

GUJARAT TECHNOLOGICAL UNIVERSITY, AHMEDABAD, GUJARAT

**COURSE CURRICULUM
COURSE TITLE: THERMAL SYSTEMS AND ENERGY EFFICIENCY
(COURSE CODE: 3361907)**

Diploma Programme in which this course is offered	Semester in which offered
Mechanical Engineering	Sixth

1. RATIONALE.

Thermal systems are most important part of industrial sector. In the absence of proper operation & maintenance of thermal systems it becomes difficult to manage economic use of energy and its conservation with the least damage to the environment. This course provides the underpinning knowledge and skills related to principles, types & working of these systems like boilers, heat exchangers, furnaces, HVAC etc. which are normally high energy consumption devices. Study of this course would help students to choose proper design and specifications of these high energy consuming devices so that energy is saved in resulting low cost of production as well as less damage to environment. This course is therefore a key course for thermal engineers.

2. COMPETENCY.

The course content should be taught and implemented with the aim to develop required skills in the students so that they are able to acquire following competency:

- **Apply concepts, laws and principles of thermal systems to operate and maintain them for efficient use of energy and its conservation as per industrial norms & regulations.**

3. COURSE OUTCOMES (COs).

The theory should be taught and practicals should be carried out in such a manner that students are able to acquire different learning outcomes in cognitive, psychomotor and affective domain to demonstrate following course outcomes.

- Select available energy sources in a given situation.
- Determine boiler performance based on energy efficiency parameters.
- Analyze performance of furnace for a particular application.
- Determine the performance of heat exchanger in a given situation.
- Calculate load of HVAC systems.

4. TEACHING AND EXAMINATION SCHEME.

Teaching Scheme (In Hours)				Total Credits (L+T+P)	Examination Scheme			
					Theory Marks		Practical Marks	
L	T	P	C	ESE	PA	ESE	PA	150
03	00	02	05	70	30	20	30	

Legends: L-Lecture; T – Tutorial/Teacher Guided Theory Practice; P -Practical; C – Credit, ESE -End Semester Examination (3 hours duration) ; PA - Progressive Assessment.

5. COURSE CONTENT DETAILS.

Unit	Major Learning Outcomes (in cognitive domain)	Topics and Sub-topics
Unit – I. Introduction to Energy Sources and Thermal Systems.	1a. Compare various energy sources & forms. 1b. Differentiate various renewable and non-renewable energy sources. 1c. Explain Energy conservation and related act. 1d. Describe basic concepts of various thermal systems.	1.1 Energy sources: <ol style="list-style-type: none"> i. Primary and secondary. ii. Commercial energy and non-commercial. iii. Various forms of energy, i.e. potential energy (chemical, nuclear or stored mechanical, gravitational energy), kinetic energy (radiant, thermal, motion, sound, electrical energy) and high grade energy and low grade energy. iv. Renewable and nonrenewable. 1.2 Energy conservation and its importance. 1.3 Overview of Energy Conservation Act 2001. 1.4 Introduction to various thermal systems like furnace, steam generation and distribution system, heat exchanger, HVAC(Heating, Ventilating and Air Conditioning) and refrigeration system, cogeneration system (concept, need and principle based on steam and gas turbine cogeneration system), air compressor.
Unit – II Boilers.	2a. Determine performance of boilers by direct and indirect method. 2b. Analyze effect of energy efficiency parameters on performance of boiler. 2c. Describe energy saving measures in steam distribution system.	2.1 Performance evaluation of typical boiler system (Attached data sheet is allowed in exams): <ol style="list-style-type: none"> i. Indirect method. ii. Direct method. 2.2 Energy efficiency measures in boiler system. 2.3 Steam distribution system and concept of steam pipe sizing. 2.4 Steam traps-operation and maintenance of: <ol style="list-style-type: none"> i. Float and thermostatic. ii. Thermodynamic. iii. Inverted bucket. iv. Thermostatic with thermal element (Bellow or bi-metallic strip). 2.5 Energy saving in steam distribution systems.
Unit – III Furnaces.	3a. Describe concept and types of furnaces. 3b. Determine the performance of heat treatment furnaces.	3.1 Concept of furnace. 3.2 Classification and working of furnaces: <ol style="list-style-type: none"> i. Forging furnace. ii. Rerolling mill furnace (batch type, continuous pusher type, continuous steel reheating furnace,(pusher type, walking hearth type, rotary hearth

Unit	Major Learning Outcomes (in cognitive domain)	Topics and Sub-topics
	3c. Derive energy efficiency parameters.	type, continuous recirculating bogie type etc.). 3.3 Heat transfer in furnaces. 3.4 Performance evaluation of typical heat treatment furnace system (Attached data sheets are allowed in exams). i. Indirect method. ii. Direct Method. 3.5 Energy efficiency measures in furnace systems.
Unit – IV Heat Exchangers and Air Compressor.	4a. Differentiate heat exchangers. 4b. Determine performance of Heat exchangers based on given method. 4c. Describe energy saving measures in air compressor.	4.1 Heat exchangers: types and classification. 4.2 Performance evaluation of heat exchangers based on LMTD and NTU methods (Attached data sheets are allowed in exams). 4.3 Air compressor: Free air delivery (Attached data sheets are allowed in exams), energy saving measures.
Unit – V HVAC systems.	5a. Use concept of HVAC and refrigeration system. 5b. Calculate load of HVAC system based on given data	5.1 Concept of HVAC and refrigeration system. 5.2 Selection criteria for suitable refrigeration system. 5.3 Load calculation for refrigeration/ air conditioning system, such as: room, restaurant, cold storage, theatre, conference hall, sweet shop, etc. (Attached data sheets are allowed in exams). 5.4 Energy efficiency measures in refrigeration/ air conditioning systems.

