifications, types of patent application; patenting process - patent filling, examination of patent, grant of patent, revocation; equitable assignments; Licenses, licensing of patents; patent agents, registration of patent agents.

TOTAL: 45 PERIODS

COURSE OUTCOMES

Upon completion of the course, the student can

CO1: Describe different types of research; identify, review and define the research problem

CO2: Select suitable design of experiment s; describe types of data and the tools for collection of data

CO3: Explain the process of data analysis; interpret and present the result in suitable form

CO4: Explain about Intellectual property rights, types and procedures

CO5: Execute patent filing and licensing

REFERENCES:

1. Cooper Donald R, Schindler Pamela S and Sharma JK, “Business Research Methods”, Tata McGraw Hill Education, 11e (2012).
2. Soumitro Banerjee, “Research methodology for natural sciences”, IISc Press, Kolkata, 2022,
3. Catherine J. Holland, “Intellectual property: Patents, Trademarks, Copyrights, Trade Secrets”, Entrepreneur Press, 2007.
4. David Hunt, Long Nguyen, Matthew Rodgers, “Patent searching: tools & techniques”, Wiley, 2007.
5. The Institute of Company Secretaries of India, Statutory body under an Act of parliament, “Professional Programme Intellectual Property Rights, Law and practice”, September 2013.

RA3111 **TECHNICAL SEMINAR** **L T P C**
0 0 2 1

COURSE OBJECTIVES

1. This course will prepare you to prepare and deliver instructive, informational, and persuasive presentations based on well-defined and achievable outcomes
2. This course will improve the communication and lecture delivering skills

Selection of topics, Abstract writing for review articles, literature collection and critical review of articles, Writing conclusion and future research directions, Case studies on published review articles.

Selection of problem, Experimental design of the article, Checking the scientific originality and novelty of the designed experiment

Selection of template, Background, Planning of number of slides, Planning of content structure, Selection of font, font size, and color, Readability of the presentation, Animation, clarity on pictures, and videos

TOTAL: 30 PERIODS

COURSE OUTCOMES:

On successful completion of this course the student will be able to

CO1 Demonstrate theoretical knowledge to create and present effective technical presentation

CO2 Apply and adapt flexible process strategies to produce clear, high-quality deliverables in a multitude of technical writing genres

CO3 Gather and apply researched information that is appropriate to your field, as demonstrated by reading and analyzing documents, and citing sources correctly.

Mapping of CO with PO

CO	PO					
	1	**2**	**3**	**4**	**5**	**6**
1	2	3	2		3	1
2	1	3	2		3	
3	2	3	2		3	
4	2	3	1		3	
5	1	3	3		3	2
Avg	2	3	2		3	1.5

RA3201 DESIGN OF HEAT EXCHANGERS FOR HVAC SYSTEMS

L	T	P	C
3	0	2	4

COURSE OBJECTIVES:

- To impart the design concepts of different types of heat exchangers with practical experiments.
- To offer hands-on training and exercise simulation tools for heat exchangers and the sub-systems.

UNIT – I THERMAL DESIGN 9T, 6L

Classification, Heat Exchanger Variables and Thermal Circuit, LMTD, NTU Method, Design of Double-Pipe & Concentric tube Heat Exchangers, Heat Transfer & Pressure drop, Thermal stress, Temperature Distribution and Its Implications, Materials & Sizing.

PRACTICALS:
Plotting of friction factor, heat load & temperature profiles in a Concentric tube heat exchanger

UNIT – II SHELL AND TUBE HEAT EXCHANGERS 9T, 6L

TEMA Classification, Construction, Mechanical & Thermal design considerations, fluids allocation, Shell Side Heat Transfer Coefficient & Pressure drop – Kern Method – Bell Delware method – Stream analysis method.

PRACTICALS:
Thermo-hydraulic performance of a Shell & tube heat exchanger, Technical drawing of Shell & Tube Heat Exchangers.

UNIT – III FIN-AND-TUBE HEAT EXCHANGERS 9T, 6L

Heat Transfer and Friction Characteristics – Periodic Flow type, Core pressure drop, Flow Distribution & Header design, Fin Geometries and Fin Efficiency, Heat Transfer Surface Geometries, Sizing of Heat Exchanger

PRACTICALS:
Overall thermal performance of Finned tube heat exchanger

UNIT – IV PLATE, SPIRAL & HELICAL HEAT EXCHANGERS 9T, 6L

Plate Heat Exchanger – Types, Construction, Flow Pattern, Design Considerations, Heat Transfer Coefficient & Pressure drop.
Spiral & Helical Heat Exchangers – Construction & Design, Applications

PRACTICALS:
Assembly & Dismantling of plate heat exchanger, comparison of plate, spiral & helical heat exchanger performance.

UNIT – V CONDENSERS & EVAPORATORS 9T, 6L

Condensers – Construction Types, Heat Transfer Coefficient, Operational considerations, Water-cooled, air-cooled & evaporative condensers for HVAC applications, Wilson plot.
Evaporator – Types – Micro-channel evaporators, Flow patterns, Heat Transfer Coefficient, Heat Load, Design considerations, Multi-effect evaporators, Testing of Heat Exchangers as per standards.

PRACTICALS:
Heat Transfer analysis in the chiller unit, Use of thermal process design and simulation software

TOTAL: 75 PERIODS

COURSE OUTCOMES:
Upon completion of this course, the students will be able to:
1. Demonstrate in practice the ability to model typical heat exchangers and interpret the results in experiments.
2. Select appropriate solution technique, analyse the performance of shell and tube heat exchangers and evaluate the significance of results.
3. Appraise the heat transfer enhancement methods in Fin and tube heat exchangers and formulate real-time problems.
4. Compare the thermo-hydraulic performance of different specialised heat exchangers and evaluate the same through experimentation.
5. Analyse and optimise the heat exchangers used in the refrigeration systems.

REFERENCES:

1. Sadik Kakaç, Hongtan Liu, Anchasa Pramuanjaroenkij, Heat Exchangers: Selection, Rating, and Thermal Design, CRC Press, 2020.
2. Kays W. M, London A. L, Compact Heat Exchangers, Scientific International, 2018.
3. Manfred Nitsche, Raji Olayiwola Gbadamosi, Heat Exchanger Design Guide, Elsevier Science, 2015.
4. Robert W. Serth, Thomas Lestina, Process Heat Transfer: Principles, Applications and Rules of Thumb, Elsevier Science, 2014.
5. Arthur P. Fraas, Heat Exchanger Design, Wiley, 2000.
6. Ann Marie Flynn, Toshihiro Akashige, Louis Theodore, Kern's Process Heat Transfer, Wiley, 2019.
7. Hesselgreaves J.E, Compact Heat Exchangers: Selection, Design and Operation, Elsevier Science, 2001.
8. Geoffrey Hewitt, Heat Exchanger Design Handbook, Begell House, 2008.
9. TEMA Standards, 10th Edition, 2019.

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	2	1	2	-	-	1
2	1	1	2	3	-	1
3	1	1	2	3	3	1
4	1	1	1	3	2	1
5	-	-	2	-	2	2
Avg.	1.25	1	1.8	3	2.33	1.25

RA3202 AIR CONDITIONING AND VENTILATION

L	T	P	C
3	0	0	3

COURSE OBJECTIVE

To impart knowledge so that the students gain mastery on Airconditioning and Ventilation principles as well as systems.

UNIT I FUNDAMENTALS 9

Air conditioning concepts, Psychrometry, Wetted surface heat transfer, Psychrometry of air conditioning processes, Estimation of true air temperature & humidity ratio, Air Washers, Evaporative Cooling, Ventilation implications in HVAC Systems.

UNIT II COMFORT AIR CONDITIONING 9

Psychrometric analysis of Summer and Winter air conditioning, Selection of design conditions Thermal Comfort models, Comfort charts, Adaptive Thermal Comfort models, Indoor Air Quality, Clean room concepts.

UNIT III AIR CONDITIONING LOAD 9

Heat transmission through building envelope, Solar radiation, Infiltration & ventilation loads, Cooling and heating load calculations. Passive Airconditioning, ECBC norms, Green Building principles Methods to reduce AC load. Sustainable cooling solutions.

UNIT IV AIR DISTRIBUTION 9

Flow through Ducts, Static and Dynamic Losses, Diffusers, Duct Design – Equal Friction Method and Static Regain Method, Duct Balancing. Fan Duct Interactions, Selection of Fans, - Fan Coil units.

UNIT V OPERATION OF DIFFERENT SYSTEMS 9

Room Air Conditioners, Packaged Air conditioning systems, Centralized Air conditioning systems, Radiant cooling systems, DCV and VAV systems, UFAD systems, Hydronic systems, Air handling systems. MAC systems.

TOTAL: 45 PERIODS

COURSE OUTCOMES

On successful completion of the course the student will be able to:

1. Understand and Analyse the Air-conditioning systems in respect of fundamental aspects and their implications.
2. Describe and examine the systems designed for Comfort Air-conditioning.
3. Understand and Evaluate the Heat load in Air-Conditioning Applications.
4. Explain and Design the Ducts as well as select the Fans for proper Air distribution.
5. Describe and Compare the different Air-conditioning systems to make best use of available models.

REFERENCES:

1. Arora C.P., Refrigeration and Air Conditioning, Tata McGraw Hill Pub. Company, 2010.
2. ASHRAE, Fundamentals and equipment , 4 volumes-ASHRAE Inc. 2021.
3. Ali Vedavarz, Sunil Kumar, Mohammed Iqbal, Hussain Handbook of Heating**,** Ventilation and Air conditioning for Design Implementation, Industrial pressInc,2017.

4. Billy C. Langley., Fundamentals of Air Conditioning Systems, The Fairmont Press, Inc., 2000.
5. Carrier Air Conditioning Co., Handbook of Air Conditioning Systems design, McGraw Hill, 1985.
6. Jones, Air Conditioning Engineering, Edward Amold pub. 2001.

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	3		1		3	3
2	3		1		3	3
3	3		1		3	3
4	3		1		3	3
5	3		1		3	3
Avg.	3		1		3	3

RA3203	COMPUTATIONAL FLUID DYNAMICS FOR THERMAL SYSTEMS	L	T	P	C
		3	0	2	4

COURSE OBJECTIVES:

1. To impart fundamentals of Computational fluid dynamics and provide hands-on training to the students.
2. To teach the advancement of modern CFD tools students for complex systems.

UNIT – I GOVERNING DIFFERENTIAL EQUATIONS 9T, 6L

Finite Volume approach – Scalar, Vector, Tensor, Governing equations for conservation of mass, momentum and energy – Classification of partial differential equations – Types of Boundary Conditions, Initial and Boundary value problems, Taylor's Series, Stoke's law, Vorticity, Diffusion, Divergence theorem, Types of Errors

PRACTICALS:

Determination of approximate solutions for Navier-Stokes equation using computer software

UNIT – II GRID GENERATION 9T, 6L

Types of Meshes – Structured, Body-Fitted & Unstructured Mesh, Coordinate Transformations, Topology, Refinement, Overlapping, Adaptive Mesh, Moving Mesh, Mesh Quality & Mesh Design, Coarse & Fine Mesh, Grid Independence Test.

PRACTICALS:

Mesh Generation for various geometries

UNIT – III DIFFUSION 9T, 6L

Multidimensional diffusion problems, Discretisation of steady & unsteady diffusion equations – Explicit, Implicit and Crank-Nicholson's schemes, Stability of schemes, Numerical Solutions.

PRACTICALS:

Simulation of steady & transient diffusion problem using CFD Tool with results and reports.

UNIT – IV CONVECTION-DIFFUSION 9T, 6L

1D convection – diffusion problem, Discretisation using Central difference scheme, upwind scheme, QUICK scheme.
Phase Change – Mathematical Formulation, Discretisation, Enthalpy method, Problems

PRACTICALS:

Discretisation of governing equation using software, Simulation of phase-change problems using CFD Tool.

UNIT – V FLOW MODELLING 9T, 6L

Pressure-velocity coupling algorithms – SIMPLE, SIMPLEC, PISO, Turbulence Models – Governing equation for turbulent kinetic energy & dissipation (k-ε model), Large Eddy Simulation

PRACTICALS:

Simulation of internal and external flows and execution of CFD Project with results and reports.

TOTAL: 75 PERIODS

COURSE OUTCOMES:

Upon completion of this course, the students will be able to:

1. Use the appropriate governing equations & to investigate flow and energy transfer in a physical system.
2. Demonstrate the appropriate mesh generation for an accurate solution using software.
3. Classify the different discretisation schemes and evaluate solutions using CFD tool.
4. Solve and investigate the convection-diffusion problems and interpret the result through hands-on training.
5. Determine various parameters of interest, such as flow rates, heat fluxes, pressure drops, losses, etc. through simulation.

REFERENCES:

1. Versteeg and Malalasekera, N, "An Introduction to computational Fluid Dynamics, Finite Volume Method," Pearson Education, Ltd., Second Edition, 2014.
2. Subas and V. Patankar "Numerical heat transfer fluid flow", CRC Press, 2018.
3. Jiyuan Tu, Gaun-Heng Yeoh, Chaoqun Liu, Computational Fluid Dynamics: A practical approach, Elsevier, 2018.
4. Chung T.J, Computational Fluid Dynamics, Cambridge University Press, 2014.
5. Randall J. LeVeque, Finite Volume Methods for Hyperbolic Problems, Cambridge University Press, 2004.
6. Vladimir D. Liseikin, Grid Generation Methods, Springer, 2017.
7. Moukalled F, Mangani L, Darwish M, The Finite Volume Method in Computational Fluid Dynamics, Springer, 2016.
8. Hirsch Ch, Numerical Computation of Internal and External Flows: The Fundamentals of Computational Fluid Dynamics, Elsevier, 2007.
9. Oleg Zikanov, Essential Computational Fluid Dynamics, Wiley, 2019.

Mapping of CO with PO

CO	PO					
	1	**2**	**3**	**4**	**5**	**6**
1	1	-	-	2	1	2
2	1	-	-	1	2	2
3	-	-	-	2	2	3
4	1	-	-	3	1	3
5	2	-	-	2	2	2
Avg.	1.25	-	-	2	1.6	2.5

RA3204 PROCESSING AND PRESERVATION OF PERISHABLES

L	T	P	C
3	0	0	3

COURSE OBJECTIVES:
1. To introduce microbiology of food products.
2. To give an overview of thermodynamic properties of food products and different food processing techniques.
3. To explain the freezing and drying principles and estimate freezing time calculation.
4. To give an understanding of the various cold storage design
5. To introduce about grain storage systems and its design features

UNIT I INTRODUCTION and MICROBIOLOGY OF FOOD PRODUCTS 9

Importance and Scope of Food Preservation, Status in India, National Horticultural policy, Microbiology of food products, Mechanism of food spoilage, Critical microbial growth requirements, Design for control of micro-organisms, Regulations and Standards.

UNIT II PROCESSING & PRESERVATION 9

Thermodynamic Properties, Water Content, Initial Freezing Temperature, Ice Fraction, Transpiration of Fresh Fruits and Vegetables, Food Processing Techniques for Dairy Products, Poultry, Meat, Fruits and Vegetables.

UNIT III FREEZING & DRYING 9

Precooling, Freeze Drying Principles, Cold Storage and Freezers, Freezing Drying limitations, Irradiation Techniques, Cryo Freezing, Energy Conservation in Food industry, Numerical and Analytical Methods in Estimating Freezing, Thawing Times.

UNIT IV COLD STORAGE DESIGN AND INSTRUMENTATION 9

Cold storage of Agricultural products, Initial Building Consideration, Building Design, Specialized Storage Facility, Construction Methods, Refrigeration Systems, Insulation Techniques, Control and Instrumentation, Fire Protection, Inspection and Maintenance.

UNIT V STORAGE OF GRAINS 9

Types of Storage, Structural Aspects, Grain handling, Quality aspects, Operational and Safety issues, grain aeration and storage management, Dust and Insects control and Management

TOTAL: 45 PERIODS

COURSE OUTCOMES:

Upon completion of this course, the students will be able to:
1. Explain microbiology of food products.
2. Estimate the thermodynamic properties of food and discuss various food processing techniques
3. Calculate freezing and thawing time of food products.
4. Design the cold storage for various types food products.
5. Discuss the design feature of different systems for grain storage and management

REFERENCES

1. ASHRAE Handbook - Refrigeration, AHSRE Inc, 2020.
2. Paul Singh R., Dennis R. Heldman., Introduction to Food Engineering, 4th Edition, Academic Press, Elsevier, 2009.
3. Peter Fellows, Food Processing Technology: Principles and Practice, Wood Head, CRC press, 2000.

4. Sivasankar. B, Food processing and preservation, PHI learning, 2005.
5. Kurt A Rosentrater, Storage of Cereal Grain and their products, Wood Head Publishing, 2022.