6. SUGGESTED SPECIFICATION TABLE WITH HOURS AND MARKS (THEORY).

Unit No.	Unit Title	Teaching Hours	Distribution of Theory Marks			
			R Level	U Level	A Level	Total Marks
I	Introduction to Energy Sources and Thermal Systems.	06	02	04	02	08
II	Boilers.	08	02	03	09	14
III	Furnaces.	08	02	04	12	18
IV	Heat Exchangers and Air Compressors.	10	02	03	09	14
V	HVAC systems.	10	02	04	10	16
	Total	42	10	18	42	70

Legends: R = Remember U= Understand; A= Apply and above levels (Bloom's revised taxonomy).

Notes:

- This specification table shall be treated as a general guideline for students and teachers. The actual distribution of marks in the question paper may vary slightly from above table.
- Duration of End Semester Examination (Theory) is 3 hours.**
- If mid-sem test is part of continuous evaluation, unit numbers I, II and IV are to be considered.
- Ask the questions from each topic as per marks weightage. Numerical questions are to be asked only if it is specified. Optional questions must be asked from the same topic.
- Use of enclosed data sheets are to be allowed to student during examination (They should be provided by the examining agency).
- In examination, example of same chapter is to be asked in place of example.

7. SUGGESTED LIST OF EXERCISES/PRACTICALS.

The practical/exercises should be properly designed and implemented with an attempt to develop different types of skills (**outcomes in psychomotor and affective domain**) so that students are able to acquire the competencies/programme outcomes. Following is the list of practical exercises for guidance.

*Note: Here only outcomes in psychomotor domain are listed as practical/exercises. However, if these practical/exercises are completed appropriately, they would also lead to development of certain outcomes in affective domain which would in turn lead to development of **Course Outcomes related to affective domain**. Thus over all development of **Programme Outcomes (as given in a common list at the beginning of curriculum document for this programme)** would be assured.*

Faculty should refer to that common list and should ensure that students also acquire outcomes in affective domain which are required for overall achievement of Programme Outcomes/Course Outcomes.

Sr. No.	Unit No.	Practical Exercises (outcomes in Psychomotor Domain)	Approx Hours required
1	I to V	Preparatory activity: a. Visit laboratory/ workshop and identify various thermal systems such as heat exchangers, boilers, furnaces, air compressors, etc. Write down technical specifications of the same along with manufactures. b. Compare price of various fuels. c. Plot sankey diagram for given data. d. Interpret terms and equations of data sheets provided with the curriculum.	04
2	II	Case study (based on real life example): a. Calculate losses in the boiler using given data by direct and indirect method. b. Prepare sankey diagram. c. Prepare heat balance sheet. d. List various instrumentation required to measure the required data.	04
3	III	Case study (based on real life example):	04

		<ul style="list-style-type: none"> a. Calculate losses in the furnace using given data by direct and indirect method. b. Prepare sankey diagram. c. Prepare heat balance sheet. d. List various instrumentation required to measure the required data. 	
4	IV	<p>Case study (based on real life example):</p> <ul style="list-style-type: none"> a. Calculate efficiency and over all heat transfer co efficient of heat exchanger based on given data. Use LMTD or NTU methods. b. List various instrumentation required to measure the required data. <p style="text-align: center;">OR</p> <ul style="list-style-type: none"> a. Write technical specifications of any heat exchanger available in vicinity. b. Determine its performance based on the technical data available. Tabulate the observation. c. List the parameters which lead to energy losses in heat exchangers. Also show the effect of such parameters. d. Recommend your suggestions for energy saving in heat exchangers. 	04
5	V	<p>Case study (based on real life example):</p> <ul style="list-style-type: none"> a. Calculate air conditioning load of given room/ conference hall. Use standard data sheets. (Volume not more than 80-100 m³.) b. List various instrumentation required to measure the required data. 	06
6	V	<p>Case study (based on real life example):</p> <ul style="list-style-type: none"> a. Calculate refrigeration/ air conditioning load of given theater/ restaurant/cold storage. Use standard data sheets. (Volume >200 m³.) b. List various instrumentation required to measure the required data. 	06
Total Hours			28

Notes:

- a. It is compulsory to prepare log book of exercises. It is also required to get each exercise recorded in logbook, checked and duly dated signed by teacher. PA component of practical marks is dependent on continuous and timely evaluation and submission of exercises.
- b. Term work report must not include any photocopy/ies, printed manual/pages, litho, etc. It must be hand written / hand drawn by student only.
- c. For practical ESE part, students are to be assessed for competencies achieved. They should be given experience/part of experience to perform.

8. SUGGESTED LIST OF STUDENT ACTIVITIES.

SR.NO.	ACTIVITY
1	List thermal systems employed in your house, shops, malls in nearby area. Identify the parameters which lead to energy losses. List energy saving measures.
2	Visit any industry and find the major areas boilers/ furnaces/ air compressor system/ heat exchangers etc. from point of energy conservation.

3	Present seminar on energy conversion act 2001 and latest amendments.
4	Visit any small shop where refrigeration repairing or maintenance work is done. List the equipments used in the refrigeration maintenance with its technical data. Prepare a layout of shop. List different work carried out for maintenance in refrigeration/ air conditioning. Prepare a report along with photographs of the equipments.

9. SPECIAL INSTRUCTIONAL STRATEGIES (if any).

Sr. No.	Unit	Unit Name	Strategies
1	I	Introduction to energy sources and thermal systems.	Demonstration of systems, movies, industrial visits, on-hand practice on available systems.
2	II	Boilers.	Standard data of boiler room and other auxiliaries from real life example, Industrial visits, movies.
3	III	Furnaces.	Standard data of furnace room and other auxiliaries from real life example, Industrial visits, movies.
4	IV	Heat exchangers and air compressors.	Standard data of any heat exchanger from thermal plant and air compressor room as well as air compressor system, Industrial visits, and movies.
	V	HVAC systems.	Standard data of load calculation to compare with the calculated load calculations, industrial visits, demonstration of plants having HVAC systems.

10. SUGGESTED LEARNING RESOURCES.

A. List of Books:

S. No.	Title of Book	Author	Publication
1.	Materials science	R.S.Khurmi, R.S.Sedha	S.Chand
2.	Material science	O. P. Khanna	
3.	Guide book for NCE for EM & EA (Vol I to IV)	--	Bureau of Energy Efficiency
4.	Energy Conservation Guide book	Steven R. Patrick, Dale R. Patrick, Stephen W. Fardo	
5.	Energy Management Handbook	Wayne C. Turner	
6.	The Efficient Use of Energy	The Rt Hon Tony Benn, MP	BSI, 2 Park street, London

B. List of Major Equipment/ Instrument with Broad Specifications:

Sr.No.	Resource with brief specification.
1	Experimental setup for Heat exchanger (Plate Heat Type heat exchanger is preferable) Facilities preferable are: In/ out flow quantity of both fluids, In/ Out temperature of both fluids, In/ out pressure drop of both fluids, specific heat of both fluids, number of passes available etc. This parameters are required to measure performance of heat exchanger.

2	Experimental setup for air compressor, boiler already prescribed in thermal engineering-I.
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C. List of Software/Learning Websites.

- i. http://nptel.ac.in/courses/112101005/downloads/Module_4_Lecture_7_final.pdf
- ii. <http://btech.mit.asia/downloads/svlomte/HT2011.pdf>
- iii. http://powermin.nic.in/acts_notification/pdf/ecact2001.pdf
- iv. www.energymanagertraining.com (register for free guide book downloads)
- v. <http://www.ureda.uk.gov.in/upload/downloads/Download-7.pdf>
- vi. <http://www.fao.org/docrep/t0269e/t0269e05.htm>
- vii. <http://energy.gov/eere/government-energy-management>
- viii. http://www.sarienergy.org/PageFiles/What_We_Do/activities/SAWIE/wiser/cap_dev_program_for_afghan_women_march_22-30_2010/PRESENTATIONS/24032010/ENGLISH/Energy_Conservation_Act_2001_NT_Nair.pdf

11. COURSE CURRICULUM DEVELOPMENT COMMITTEE

Faculty Members from Polytechnics.

- **Prof. S. R. Pareek**, Head of Department, Mechanical Engineering, Tolani F. G. Polytechnic, Adipur.
- **Prof. M. N. Patel**, LME, Government Polytechnic, ChhotaUdepur.
- **Dr. Shah Atul S.**, LME, Dr. S & SS Ghandhy Collage of Engineering and Technology, Surat.
- **Prof. Hareesh G. Ranipa**, LME, Shri N M Gopani Polytechnic, Ranpur.
- **Prof. Patadiya Viren N.**, LME, N.M.Gopani Polytechnic, Ranpur.
- **Prof. (Smt.) Krutika V. Prajapati**, LME, Parul Institute of Engineering and Technology, Vadodara.
- **Prof. Patel Rameshbhai Babubhai**, LME, R.C.T.I., Ahmedabad.
- **Prof. Ajbani Vimlesh Chandrakant**, LME, Government Polytechnic, Ahmedabad.

Coordinator and Faculty Members from NITTTR Bhopal.

- **Dr. A.K. Sarathe**, Associate Professor; Department of Mechanical Engineering.
- **Dr. K.K. Jain**, Professor, Department of Mechanical Engineering.