MAPPING OF CO'S WITH PO'S

CO	PO					
	1	2	3	4	5	6
1	3	1	1	3	3	3
2	2	1	3	3	3	3
3	2	1	2	3	3	3
4	3	1	2	2	3	3
5	3	1	3	3	2	3
Avg.	2.6	1	2.2	2.8	2.8	3

RA3261 **THERMAL SIMULATION LABORATORY**

L	T	P	C
0	0	4	2

COURSE OBJECTIVE:

- To offer hands-on training on Modeling and simulation algorithms, and methods of energy-based systems.

LIST OF EXPERIMENTS

1. Solution to Laplace equation on a two-dimensional grid using program code.
2. Solution to linear wave equation on a two-dimensional grid using program code.
3. Simulation studies of fluid flow over a heated flat plate under laminar & turbulent flow conditions using CFD software
4. Heat transfer analysis from a heatsink for electronic cooling applications using CFD software.
5. Thermo-hydraulic performance of a tubular heat exchanger using CFD Software.
6. Simulation studies on Ventilation of space using CFD software.
7. Transient Simulation of HVAC systems.
8. Transient Simulation of solar water heating systems.
9. Energy Simulation of residential / commercial buildings.

TOTAL: 30 PERIODS

COURSE OUTCOMES:

Upon completion of this course, the students will be able to:

1. Develop models and perform simulation studies.
2. Analyse and interpret data of simulated results.
3. Prepare technical reports for simulation of thermal systems.

LAB REQUIREMENTS:

1) Software – CAD Modeling software, CFD Meshing Software, FVM based CFD Solvers, Post-Processing tools, programming & computing software, equation-solving program, building energy simulation software, transient energy simulation software.
2) Computer Hardware compatible with the requirements of the above software.

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	1	1	-	2	-	2
2	2	2	-	2	-	1
3	2	3	-	2	-	-
Avg.	1.67	2	-	2	-	1.5

RA3211 REFRIGERATION AND AIR-CONDITIONING LABORATORY

L	T	P	C
0	0	4	2

COURSE OBJECTIVE:

- To provide hands-on training on various types of Refrigeration & Air-Conditioning systems for performance assessment.

LIST OF EXPERIMENTS

1. Studies on various components of Refrigeration and Air conditioning systems and tools.
2. Thermal analysis of vapour compression refrigeration system.
3. Study of heat pump performance under different indoor and outdoor conditions.
4. Pull-down test in a Deep freezer at various load conditions.
5. Performance analysis of heat pump dryer.
6. Determination of Coefficient of Performance of a Thermoelectric refrigeration system.
7. Performance evaluation of a Vortex refrigeration system.
8. Plotting of fan performance characteristic curves.
9. Performance evaluation of Hybrid Evaporative Cooler
10. Environment air quality measurement and analysis.
11. Building Energy Studies – Field visit.

TOTAL: 60 PERIODS

COURSE OUTCOMES:

Upon completion of this course, the students will be able to:

1. Conduct studies on different types of refrigeration & air-conditioning systems.
2. Analyse the performance of HVAC systems including energy consumption and environmental impacts.
3. Arriving the major specifications of various components and prepare a technical report.

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	2	3	2	2	---	1
2	2	2	2	2	1	1
3	---	1	2	1	1	1
Avg.	2	2	2	1.67	1	1

RA3212 **SUMMER INTERNSHIP**

L	T	P	C
0	0	0	2

COURSE OBJECTIVE

1. To gain hands-on experience in industries for understanding various real-time processes and work environment in industrial setup.

DURATION

The students have to undergo practical industrial training for four weeks (During summer vacation in first year of the course) in recognized industrial establishments.

I. At the end of the training they have to submit a report with following information:

1. Profile of the Industry,
2. Product range,
3. Organization structure,
4. Plant layout,
5. Processes/Machines/Equipment/devices,
6. Personnel welfare schemes,
7. Details of the training undergone,
8. Projects undertaken during the training, if any
9. Learning points.

II. End Semester examination will be a Viva-Voce Examination type which will be evaluated by a committee consisting of Programme Incharge, Professor and Course Coordinator during Third Semester.

COURSE OUTCOME

On successful completion of this course the student will be able to:

- Understand the different forms of organization, functions of management, organizational behavior, group dynamics and requirements for working in industrial environment.

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	2	2	---	3	2	2
Avg	2	2	---	3	2	2

RA3311 **PROJECT WORK I**

L	T	P	C
0	0	12	6

COURSE OBJECTIVES

1. The main learning objective of this course is to prepare the students for identifying a specific problem for the current need of the society and or industry, through detailed review of relevant literature, developing an efficient methodology to solve the identified specific problem.

   Note: A project topic must be selected by the students in consultation with their guides. The progress of the project is evaluated based on a minimum of three reviews. The review committee may be constituted by the Head of the Department. A project report is required at the end of the semester. The project work is evaluated jointly by external and internal examiners constituted by the Head of the Department based on oral presentation and the project report.

COURSE OUTCOMES:

On successful completion of this course the student will be able to

CO1 Identify a suitable industrial problem with regard to engines..

CO2 Develop the required setup for testing

Mapping of CO with PO

CO	PO					
	1	**2**	**3**	**4**	**5**	**6**
1	3	3	3	3	3	3
2	3	3	3	3	3	3
Avg	3	3	3	3	3	3

RA3312 ADVANCED THERMAL VIRTUAL LABORATORY

L	T	P	C
0	0	4	2

COURSE OBJECTIVE:

- To perform experiments through online platform for enhancing the practical skills of the students for better understanding of concepts.

LIST OF EXPERIMENTS

1. Development of Thermal and velocity boundary layers.
2. Heat Transfer analysis in a double pipe & Shell & tube heat exchanger.
3. Two Phase Flow in Horizontal & Vertical Tubes.
4. Melting of Ice.
5. Heat & Mass Transfer operations in Water Cooling Tower.
6. Simulation of VCR / VAR system.
7. Simulation of Piston compressor and expansion valves in refrigeration system.
8. Performance of Solar Photovoltaic Panel and Solar Thermal Collectors.
9. Power Generation from Wind Turbine.
10. Study of characteristics for different types of fans.

TOTAL: 60 PERIODS

COURSE OUTCOMES:

Upon completion of this course, the students will be able to:

1. Make use of the ICT for exploring the underlying mechanisms in a thermal system.
2. Analyse the results and improve the understanding of concepts.
3. Design efficient thermal system for specific applications.

LAB REQUIREMENTS:

- ICT based tools and software.
- Computer Hardware compatible with the requirements of ICT tools.

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	1	-	-	2	2	1
2	2	-	-	2	2	1
3	2	-	-	3	2	1
Avg.	1.67	-	-	2.33	2	1

RA3411 **PROJECT WORK II** **L T P C**

0 0 24 12

COURSE OBJECTIVES

1. The main learning objective of this course is to prepare the students for solving the specific problem for the current need of the society and or industry, through the formulated efficient methodology, and to develop necessary skills to critically analyse and discuss in detail regarding the project results and making relevant conclusions.

Note: A project topic must be selected by the students in consultation with their guides. The progress of the project is evaluated based on a minimum of three reviews. The review committee may be constituted by the Head of the Department. A project report is required at the end of the semester. The project work is evaluated jointly by external and internal examiners constituted by the Head of the Department based on oral presentation and the project report.