DATA SHEETS (Allowed in Final Examinations) :**1. BOILERS:**Direct method:

$$\text{Boiler Efficiency}(\eta) = (\text{Heat output} / \text{Heat input}) \times 100$$

$$\text{Boiler Efficiency}(\eta) = \frac{M \times (h_g - h_f)}{mf \times \text{GCV}} \times 100$$

where, M	=	Quantity of steam generated per hour in kg/ hr
mf	=	Quantity of fuel used per hour in kg/ hr
GCV	=	Gross calorific value of fuel (kCal/ kg of fuel)
h_g	=	Enthalpy of saturated steam in kCal/ kg of steam
h_f	=	Enthalpy of feed water in kCal/ kg of water
Temperatures are in degree centigrade and pressure in kg/ cm ²		

Indirect Method:

Conversion of proximate analysis into ultimate analysis,

$$\begin{aligned} \%C &= 0.97C + 0.7(VM + 0.1A) - M(0.6 - 0.01M) \\ \%H &= 0.036C + 0.086(VM - 0.1A) - 0.0035M^2(1 - 0.02M) \\ \%N_2 &= 2.10 - 0.020VM \end{aligned}$$

Where, %C	=	% of fixed carbon
A	=	% of ash
VM	=	% of volatile matter
M	=	% of moisture in general notations.

Theoretical air required for combustion:

$$\begin{aligned} \text{Theoretical air required for combustion} &= [11.6C + \{34.8(H_2 - \frac{O_2}{8})\} + 4.35S] / 100 \text{ kg / kg of fuel} \\ \% \text{ Excess air supplied (EA)} &= \frac{O_2 \%}{21 - O_2 \%} \times 100 = \frac{7900[(CO_2\%)_t - (CO_2\%)_a]}{(CO_2\%)_a [100 - (CO_2\%)_t]} \rightarrow \text{From flue gas analysis} \\ (CO_2\%)_t &= \text{Theoretical } CO_2 \\ (CO_2\%)_a &= \text{Actual } CO_2 \% \text{ measured in flue gas} = \frac{\text{Moles of C}}{\text{Moles of } N_2 + \text{Moles of C}} \\ \text{Moles of } N_2 &= \frac{\text{Wt of } N_2 \text{ in theoretical air}}{\text{Mol. wt of } N_2} + \frac{\text{Wt of } N_2 \text{ in fuel}}{\text{Mol. wt of } N_2} \\ \text{Moles of C} &= \frac{\text{Wt of C in fuel}}{\text{Molecular Wt of C}} \\ \text{Actual mass of air supplied / kg of fuel (AAS)} &= [1 + \frac{EA}{100}] \times \text{theoretical air} \end{aligned}$$

$$\text{Total mass of dry flue gas} = \left(C \times \frac{44}{12}\right) + \left(\text{AAS} \times \frac{77}{100}\right) + \left[(\text{AAS} - \text{Theoretical Air}) \times \frac{23}{100}\right] + \left(S \times \frac{64}{32}\right) + N_2$$

$$\% \text{ Loss due to dry flue gas} = L_1 = \frac{m_d \times C_p \times (T_f - T_a)}{\text{GCV of fuel}} \times 100 = \text{Total AAS} + 1$$

Where, m_d = Mass of dry flue gas in kg/ kg of fuel
 = Combustion product from fuel: $\text{CO}_2 + \text{SO}_2 + \text{N}_2$ in fuel + N_2 in actual mass of air supplied + O_2 in flue gas (H_2O /water vapour in the flue gas should not be considered)
 C_p = Specific heat of flue gas in kCal/ kg degree C
 T_f = Flue gas temperature in degree C
 T_a = Ambient temperature in degree C

$$\% \text{ Heat loss due to evaporation of water formed due to } H_2 \text{ in fuel} = L_2 = \frac{9H_2[584 + C_p(T_f - T_a)]}{\text{GCV of fuel}} \times 100$$

$$\% \text{ Heat loss due to moisture present in fuel} = L_3 = \frac{M[584 + C_p(T_f - T_a)]}{\text{GCV of fuel}} \times 100$$

$$\% \text{ Heat loss due to moisture present in air} = L_4 = \frac{\text{AAS} \times \text{Humidity factor} \times C_p(T_f - T_a) \times 100}{\text{GCV of fuel}}$$

where (for L_3 to L_4), H_2 = kg of hydrogen present in fuel on 1 kg basis
 C_p = Specific heat of superheated steam in kCal/ kg degree C
 T_f = Flue gas temperature in C
 T_a = Ambient temperature in C
 584 = Latent heat corresponding to partial pressure of water vapour
 M = kg moisture in fuel on 1 kg basis
 AAS = Actual mass of air supplied per kg of fuel
 Humidity factor = kg of water/ kg of dry air

DBT (Degree C)	WBT degree C	Relative Humidity	Kg water per kg of dry air(Humidity Factor)
20	20	100	0.016
20	14	50	0.008
30	22	50	0.014
40	30	50	0.024

$$\text{Heat loss due to incomplete combustion} = L_5 = \frac{\% \text{CO} \times C}{\% \text{CO} + \% \text{CO}_2} \times \frac{5744}{\text{GCV of fuel}} \times 100$$