COURSE OUTCOMES:

On successful completion of this course the student will be able to

CO1 Conduct the experiments, interpret and analyse the data

CO2 Validate, present and publish the findings

Mapping of CO with PO

CO	PO					
	1	**2**	**3**	**4**	**5**	**6**
1	3	3	3	3	3	3
2	3	3	3	3	3	3
Avg	3	3	3	3	3	3

RA3001 HVAC MACHINERY AND COMPONENTS

L	T	P	C
3	0	0	3

COURSE OBJECTIVES:

1. To understand the HVAC systems and Components
2. To understand various heating and cooling systems
3. To know the HVAC air distributions equipment
4. To gain knowledge on HVAC dehumidification and dehumidification components
5. To learn about the ventilation and control components

UNIT– I HVAC SYSTEM 9

Decentralized Cooling and Heating, Central Cooling and Heating Plants, Air Handling and Distribution, In-Room Terminal Systems , Radiant Heating and Cooling, Combined Heat and Power Systems ,Combustion Turbine Inlet Cooling

UNIT– II HEATING AND COOLING SYSTEMS 9

Applied Heat Pump and Heat Recovery Systems, Small Forced-Air Heating and Cooling Systems, Steam Systems, District Heating and Cooling, Hydronic Heating and Cooling, Condenser Water Systems, Medium- and High-Temperature Water Heating

UNIT– III HVAC AIR DISTRIBUTION EQUIPMENT 9

Duct Construction, Room Air Distribution Equipment, Fans, Air-to-Air Energy Recovery Equipment , Air-Heating Coils

UNIT– IV HVAC DEHUMIDIFICATION AND DEHUMIDIFICATION COMPONENTS 9

Humidifiers, Air-Cooling and Dehumidifying Coils, Desiccant Dehumidification and Pressure- Drying Equipment, Mechanical Dehumidifiers and Related Components

UNIT– IV HVAC VENTILATION AND CONTROL COMPONENTS 9

Unit Ventilators, Unit Heaters, and Makeup Air Units, Air Cleaners for Particulate Contaminants, Industrial Gas Cleaning and Air Pollution, Control Equipment

TOTAL: 45 PERIODS

REFERENCES:

1. ASHRAE-Handbook-2016, HVAC Systems and Equipment: SI Edition, 2020.
2. Nils Grimm and Robert Rosaler, HVAC Systems and Components Handbook, McGraw-Hill Education, 1997
3. Roger W. Haines HVAC Systems Design Handbook, Fifth Edition, McGraw Hill; 5th edition (2 November 2009)
4. Gupta NC , Comprehensive HVAC System Design , Viva Books, 2016
5. Samuel C. Monger, HVAC Systems: Operation, Maintenance, & Optimization, Building News, 1993.

COURSE OUTCOMES:

Upon completion of this course, the students will be able to:

1. Understand various HVAC systems.
2. Analysis of various heating and cooling systems
3. To select suitable air distribution equipment
4. Know the HVAC dehumidification and dehumidification components
5. Understand the HVAC ventilation systems and control components

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	2	-	2	1	3	1
2	2	-	2	1	3	1
3	3	-	3	2	3	1
4	2	-	3	2	3	1
5	1	-	3	1	2	1
Avg.	2	-	2.6	1.4	2.8	1

RA3053	THERMAL MANAGEMENT OF ELECTRONICS AND BATTERIES	L	T	P	C
		3	0	0	3

COURSE OBJECTIVES:

- To impart the knowledge on thermal management of electronic devices and batteries.
- To provide students with an appreciation for the application of heat transfer to problems in industries related to thermal management of electronics and batteries.

UNIT – I FUNDAMENTALS 9

Heat transfer modes, electronics packaging, Properties of materials used in electronics and equipment, contact and spreading resistances, heat sink design, Thermal Interface Materials & Heat Spreaders, Jedec Standards.

UNIT – II COOLING TECHNOLOGIES 9

Microchannels, Fluid selection, Jet impingement, Immersion cooling, Heat pipes, Vapour chambers, Thermoelectric coolers, MEMS / NEMS based cooling system. Current trends in cooling.

UNIT – III APPLICATIONS 9

Automobiles, Trains, Ships, Avionics, Data Centres, Laptop / Computers / Mobile phone, Internet of Things, Television, RADAR, Satellite Electronics, LED – Lights and Display units, LASER.

UNIT – IV BATTERIES 9

Types and comparison, Thermodynamics of Batteries – Energy Balance, Electrochemical Modelling – Surface, concentration, ohmic over potential and overall cell potential, Duty cycle, Performance of a battery cell, Thermal Behaviour of Batteries - Aging, Thermal runaway, heat generation rate, thermal behaviour model and impact.

UNIT – V BATTERY THERMAL MANAGEMENT SYSTEM 9

Mechanical and Thermal design of battery pack, Thermal management system – Air based, Liquid based and Phase Change Material based systems, Recent developments.

TOTAL: 45 PERIODS

COURSE OUTCOMES:

Upon completion of this course, the students will be able to:

1. Understand the heat transfer mechanisms, need for thermal management and sources of heat generation in electronics.
2. Compare and analyse the performance of various cooling technologies.
3. Select the appropriate cooling system for specific applications.
4. Categorise the major components of batteries and elucidate the battery characteristics.
5. Identify the challenges and requirements for thermal management of batteries.

REFERENCES:

1. Younes Shabany, Heat Transfer: Thermal Management of Electronics, CRC Press Inc, 2010.
2. L.T. Yeh, Thermal Management of Microelectronic Equipment, ASME, 2016.
3. Arman Vassighi, Manoj Sachdev, Thermal and power management of integrated circuits, Springer, 2006.
4. Marc A Rosen, Aida Farsi, Battery Technology: From Fundamentals to Thermal Behaviour and Management, Elsevier, 2023.
5. Shriram Santhanagopalan, Kandler Smith, Gi-Heon Kim, Jeremy Neubauer, Ahmad A. Pesaran, Matthew Keyers, Design and Analysis of Large Lithium-Ion Battery Systems, Artech House Publishers, 2014.
6. Jerry E. Sergent, Al Krum, Thermal Management Handbook: For Electronic Assemblies,

McGraw-Hill, 1998.
7. Shichun Yang, Xinhua Liu, Shen Li, Cheng Zhang, Advanced Battery Management System for Electric Vehicles, Springer, 2022.

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	1	-	1	2	-	1
2	2	-	1	2	-	1
3	1	-	1	2	-	1
4	-	-	1	1	-	2
5	1	-	1	1	-	2
Avg.	1.25	-	1	1.6	-	1.4

RA3054 SORPTION HEATING AND COOLING SYSTEMS

L	T	P	C
3	0	0	3

COURSE OBJECTIVES:

1. To teach fundamentals of sorption cooling systems and analysis and design of LiBr and Ammonia systems.
2. To teach pumpless system and solid sorption systems and their design of components.
3. To teach various applications of sorption systems for heating, cooling and power generation in buildings, industries etc.
4. To teach polygeneration systems
5. To teach the merits of the system for climate change mitigation

UNIT I INTRODUCTION 9

Carnot cycle : Refrigerator, Heat Pump, Heat Transformer - Working Fluids, Properties, Mixing of Fluids and the Heat of Mixing - Specific Heat of Mixtures – Thermodynamic processes - Desorption, Absorption, Condensation and Evaporation, Compression, Pumping, Throttling and Ammonia Purification

UNIT II LIQUID SORPTION SYSTEMS 9

Water–LiBr Systems; Single Effect, Double Effect Systems, Types–Analysis of Advanced Cycles for Refrigeration Systems–Heat Pumps and Heat Transformers, Membrane based Systems - Crystallization and other issues, Ammonia–Water Systems–Single Effect, Two stage and GAX Systems.

UNIT III PUMPLESS AND SOLID SORPTION SYSTEM 9

Diffusion Absorption Systems–Bubble Pump Systems–Solid Sorption Systems– Working Fluids–Single and Multi effect Systems–Metal Hydride Heating and Cooling Systems–Applications and Issues

UNIT IV COMPONENT DESIGN 9

Design of Generator – Absorber – Condenser – Evaporator – Solution Heat Exchanger – Reactors – Rectifiers – Overall System Balance.

UNIT V APPLICATIONS OF SOPRTION SYSTEMS 9

Combined power and cooling, Solar Cooling, Low and medium grade Industrial waste heat Utilization, Gas turbine inlet cooling, Polygeneration systems, Economics of Sorption Systems–Sorption refrigeration Systems for Climate Change Mitigation.

TOTAL : 45 PERIODS

COURSE OUTCOMES:

Upon completion of this course, the students will be able to:

1. Understand the fundamentals of sorption heating and cooling systems, processess and the working fluids requirement and their properties
2. Analyze the energy input requirements for both LiBr and Ammonia systems for various applications
3. Understand the principle of working in respects of pumpless refrigerators and solid sorption heating and cooling systems.
4. Design various components used both in liquid and solid sorption heating and cooling systems.
5. Appreciate the use of the systems for various building energy requirements such as heating, cooling and power and its ability for climate change mitigation.

REFERENCES

1. Alefeld G. and Radermacher R., Heat Conversion Systems, CRC Press, London,1994.
2. ASHRAE Hand Book–HVAC Systems & Equipment 2023, ASHRAE Inc. Atlanta.
3. Herold K. E., Radermacher R. and Klein S. A., Absorption Chillers and Heat Pumps, CRC Press, London, 2016.
4. Ibrahim Dincer, Tahir Abdul Hussain Ratlamwala., Integrated Absorption Refrigeration Systems: Comparative Energy and Exergy Analyses, Springer, 2016
5. Ibrahim Dincer and Yusulf bicer, Integrated Energy Systems for multigeneration, Elesvier Ltd, 2020
6. Franceso Calise, Maasimo Daccadia, Laura Vanoli and Maria Vicidomini, Polygeneration systems – Deign, Process and echnlogies, Academic Press, 2022
7. Majid Amidpour, Mohammad Hasan Khoshgoftar Manesh, Cogeneration and Polygeneration Systems, Elesevier Science, 2020

MAPPING OF CO'S WITH PO'S

CO	PO					
	1	2	3	4	5	6
1	3	1	1	3	1	3
2	2	1	2	3	1	2
3	2	1	3	3	3	3
4	3	1	3	3	3	2
5	3	1	3	3	3	3
AVg.	2.6	1	2.4	3	2.2	2.6

RA3055 LOW TEMPERATURE REFRIGERATION AND CRYOGENICS

L	T	P	C
3	0	0	3

COURSE OBJECTIVE

To impart knowledge on Low Temperature Refrigeration as well as Cryogenics so that the students gain confidence in working independently with high end systems related to liquefaction of gases, Material behaviour at Cryogenic applications

UNIT I LOW TEMPERATURE REFRIGERATION 9

Temperature limits for Low Temperature Refrigeration and Cryogenics, Material characteristics, Applications of Low Temperature in Industries, Space, Medicine, Gas Industry, High Energy Physics, Super-conductivity, Levitation principle

UNIT II LIQUEFACTION OF GASES 9

Carnot Liquefaction Cycle, F.O.M. and Yield of Liquefaction Cycles. Inversion Curve- Joule Thomson, Effect. Linde Hampson Cycle, Precooled Linde Hampson Cycle, Claude Cycle Dual Pressure Cycle, Ortho-Para hydrogen conversion, Critical Components in Liquefaction Systems.

UNIT III PURIFICATION OF GASES 9

Principle of Rectification, Rectification Column Analysis-McCabe Thiele Method, Adsorption Systems for purification.

UNIT IV CRYO COOLERS 9

J.T Cryo-coolers, Stirling Cycle Refrigerators, G.M.Cryo-coolers, Pulse Tube Refrigerators Regenerators used in Cryogenic Refrigerators, Magnetic Refrigerators.

UNIT V STORAGE AND TRANSPORT 9

Cryogenic Dewar Design, Cryogenic Transfer Lines. Insulations in Cryogenic Systems, Operating principle of different Types of Vacuum Pumps, Instruments to measure Flow, Level and Temperature operating principles

TOTAL: 45 PERIODS

COURSE OUTCOMES

On successful completion of the course the student will be able to:

1 Recognize and explain the material characteristics and Applications at Low temperature.
2. Analyse and evaluate the systems used for Liquefaction of Gases.
3. Understand and Evaluate the systems for purification of Gases.
4. Explain and Differentiate the different Cryo-coolers.
5. Discuss and Compare the different systems /components in handling the Cryogens.

REFERENCES:

1. Klaus D. Timmerhaus and Thomas M. Flynn, Cryogenic Process Engineering, Plenum Press NewYork, 1989.
2. Mukhopadhay Mamata, Fundamentals of cryogenic engineering, PHI learning, 2010.
3. Pipkov, "Fundamentals of Vacuum Engineering", Meer Publication.
4. Randall F. Barron, "Cryogenics Systems", Second Edition Oxford University Press New York, Clarendon Press, Oxford, 1985.
5. Thomas Flynn, Cryogenic Engineering, Revised and Expanded, CRC Press, 2004.

Mapping of CO with PO

CO	PO					
	1	**2**	**3**	**4**	**5**	**6**
1	2	-	1	-	2	2
2	3	-	1	-	3	3
3	3	-	1	-	3	3
4	3	-	1	-	3	3
5	3	-	1	-	3	3
Avg.	2.8	-	1	-	2.8	2.8

RA3051 CHILLED WATER AND AIR HANDLING SYSTEMS

	L	T	P	C
	3	**0**	**0**	**3**

COURSE OBJECTIVES:

1. To understand the need of Chillers and its operations
2. To Design Chillers for various applications
3. To learn about the selection, classification of Air- Handling units and duct design methods
4. To gain knowledge about the constant and variable volume systems in air handlingsystems.
5. To learn about the ventilation, the test methods for air filters and digital controlling methods for the ventilation

UNIT – I WATER CHILLERS: FUNDAMENTALS, APPLICATION, AND OPERATION 9

Chilled Water for HVAC Applications - Determining the Chilled Water Supply Temperature Establishing the Temperature Range - Chiller Configurations -The Single-Chiller System, Multichiller Systems, One-Pump Parallel Configuration, Multiple-Pump Parallel Configuration, Primary Secondary Parallel Configuration, Variable Primary Flow Parallel Configuration , System Peak Cooling Load and Load Profile, Selecting Water Chillers , Basic Chiller Requirements, Part Load Efficiency. Load versus Capacity, Atmospheric Impacts, Mixed Energy Source Chiller Systems

UNIT – II CHILLER DESIGN AND APPLICATION 9

Chilled Water System Elements, Chiller Placement and Installation, Chilled Water Piping- Pump Selection and Piping- Chilled Water System Control and Performance - Cooling Thermal Energy Storage - Special Chiller Considerations

UNIT – III AIR-HANDLING UNITS 9

Psychrometric, Classifications of Air-Handling Units, Main components, Selection of Air-Handling units, economizer cycle, single zone system, multi zone system-Design Consideration, ductdesign static Regain-equal friction-T method.

UNIT IV CONSTANT AND VARIABLE VOLUME SYSTEMS 9

Terminals reheat system, Double-Duct systems, Sub zone heating, Draw-through cooling, Triple-Duct system, Fan Coil Unit, Induction system. Various System Configurations - Hydronic heat pump, Heat recovery and Economizer, Indirect evaporative cooling, Energy conservation and system retrofit.

UNIT V VENTILATION AND AIR CONTROLS 9

Ventilation, Measurements control and exhaust, Air cleaning devices, Rating and Assessments, Test method for air filters, and replacement-Air system, evaluation and control of the thermal Environment, Indoor Air Quality and Outside Air Requirements, Demand control ventilations, Thermostats, Damper and damper motor, Automatic Valves, Direct digital control, Application of fuzzy logic & neural network-Demand control ventilation

TOTAL : 45 PERIODS

COURSE OUTCOMES:

Upon completion of this course, the students will be able to:

1. Know the various Chillers and its operations

2. Design the Chillers, on the Industrial requirements
3. Know the basic terms in psychrometric analysis, briefly about Air-Handling Units and duct design methods.
4. Understand the constant and variable volume systems used in heating and cooling applications
5. Understand the ventilation in work environment, and the digital controlling methods for the ventilation

REFERENCES:

1. Herbert W. Stanford III, HVAC Water Chillers and Cooling Towers Fundamentals, Application, and Operation , Second Edition , CRC PressTaylor & Francis Group Boca Raton London New York , 2011
2. Tseng-Yao Sun Air Handling Systems Design, McGraw-Hill Professional; 1st edition, 1994
3. Allan T. Kirkpatrick & James S. Elleson, cold air distributionsystem design guide, ASHEAC - 1996 USA.
4. John I. Levenhagen, Donald H. Spethmann, HVAC controls and systems, McGraw – Hill International Edition. NY – 1992.
5. Shan K.Wang, Handbook of Air-conditioning and Refrigeration, McGraw -Hill, 2001
6. SMACNA, HVAC System Duct Design, SMACNA Virginia - 1990.

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	2	3	3	3	1	1
2	2	1	2	3	3	1
3	3	1	3	3	2	1
4	3	1	3	3	2	1
5	2	1	3	3	2	1
Avg.	2.4	1.4	2.8	3	2	1

RA3052 COLD CHAIN SYSTEMS AND MANAGEMENT

L	T	P	C
3	0	0	3

COURSE OBJECTIVES:

- To teach the fundamentals, concepts and types, facilities of various cold chains and its application for various sectors including socio-economic and environmental impacts.

UNIT – I FUNDAMENTALS 9

History of Cold storage, Traditional Methods, Modern Storage Methods, Controlled Atmosphere Storage, Modified Atmosphere Packing, Socio-economic and environmental impacts.

UNIT – II COLD CHAIN & REFRIGERATION 9

Cold chain – Components, Refrigerators, Logistics Management. Electrical Cold chain Equipment – Walk-in-Freezers, Walk-in-Coolers, Deep Freezers, Growth of Cold Storage industries

UNIT – III COLD CHAIN APPLICATIONS 9

Food cold chains – Handling, Storage & Transportation of Citrus, Mango, Pear, Banana, sub-tropical fruits, Fish and Meat. Medicinal and Vaccine cold chains.