Where, L_5 = %Heat loss due to partial conversion of C to CO
 CO = Volume of CO in flue gas leaving economiser %
 CO_2 = Actual volume of CO_2 in flue gas %
 C = Carbon content kg/ kg of fuel

OR

When CO is obtained in ppm during the flue gas analysis

$\text{CO formation}(M_{\text{co}})$ = $\text{CO}(\text{in ppm}) * M_f * 28 * 10^{-6}$
 M_f = Fuel consumption in kg/ he
 L_5 = $M_{\text{co}} * 5744$

$$\% \text{ Heat loss due to radiation \& convection} = L_6 = 0.548 \left[\left(\frac{T_s}{55.55} \right)^4 - \left(\frac{T_a}{55.55} \right)^4 \right] + [1.957 \times (T_s - T_a)^{1.25} \times \sqrt{\left[\frac{(196.85V_m + 68.9)}{68.9} \right]}]$$

Where, L_6 = Radiation loss in W/m^2
 V_m = Wind velocity in m/s
 T_s = Surface temperature (K)
 T_a = Ambient temperature (K)

$$\% \text{ Heat loss due to unburnt in flyash} = L_7 = \frac{\text{Total ash collected per kg of fuel burnt} \times \text{GCV of flyash} \times 100}{\text{GCV of fuel}}$$

$$\% \text{ Heat loss due to unburnt in bottom ash} = L_8 = \frac{\text{Total ash collected per kg of fuel burnt} \times \text{GCV of bottom ash} \times 100}{\text{GCV of fuel}}$$

$$\text{Boiler Efficiency in } \% \eta = 100 - (\text{Addition of } \%L_1 \text{ to } \%L_8)$$

2. Furnace:

Specific energy consumption = **Quantity of fuel or energy consumed/ quantity of material processed.**

Direct Method:

$$\text{Thermal efficiency of furnace} = \frac{\text{Heat in stock (material) in kCal}}{\text{Heat in fuel in kCal}} \times 100$$

$$\text{Heat imparted to stock } Q = mC_p(t_2 - t_1)$$

Where, Q = Quantity of heat in kCal
 m = Mass of material in kg
 C_p = Mean Specific Heat in kCal/ kg degree C
 t_2 = Final temperature desired in degree C
 t_1 = Initial temperature of the charge before it enters the furnace in degree C

Indirect Method:

Calculation of air quantity and specific fuel consumption:

$$\text{Theoretical air required for combustion} = [11.6C + \{34.8(H_2 - \frac{O_2}{8})\} + 4.35S] / 100 \text{ kg / kg of fuel}$$

$$\text{Excess air supplied (EA)} = \frac{O_2\%}{21 - O_2\%} \times 100$$

$$\text{Actual mass of air supplied / kg of fuel (AAS)} = [1 + \frac{EA}{100}] \times \text{theoretical air}$$

$$\begin{aligned} \text{Total mass of dry flue gas} &= \text{Mass of C} + \text{Mass of N}_2 \text{ in fuel} + \text{Mass of SO}_2 + \\ &\quad \text{Mass of N}_2 \text{ in Combustion air supplied} + \text{Mass of O}_2 \text{ in flue gas} \\ \text{or} \\ &= \left(C \times \frac{44}{12}\right) + \left(AAS \times \frac{77}{100}\right) + \left[(AAS - \text{Theoretical Air}) \times \frac{23}{100}\right] + \left(S \times \frac{64}{32}\right) + N_2 \end{aligned}$$

Above values can be taken from proximate or ultimate analysis of fuel.

Specific fuel consumption(F) = Amount of fuel consumed in kg per hour/ amount of billet in tonne per hour

Heat input calculation for furnace heat balance sheet (one tonne basis):

Heat Input = Combustion heat of fuel Q_1 + Sensible heat of fuel Q_2
 = (fuel consumption per tonne of billet * GCV) + (fuel consumption per tonne of billet * C_p of fuel * Temperature difference of flue gas to atmosphere)
 = $Q_1 + Q_2$ in kCal per tonne of billet.

Heat out to furnace calculation for heat balance sheet (on one tonne basis):

$$\text{Heat carried away by 1 tonne of billet} = Q_3 = 1000 \text{ kg / tonne} \times C_p(T_o - T_i)$$

Where, T_o = Temperature of billet at outlet of furnace in degree C
 T_i = Temperature of atmosphere at outlet
 C_p = Specific heat of billets in lCal/ kg/degree C

Sensible heat loss in flue gases:

$$\text{Heat loss in flue gas} = Q_4 = \text{Sensible heat loss} = m \times C_{p_{fg}} \times (T_1 - T_a)$$

Where, m = Amount of fuel consumed per tonne of billet in kg/ tonne of billet.
 C_{pg} = Specific heat of flue gas ~ 0.24 kCal/ kg/degree C
 T_1 = Temperature of flue gas in degree C
 T_a = Temperature of atmosphere at base in degree C
 Assumption: 1 kg of oil require 14 kg of air to burn fully.