UNIT – IV MANAGEMENT OF COLD CHAIN 9

Product Characteristics – Temperature & Humidity, Time, Chilling and Freezing Injury, Respiratory Metabolism. Monitoring Tools – Temperature Sensors, IoT, DAC, SCADA. Temperature Management – Multi-commodity management, Optimal Target Temperature Methods. Quality Assessment Methodologies.

UNIT – V WAREHOUSE 9

Types, Construction, Location, Functions, Site Selection, Storage Capacity, Basic Warehouse Equipment, Renewable energy based warehouses, Cost analysis.

TOTAL: 45 PERIODS

COURSE OUTCOMES:

Upon completion of this course, the students will be able to:

1. Classify the various types of cold chains and its applications.
2. Select the appropriate cold chain refrigeration system for various applications.
3. Elucidate the thrust applications of cold chain in Food and Healthcare sectors.
4. Infer the different control strategies in cold chain.
5. Design and analyse the warehouse for cold storage applications.

REFERENCES:

1. Myo Min Aung, Yoon Seok Chang, Cold Chain Management, Springer, 2022.
2. Ajay Kumar Gupta, The Complete Book on Cold Storage, Cold Chain & Warehouse, NIIR project consultancy services, 2022.
3. Chandra Gopala Rao, Engineering for Storage of Fruits and Vegetables: Cold Storage, Controlled Atmosphere Storage, Modified Atmosphere Storage, Elsevier, 2015.
4. Majeed Mohammed, Vijay Yadav Tokala, Cold Chain Management for the Fresh Produce Industry in the Developing World, CRC Press, 2021.
5. Luis Ruiz-Garcia, Development of Monitoring Systems for Cold Chain Logistics: Improving Food Safety through Emergent Sensing Technologies in the Cold Supply Chain, Lambert Acad. Publ., 2010.

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	1	-	2	2	2	-
2	1	-	1	2	2	-
3	1	-	1	2	1	-
4	1	-	1	1	1	-
5	2	-	3	2	2	-
Avg.	1.2	-	1.6	1.8	1.6	-

RA3002 CLEAN ROOM AND DESIGN PRACTICES

L	T	P	C
3	0	0	3

COURSE OBJECTIVES:

- To teach the concepts of clean rooms its classification and its standards.
- To teach clean room design and the requirements of the components and filtration. To teach constructional features of clean room
- To teach high efficiency filtration techniques related to clean rooms
- To teach estimation of its cost and efficiency of clean rooms for various applications.

UNIT– I INTRODUCTION 9

The History of Clean rooms -classification - Containment of Contamination, different contaminants - Supply of Liquid and Gases to Clean rooms, clean room standards- International Standards for the Design of Clean rooms, clean room Classes-Present Engineering Classes, New ISO Classification Standard, Bio contamination and Pharmaceutical Classes, Containment Classes, Recommended practices - Other Standards for the Clean room, Abbreviations/ Source Code

UNIT– II CLEAN ROOM DESIGN 9

Microelectronics Industry-Manufacturing Semiconductor Circuits, Design Guidelines, Design Features–Air flow pattern, air quantity, Pharmaceutical Industry-Types of Pharmaceutical Processes, Facility Design, Environmental Cleanliness, Commissioning, and Performance Qualification, Medical Device Industry, Biotechnology Industry, manufacturing industry, Hospitals

UNIT–III HIGH EFFICIENCY AIR FILTRATION 9

Filter Structure- Flow Patterns and Pressure Drop – Particle capture -Effects of loading - Construction of High-Efficiency Filters-HEPA Filters, ULPA Filters, Particle Removal Mechanisms, High-Efficiency Filter Testing of High Efficiency Filters, Filter Housings for High-Efficiency Filters, In service Tests for High- Efficiency Filters, Filter Standards.

UNIT– IV CONSTRUCTIONAL FEATURES 9

General Considerations, Performance Criteria of Construction Materials and Surfaces, Specific Components, Materials and Features of Construction, Assembly, Materials for Services Pipe work- Metallic Pipeline Materials, Polymeric Pipeline Materials.

UNIT– V COST AND ENERGY EFFICIENCY 9

Air Flow Rate Optimum for Cost, Optimization of Energy Consumption in Clean room Systems, Cost Indications.

TOTAL:45PERIODS

OUTCOMES:

Upon completion of this course, the students will be able to:

1. Identify the energy storage technologies for suitable applications.
2. Analyze the energy storage systems usingTRNSYS.
3. Recognize the concepts and types of batteries.
4. Diagnose the principle operations of Hydrogen and Biogas storage.
5. Analyze the concepts of Flywheel and compressed energy storage systems

REFERENCES:

1. Engt Ljungqvist and Berit Reinmuller CLEAN ROOM DESIGN: Minimizing Contamination , Through Proper Design, CRC; 1edition,1996.

2. DavidM.Carlberg, Cleanroom Microbiology for the Non-Microbiologist, Second Edition CRC; 2edition, 2004.
3. Michael Kozicki., Cleanrooms: Facilities and Practices, Springer Science & Business Media, 2012.
4. Whyte W.,Clean room Design, Second Edition,JohnWiley&Sons,1999.
5. Whyte W., Clean room Technology: Fundamentals of Design, Testing and Operation Wiley,2001.

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	2	-	3	1	3	2
2	3	-	3	3	3	2
3	3	-	2	2	2	3
4	3	-	2	2	2	2
5	2	-	3	1	2	3
Avg.	2.6	-	2.6	1.8	2.4	2.4

RA3003 SUSTAINABILITY FOR BUILDINGS

	L	T	P	C
	3	0	0	3

COURSE OBJECTIVES:

- To impart strategies and technologies for assessing energy utilization in building and improving energy efficiency
- To introduce the sustainability concepts in buildings.

UNIT – I FUNDAMENTALS 9

Overview of climatic zones & Global trends in building energy consumption. Energy utilisation pattern in Buildings, Thermal load in buildings, shading, Daylighting.

UNIT – II BUILDING MATERIALS 9

Building Materials – Heritage Buildings, Thermal, optical, hygrometric & acoustic properties. Insulation Materials – Loose fill, Sprayed, Foamed, Batts & Boards, thermal performance of insulation materials. Glazing Materials – Properties, Advanced innovative materials. Roofs – Materials, Types, Cool roofs

UNIT – III ENERGY MODELLING OF BUILDINGS 9

General approaches, Forward and data-driven model, simplified methods and special applications, Simulation tools – Commercial and open source, validation of tools and calibration procedure.

UNIT – IV BUILDING ENERGY EFFICIENCY 9

Review of energy standards / codes, Life cycle analysis, Development of Green buildings and ratings, Energy Efficiency in Buildings – Trends & Perspectives, Office Buildings, Commercial buildings, Hospitals, Hotels, Schools.

UNIT – V SUSTAINABILITY 9

Building integrated Photo-Voltaics – Components and system design, Benefits & Barriers, Future opportunities. Solar space heating and cooling – Air & Water systems, Zero Energy Buildings, Net Zero Energy Buildings – Energy Balance, Micro grid, Energy Storage, Building energy management system, retrofitting of building envelope, Case studies.

TOTAL: 45 PERIODS

COURSE OUTCOMES:

Upon completion of this course, the students will be able to:

1. Understand energy consumption and usage pattern in buildings.
2. Select the suitable materials for energy efficient buildings.
3. Utilise the various model for computing performance of buildings.
4. Demonstrate the various methods for enhancing the energy efficiency in buildings.
5. Summarise the adaption of various methods towards sustainability.

REFERENCES:

1. Mattheos Santamouris, Olatz Irulegi, Sofia-Natalia Boemi, Energy Performance of Buildings: Energy Efficiency and Built Environment in Temperate Climates, Springer, 2015.
2. Matthew R Hall, Materials for Energy Efficiency and Thermal Comfort in Buildings, Elsevier, 2010.
3. Francesco Asdrubali, Umberto Desideri, Handbook of Energy Efficiency in Buildings: A Life Cycle Approach, Elsevier, 2018.
4. Dorota Chwieduk, Solar Energy in Buildings: Thermal Balance for Efficient Heating and Cooling, Elsevier, 2014.
5. Moncef Krarti, Optimal Design and Retrofit of Energy Efficient Buildings, Communities, and Urban Centers, Elsevier, 2018.
6. Ali Sayigh, Sustainability, Energy and Architecture: Case Studies in Realizing Green Buildings,

Elsevier, 2013.

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	1	1	2	2	-	1
2	1	1	2	2	-	1
3	2	1	1	3	-	1
4	3	1	-	-	2	1
5	1	2	-	2	3	2
Avg.	1.6	1.2	1.67	2.25	2.5	1.2

EY3061 **ENERGY STORAGE TECHNOLOGIES**

L	T	P	C
3	0	0	3

OBJECTIVE:

To understand the significance and need for various types of energy storage technologies and their uses for real world applications. This course will also enable students to understand the Green Energy Storage of Hydrogen and the challenges associated

UNIT – I INTRODUCTION TO ENERGY STORAGE 9

Necessity of Energy Storage – Types of Energy Storage – Thermal, Mechanical, Chemical, Electrochemical and Electrical - Comparison of Energy Storage Technologies.

UNIT – II THERMAL ENERGY STORAGE SYSTEM 9

Thermal Energy Storage – Types – Sensible, Latent and Thermo-chemical – Sensible Heat Storage - Simple water and rock bed storage system – pressurized water storage system – Stratified System - Latent Heat Storage System - Phase Change Materials – Simple units, packed bed storage units - Other Modern Approaches.

UNIT – III ELECTRICAL ENERGY STORAGE 9

Batteries - Fundamentals and their Working – Battery performance, Charging and Discharging - Storage Density - Energy Density - Battery Capacity - Specific Energy - Memory Effect - Cycle Life - SOC, DOD, SOL - Internal Resistance - Coulombic Efficiency and Safety issues. Battery Types - Primary and Secondary – Lead Acid, Nickel – Cadmium, Zinc Manganese dioxide, Zinc-Air, Nickel hydride, Lithium Ion.

UNIT – IV HYDROGEN ENERGY STORAGE 9

Hydrogen Storage Options – Physical and Chemical Methods - Compressed Hydrogen – Liquefied Hydrogen – Metal Hydrides, Chemical Storage - Other Novel Methods - comparison - Safety and Management of Hydrogen - Applications - Fuel Cells.

UNIT – V ALTERNATE ENERGY STORAGE TECHNOLOGIES 9

Flywheel, Super Capacitors - Pumped Hydro Energy Storage System - Compressed Air Energy Storage System, SMES - Concept of Hybrid Storage – Principles, Methods, and Applications - Electric and Hybrid Electric Vehicles.

TOTAL: 45 PERIODS

OUTCOMES:

Upon completion of this course, the students will be able to:

CO1 Identify the energy storage technologies for suitable applications.
CO2 Apply the appropriate thermal energy storage methods suitably.
CO3 Introduce the concepts, types and working of various batteries.
CO4 Understand the use of Hydrogen as Green Energy for our Future.
CO5 Recognize and choose appropriate methods of Energy Storage and Hybrid Systems.

REFERENCES:

1. Ibrahim Dincer and Mark A. Rosen, “Thermal Energy Storage Systems and Applications”, John Wiley & Sons 2002.
2. James Larminie and Andrew Dicks, “Fuel cell systems Explained”, Wiley publications, 2003.
3. Luisa F. Cabeza, “Advances in Thermal Energy Storage Systems: Methods and Applications”, Elsevier Woodhead Publishing, 2015.

4. Robert Huggins, “Energy Storage: Fundamentals, Materials and Applications”, 2nd edition, Springer, 2015.
5. Ru-shiliu, Leizhang, Xueliang sun, “Electrochemical technologies for energy storage and conversion”, Wiley publications, 2012.

Mapping of CO with PO

CO	PO					
	1	**2**	**3**	**4**	**5**	**6**
1	2	3	-	-	3	2
2	2	3	-	-	3	2
3	2	3	-	-	3	3
4	2	3	-	-	3	3
5	2	3	-	-	3	3
Avg	**2**	**2**	**-**	**-**	**3**	**2.6**

SY3051 SOLAR REFRIGERATION AND AIR CONDITIONING

	L	T	P	C
	3	0	0	3

OBJECTIVES:

The major objective of this course is to learn about the utilization of solar energy for cooling applications in both buildings and industries in economical way through the systems such as absorption, adsorption, desiccant and organic Rankine Cycles.

UNIT I THERMODYNAMIC CYCLES FOR SOLAR COOLING 9

Carnot cycles for refrigeration and Heat Pumps, Vapour compression cycle, Absorption Cycle, Adsorption Cycle, Desiccant cycle, Organic Rankine Cycle and Super Critical CO_2 Cycle

UNIT II SOLAR THERMAL COLLECTORS AND STORAGE SYSTEMS 9

Non-concentrating solar collectors, concentrating solar collectors, Collector applications – Medium and high temperature – Sensible and Latent heat Storage, Heat transfer enhancement techniques, Thermal Chemical storages

UNIT III SOLAR THERMAL COOLING TEHCNOLOGIES 9

Absorption Systems, Adsorpion systems, Desiccant systems and Ejector Jet systems – Working fluids, Process modeling, Types, Applications, Energy and environment analysis – Thermo economic analysis for both cooling and heating applications

UNIT IV PV DRIVEN COOLING AND HEATING SYSTEMS ` 9

PV cell, Design of PV systems for Vapour compression cycles, Thermo electric cycle, Solar PV based chillers, Photvoltatic thermal systems - Energy and environment analysis – Thermo economic analysis for cooling applications

UNIT V ALTERNATE AND HYBRID COOLING SYSTEMS 9

Alternate cooling systems – humidification, Stirling, thermo chemical cooling, electro chemical, Hybrid cooling systems – desiccant compression cycle, compression-absorption cycle, adsorption-compression, Organic Rankine – absorption cycle, absorption-desiccant, ejector - compression cycles.

TOTAL : 45 PERIODS

COURSE OUTCOMES:

Upon completion of this course, the students will be able to:

CO1 Analyze the performance of different thermodynamic solar cooling cycles.
CO2 Design the different types of solar collectors for a given cooling load.
CO3 Understand and Analyze the performance of solar thermal based chillers.
CO4 Design the solar PV powered cooling system
CO5 Apply various alternate and hybrid systems for cooling applications

REFERENCES

1. Sotirios Karellas, Tryfon C Roumpedakis, Nikolaos Tzouganatos, Konstantinos Braimakis, "Solar Cooling Technologies (Energy Systems)", CRC Press, 2019
2. Alefeld G. and Radermacher R., "Heat Conversion Systems", CRC Press, 2004.
3. ASHRAE Hand Book–HVAC Systems & Equipment, ASHRAE Inc. Atlanta, 2008.
4. McVeigh J.C. and Sayigh A.A.M. " Solar Air Conditioning and Refrigeration", Pergamon Press,1992.
5. Reinhard Radermacher, S AKelin and K Herold, " Absorption chillers and heat

pumps”, CRCPress, 1996.

Mapping of CO with PO

CO	PO					
	1	**2**	**3**	**4**	**5**	**6**
1	3	2	2	-	3	-
2	3	2	3	-	3	-
3	2	2	3	-	3	-
4	2	2	3	-	3	-
5	2	2	3	-	3	-
Avg.	**2.4**	**2**	**2.8**	**-**	**3**	**-**

RA3004 FUNCTIONAL MATERIALS

	L	T	P	C
	3	0	0	3

OBJECTIVES:

- To gain understanding of the various forms of crystals, principles of theirsynthesis techniques and some characterization techniques
- To gain an understanding of the principles underlying the properties of functional of materials
- To understand the electronic, magnetic, and optical properties of materials
- To acquire knowledge on how materials are tailor-made for specific applications
- To teach the materials for polymer electronics

UNIT I INTRODUCTION 9

Historical Perspectives, Lessons from the Nature, Engineering the Functions, Tuning the functions, Multiscale Modeling and Computation, Classification of Functional Materials, Functional Diversity of Materials, Hybrid Materials, Technological Relevance, Societal Impact.

UNIT II SYNTHESIS AND FABRICATION OF FUNCTIONAL MATERIALS 9

Carbon nanotube, graphene, chalcogenide quantum dots, nanowires and nanobelts, multiferroics, superconducting oxides, and intermetallics, GMR oxides, nonlinear optical crystals, and other novel functional materials; Preparation of bulk polycrystalline materials and composites; Preparation of nanomaterials

UNIT III TECHNIQUES OF CHARACTERIZATION 9

Destructive Techniques: Principles of chemical analysis, DTA, TGA, DSC - Non-Destructive Techniques: use of x-ray electron and neutron diffraction techniques; density determination, electrical transport, and magnetic properties; Surface area measurements and hardness testing, basics of electron microscopy, microstructure analysis.