$$\text{Heat loss due to formation of water formed due in fuel} = Q_5 = \frac{F \times (M + 9H_2)[584 + C_{p_{\text{sup.heat wat}}}(T_1 - T_a)]}{\text{GCV of fuel}} \times 100$$

Where, $C_{p_{\text{super heated water}}}$ = Specific heat of superheated water vapour in kCal/ kg/degree C

$$\text{Heat loss due to moisture in combustion air} = Q_6 = F \times AAS \times \text{Humidity of air} \times C_{p_{\text{sup.heat wat}}}(T_1 - T_a)$$

$$\text{Heat loss due to partial combustion of } CO = Q_7 = \frac{F \times \%CO \times C}{\%CO + \%CO_2} \times 5654$$

Amount of heat loss from furnace body and other sections Q_7

= heat loss from furnace body ceiling q1 + heat loss from furnace side wall q2+ bottom q3 + heat loss from flue gas duct between furnace exit and air pre heater q4

$$q1 = (h \times \Delta T^{1.25} \times A_i) + (4.88 \times \varepsilon \times [(\frac{T_w}{100})^4 - (\frac{T_a}{100})^4] \times A_i)$$

Where, h = Natural convective heat transfer rate for ceiling in kCal/ m² h degree C
 Tw = External temperature of ceiling in degree C
 Ta = Room temperature in degree C
 Δt = Tw- Ta
 Ai = Ceiling surface area in m²
 ε = emissivity of furnace body surface

$$q2 = (h \times \Delta T^{1.25} \times A_i) + (4.88 \times \varepsilon \times [(\frac{T_w}{100})^4 - (\frac{T_a}{100})^4] \times A_i)$$

Where, h = Natural convective heat transfer rate for side wall in kCal/ m² h degree C
 Tw = External temperature of side wall in degree C
 Ta = Room temperature in degree C
 Δt = Tw- Ta
 Ai = side wall surface area in m²
 ε = emissivity of furnace body surface

q3 = Bottom: But as bottom surface area is not exposed to the atmosphere, here it is ignored.

$$q4 = (h \times \frac{\Delta T^{1.25}}{D^{1.25}} \times A_i) + (4.88 \times \varepsilon \times [(\frac{T_w}{100})^4 - (\frac{T_a}{100})^4] \times A_i)$$

Where, h = Natural convective heat transfer rate for duct in kCal/ m² h degree C
 Tw = External temperature of flue gas duct in degree C
 Ta = Room temperature in degree C
 Δt = Tw- Ta
 Ai = external flue gas duct in m²
 ε = emissivity of furnace body surface
 D = Outside diameter of flue gas duct

Q₈ = q1+ q2+ q3+ q4 kCal per hour/ Amount of billet (t/ hr)

$$\text{Radiation heat loss through furnace opening} = Q_9 = hr \times A \times \phi \times 4.88 [(\frac{T_f}{100})^4 - (\frac{T_o}{100})^4] / t$$

Where, hr = Open time during the period of heat balancing
 Tf = Furnace temperature in degree C
 To = base temperature in degree C
 A = Area of opening in m²
 φ = Co efficient based on the profile of the furnace opening
 = Dia. of shortest side/ wall thickness
 t = Amount of billet in ton/ hour

Q10 = Other types of unaccounted heat losses like heat carried away by the cooling water in flue damper and furnace excess door, Radiation from furnace bottom, Heat accumulated by refractory, Instrumental error or any other errors etc.

Q_{heat balance}: (Q₁+Q₂) = (Q₃+Q₄+Q₅+Q₆+Q₇+Q₈+Q₉+Q₁₀)

3. HEAT EXCHANGER.

Over all heat transfer co efficient:

$$Q = UA \times LMTD$$

Where, Q = Heat transfer in kCal/ hr
 U = Overall heat transfer co efficient in kCal/ hr/ m²/ degree C
 A = Heat transfer area in m²
 $LMTD$ = Logarithmic Mean Temperature difference in degree C

$$\varepsilon = \text{Heat exchanger effectiveness} = \frac{\text{Actual heat transfer rate in kCal / hr}}{\text{Max. possible heat transfer rate in kCal / hr}} = \frac{Q}{Q_{\max}} = \frac{Q}{C_{\min} \times \Delta T_{\max}}$$

Where, C_{\min} = Lower of two fluid heat capacities in kCal/ hr degree C
 ΔT_{\max} = Max. temp. difference from terminal stream temperature. in degree C

$$\text{Heat duty of hot fluid} = Q_h = W \times C_{ph} \times (T_{hi} - T_{ho})$$

$$\text{Heat duty of cold fluid} = Q_c = w \times C_{pc} \times (T_{co} - T_{ci})$$

Where, C_{ph} & C_{pc} = Specific heat of hot and cold fluid respectively in kCal/ kg Degree K
 $T_{hi/ho}$ & $T_{co/ci}$ = Temperature at inlet (i) and outlet (o) of hot and cold fluids respectively in degree C
 W, w = Hot and cold fluid flow respectively.

$$\text{Heat duty of heat exchanger } Q = \text{Sensible heat } q_s + \text{Latent heat } q_l$$

$$q_s = W \times C_{ph} \times (T_{hi} - T_{ho}) / 3600 = w \times C_{pc} \times (T_{co} - T_{ci}) / 3600 \dots \text{in kW}$$

$$q_l = W \times \lambda_h / 3600 = w \times \lambda_c / 3600 \dots \text{in kW}$$

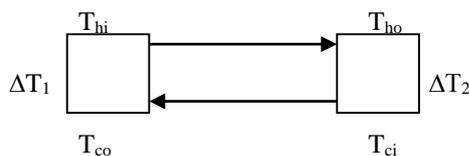
Where, λ_h & λ_c = Latent heat of condensation for hot fluid and latent heat of vaporization for cold fluid in kJ/ kg

$$\text{Hot fluid pressure drop} = \Delta P_h = P_i - P_o$$

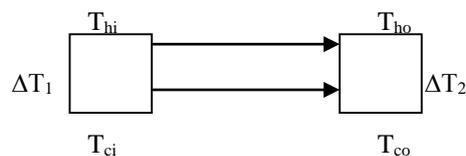
$$\text{Hot fluid temperature range} = \Delta T_h = T_{hi} - T_{ho}$$

$$\text{Cold fluid pressure drop} = \Delta P_c = P_i - P_o$$

$$\text{Cold fluid temperature range} = \Delta T_c = T_{co} - T_{ci}$$



Counter flow heat exchanger



Parallel flow heat exchanger

$$LMTD \text{ for counter flow} = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln[(T_{hi} - T_{co}) - (T_{ho} - T_{ci})]}$$

$$LMTD \text{ for parallel flow} = \frac{(T_{hi} - T_{ci}) - (T_{ho} - T_{co})}{\ln[(T_{hi} - T_{ci}) - (T_{ho} - T_{co})]}$$

LMTD correction factor F: (where two dimensionless numbers R and S are to be used as below)

$$R = \frac{T_a - T_b}{t_b - t_a} \quad P = \frac{t_b - t_a}{T_a - t_a}$$

Where, T_a & T_b = Inlet and outlet temperature of shell side fluid
 t_a & t_b = Inlet and outlet temperature of tube side fluid

For $R \neq 1$, compute as following:

$$\alpha = \left[\frac{1 - RP}{1 - P} \right]^{\frac{1}{N}} \quad \& \quad S = \frac{\alpha - 1}{\alpha - R} \quad \& \quad F = \frac{\sqrt{R^2 - 1} \ln \left(\frac{1 - S}{1 - RS} \right)}{(R - 1) \ln \left[\frac{2 - S(R + 1 - \sqrt{R^2 + 1})}{2 - S(R + 1 + \sqrt{R^2 + 1})} \right]}$$

For $R = 1$, compute as following:

$$S = \frac{P}{N - (N - 1)P} \quad \& \quad F = \frac{S\sqrt{2}}{(1 - S) \ln \left[\frac{2 - S(2 - \sqrt{2})}{2 - S(2 + \sqrt{2})} \right]}$$

Where, N = No of shell side passes
 S & α = Parameters used to calculate LMTD correction factors

Corrected LMTD	=	F*LMTD
Overall heat transfer co efficient U	=	Q / (A* Corrected LMTD)

4. REFRIGERATION AND AIR CONDITIONING LOAD CALCULATIONS: (Use standard Refrigeration Tables for values of different factors)

a. **External roof and walls (sensible):**

$$Q = UA[(TETD_p \times F_C) + (TETD_A \times F_R)]$$

Where, U = Overall heat transfer co efficient for roof walls in W/m^2 degree K
 A = Area of wall in m^2
 $TETD$ = Total Equivalent Temperature Difference,
 Time Integrated peak and average respectively
 F = Convective and radiative factor respectively for walls

b. **Glass Conduction (sensible):**

$$Q = UA\Delta T$$

Where, U = Overall heat transfer co efficient for glass in W/m^2 degree K
 A = Area of glass in m^2
 ΔT = Outside and inside temperature difference in degree C.

Glass Solar load (sensible):

$$Q = A[SC\{(F_C \times SHGF_p) + (F_R \times SHGF_A)\}]$$

Where, A	=	Glass Area m ²
SHGF	=	Solar heat gain factor for peak and average
SC	=	Shading co efficient
F	=	Convective and radiative factor respectively for glass

c. Ceiling/ Roof/ Floor/ Partition sensible (not exposed):

$$Q = UA\Delta T$$

Where, U	=	Overall heat transfer co efficient for Ceiling/ Roof/ Floor/ Partition in W/m ² degree K
A	=	Area of Ceiling/ Roof/ Floor/ Partition in m ²
ΔT	=	Outside and inside temperature difference in degree C.