UNIT IV APPLICATIONS OF FUNCTIONAL MATERIALS 9

Introduction to Functional Materials and their applications - Transport, Dielectric, Magnetic and Optical Properties Functional Materials for Energy applications,
Materials for Solar Power, Hydrogen Storage Materials, Materials for Fuel Cells, Materials for Energy Storage Multifunctional and Smart Materials

UNIT V MATERIALS FOR POLYMER ELECTRONICS 9

Polymers for Electronics, Organic Light Emitting Diodes, Working Principle of OLEDs, Illustrated Examples, Organic Field-Effect Transistors Operating Principle, Design Considerations, Polymer FETs vs Inorganic FETs, Liquid Crystal Displays, Engineering Aspects of Flat Panel Displays, Intelligent Polymers for Data Storage, Polymer-based Data Storage-Principle, Magnetic Vs. Polymer-based Data Storage.

TOTAL: 45 PERIODS

OUTCOMES:

- Students will be able to differentiate among various functional properties and select appropriate material for certain functional applications, analyze the nature and potential of functional material.
- It will enable students to synthesize and characterize different materials.

TEXT BOOKS:

1. Vijayamohanan K. Pillai and Meera Parthasarathy, “Functional Materials: A Chemist’s Perpective”, Orient Blackswan publisher (2013)
2. Hasse Fredriksson and Ulla Ãkerlind, “Physics of Functional Materials”, Wiley Blackwell publisher (2008)

REFERENCES:

1. Stephen Manne "Biomimetic Materials Chemistry" Wiley-VCH New York, 1966.
2. Engineering Materials for Technological Needs: Volume 2 Functional Materials Electrical, Dielectric, Electromagnetic, Optical, and Magnetic Applications Deborah D L Chung Publishers: World Scientific (2010)
3. Advanced Functional Materials (Advanced Material Series) Ashutosh Tiwari and Lokman Uzun Publisher: John Wiley & Sons (2015)
4. Functional Materials for Sustainable Energy Applications Edited by J A Kilner, S J Skinner, S J C Irvine, and P P Edwards Copyright Â© 2015 Elsevier B.V.

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	2	-	1	1	1	1
2	2	-	1	1	1	1
3	3	-	2	1	1	1
4	3	-	3	1	2	1
5	3	-	1	-	-	-
Avg.	2.6	-	1.6	1	1.25	1

RA3056	ENERGY AUDIT FOR HVAC SYSTEMS	L	T	P	C
		3	0	0	3

COURSE OBJECTIVES:

- To emphasise the essentiality and impart knowledge on energy audit in HVAC systems.

UNIT – I INTRODUCTION 9

Types of energy audit – Utility cost, Standard and Detailed Energy Audit, General Procedure. Energy Utility rates, Conventional & Renewable energy sources. Energy use Graphs

UNIT – II ELECTRICAL ENERGY AUDIT 9

Overview of Electrical equipment, Electrical Distribution system, Power Factor, Power quality, Various devices for electrical energy audit in Motors, Lighting systems – Fluorescent Lamps, Compact Fluorescent Lamps, Compact Halogen Lamps, LED, Lighting Controls, Appliances.

UNIT – III HVAC ENERGY AUDIT 9

Audit procedure – Commercial Buildings, Average annual energy performance, Electrical Loads, Electricity usage pattern, Thermal load calculation with respect to season for heating and cooling. Residential Buildings – Energy Consumption history, Energy evaluation – Outside wall, ceiling and roof evaluation, windows and doors. General forms and report preparation based on case studies.

UNIT – IV ENERGY AUDIT INSTRUMENTS 9

Electrical Measuring Instruments - Capacity, Power, Power Factor, Frequency, Reactive Power. Digital Multimeter, Power analyser. Thermometer – Contact, Non-contact. Hygrometer, Flow – Pitot, Ultrasonic, Coriolis. Speed – Tachometer, RADAR. Gas Leak Detectors, Lux Meters, Distance Meter, IAQ meter, Flue gas – Combustion analyser, Fyrite, Fuel Efficiency Monitor.

UNIT – V CASE STUDIES 9

Case Studies in Apartments, Schools, Colleges, Grocery Store, Hotel, IT park, Data Centres. Estimation and Forecasting of Carbon footprint. Building Energy management through Machine learning techniques.

TOTAL: 45 PERIODS

COURSE OUTCOMES:

Upon completion of this course, the students will be able to:

1. Explain the standard procedure for performing energy audit.
2. Relate the energy consumption of various electrical equipment and consumption patterns.
3. Estimate the energy consumption of electrical & HVAC appliances.
4. Make use of the various instruments used for energy audit.
5. Analyse the energy consumption in various sectors of buildings.

REFERENCES:

1. Moncef Krarti, Energy Audit of Building Systems, CRC Press, 2020.
2. Herbert C. Wendes, HVAC Procedures & Forms Manual, River Publishers, 2020.
3. Steve Doty, Commercial Energy Auditing Reference Handbook, Fairmont Press, 2011.
4. Tarik Al-Shemmeri, Energy Audits: A Workbook for Energy Management in Buildings, Wiley, 2011.
5. Chandan Kumar Shiva, Mohan Rao Ungarala, Shriram S. Rangarajan, Vedik Basetti, Artificial Intelligence and Machine Learning in Smart City Planning, Elsevier, 2003.

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	1	2	-	2	-	1
2	1	2	-	2	-	1
3	1	3	-	3	-	1
4	1	-	-	2	-	1
5	1	3	-	1	-	2
Avg.	1	2.5	-	2	-	1.2

RA3005	TURBOMACHINERY FOR HVAC SYSTEMS	L	T	P	C
		3	0	0	3

COURSE OBJECTIVES:

- To impart the fundamentals concepts, design and selection of turbomachines for HVAC applications.

UNIT – I FUNDAMENTALS 9

Static parameters – Pressure, Temperature, Velocity. Performance Characteristics, Dimensional Analysis, Similitude, Euler equation for Turbomachines, Fan laws, Losses, System resistance, Cordier Diagram, Airfoil shape, Airfoil Performance – Lift, Drag, Moment, AMCA standards.

UNIT – II CENTRIFUGAL FANS & BLOWERS 9

Terminology, Construction – Size and class, Drive arrangements, Flow Pattern, Types of Blades, Effect of Inlet Guide Vanes, Velocity Triangle, Selection of Centrifugal fans, Casing, Methods of varying fan volume, Noise and vibration control, Safety devices.

UNIT – III AXIAL, CROSS FLOW & VORTEX FANS / BLOWERS 9

Construction, Velocity triangle, Flow pattern, Performance of axial, cross & vortex blowers, Design of axial blower, Comparison, Noise level, applications.

UNIT – IV APPLICATIONS OF FANS & BLOWERS 9

Fans / Blowers in series, parallel, Air flow through ventilation system, pressure losses, Variation of static pressure in ventilation system, Roof ventilators, Tunnel ventilation, Mines ventilation. Air Distribution system for small / medium / Large capacity HVAC applications.

UNIT – V COMPRESSORS 9

Compressors for HVAC systems – Types, Construction, Open, hermetic and semi sealed, Drives, performance characteristics, part load operation, compressor cooling, Capacity control. Compressors for Cascade & Cryogenics applications – Selection. Recent developments.

TOTAL: 45 PERIODS

COURSE OUTCOMES:

Upon completion of this course, the students will be able to:

1. Infer the fan curves and system resistance of various types of fans.
2. Analyse the characteristics of different centrifugal fans & blowers.
3. Select the appropriate axial fans for specific applications.
4. Outline the applications of fans & blowers in different fields.
5. Elucidate the compressors and controls in HVAC systems.

REFERENCES:

1. S. L. Dixon, C. A. Hall, Fluid Mechanics and Thermodynamics of Turbomachinery, B&H, 2014.
2. WTW Bill Cory, Fans & Ventilation: A Practical Guide, Elsevier, 2010.
3. Erik Dick, Fundamentals of Turbomachines, Springer, 2015.
4. R. I. Lewis, Turbomachinery Performance analysis, Elsevier, 1996.
5. Frank P. Bleier, Fan Handbook: Selection, Application and Design, Mc-Graw Hill, 1998.
6. Royce N. Brown, Compressors: Selection & Sizing, Elsevier, 2011.

Mapping of CO with PO

CO	PO					
	1	2	3	4	5	6
1	2	-	2	2	-	1
2	2	-	2	2	-	1
3	-	-	2	2	-	1
4	1	-	1	3	-	1
5	2	-	2	3	-	1
Avg.	1.75	-	1.8	2.4	-	1