d. People Or Occupants (sensible and latent):

$$Q_s = \text{No of occupants in space} \times \text{Sensible heat gain factor per occupant}$$

$$Q_s = \text{No of occupants in space} \times \text{Latent heat gain factor per occupant}$$

e. Lights (sensible):

$$Q = \text{Input} \times \text{Allowance} \times \text{Use}$$

Where, Input	=	Input rating from electrical plants or lighting fixture data
Allowance	=	Usage of tube lights ~1.2
Use	=	Actual wattage in use/ installed wattage and to be decided based on application.

f. Motors and other load (sensible):

$$Q = \text{Power of motor} \times \text{Load factor} \times \text{Use factor}$$

Where, Power of motor	=	Name plate details of motor
Load factor	=	Depends on relative placement of motor and load
Use factor	=	Generally taken as 1 if not specified.

g. Appliances (sensible):

$$Q_s = \text{No appliances in space} \times \text{Sensible heat factor}$$

$$Q_s = \text{No of appliances in space} \times \text{Latent heat factor}$$

h. Ventilation and Infiltration (sensible):

$$Q_s = 20.43 \times Q_m (t_o - t_i) W$$

$$Q_L = 49.1 \times Q_m (W_o - W_i) W$$

Where, Qm	=	Outside air in m ³ / min infiltration or ventilation which ever is more.
t	=	Outside and inside temperature difference respctively in degree K.
W	=	Humidity ratio difference of outside and inside in gms/ kg

i. Ventilation and Infiltration (latent):

$$\text{Infiltration for room} = HLWG / 60$$

$$\text{Door inf iltration} = \text{door opening} \times \text{Factor} / 60$$

Where, H	=	Room height in m.
W	=	Room width in m
L	=	Room Length in m
G	=	Factor for infiltration

5. AIR COMPRESSOR AND FREE AIR DELIVERY:

Load unload test of compressor for compressed air system leakage:

$$\% \text{ Leakage} = \frac{\text{Time for load in min utes}}{\text{Time for load} + \text{Time for unload in min utes}} \times 100$$

$$\text{System leakage quantity} = \frac{\text{Time for load in min utes}}{\text{Time for load} + \text{Time for unload in min utes}} \times \text{Comp. capacity in m}^3 / \text{min}$$

Free air delivery by nozzle method:

$$Q_{\text{free}} = c \times \pi \times \frac{d^2}{4} \times \frac{T_a}{P_a} \left[\frac{2(P_{bn} - P_n)(P_{bn} - R)}{T_{bn}} \right]^{1/2}$$

Where, Q_{free}	=	Free air delivery in m ³ / sec
c	=	Flow constant to be specified
d	=	diameter of nozzle in m
T_a	=	Absolute inlet temperature in degree K
P_a	=	Absolute inlet pressure in kg/ cm ²
P_{bn}	=	Absolute pressure before nozzle in kg/ cm ²
$P_{bn}-P_n$	=	Difference of pressure across nozzle in kg/ cm ²
R	=	Gas constant for air and is taken as 287.10 J/ kg K
T_{bn}	=	Absolute temperature before nozzle in degree K

Isothermal efficiency = Isothermal Power/ Actual measured input power

Isothermal Power = $PV \log_e r / 36.7$

Where, P	=	Absolute inlet pressure in kg/ cm ²
V	=	Free air delivery in m ³ / hr
r	=	pressure ratio P_d/P
P_d	=	Delivery Pressure m ³ / hr

Volumetric Efficiency = $[\text{Free air delivery (in m}^3/\text{min)} / \text{Compressor displacement (in m}^3/\text{hr)}] \times 100$
 = $[\text{Free air delivery (in m}^3/\text{min)} / (0.785 \times D^2 \times L \times N \times X \times n)]$

Where, D	=	Cylinder bore in m
V	=	Free air delivery in m ³ / hr
L	=	Stroke length in m
N	=	RPM of compressor or speed in RPM
x	=	Single or double acting compressor cylinder
n	=	Nos. of cylinder in compressor

Specific power consumption at rated discharge pressure = Power consumption in kW/ Free air delivered m³/ hr

SUGGESTED QUESTION PAPER FORMAT

(This is for reference only and is in suggestive form. Paper setter may opt for other marks distribution pattern maintaining distribution of marks as per specification table)

Q.NO.	SUB Q.NO.	QUESTION	MARKS DISTRIBUTION			UNIT
			R	U	A	
1		Answer ANY seven from following.				14
	i.		2			I
	ii.		2			II
	iii.		2			III
	iv.		2			IV
	v.		2			V
	vi.		2			I
	vii.		2			II or III
	viii.		2			IV
	ix.			2		IV
	x.				2	I
2	a.			3		II
		OR				
	a.			3		II
	b.			3		II
		OR				
	b.			3		II
	c.				4	III
		OR				
	c.				4	III
	d.			4		V
		OR				
	d.			4		V
3	a.			3		II
		OR				
	a.			3		II
	b.			3		IV
		OR				
	b.			3		IV
	c.				4	II
		OR				
	c.				4	II
	d.				4	III
		OR				
	d.				4	III
4	a.				3	IV
		OR				
	a.				3	IV
	b.			4		III
		OR				
	b.			4		III
	c.				7	V
5	a.			4		I
	b.				4	III
	c.				3	V
	d.				3	IV