GUJARAT TECHNOLOGICAL UNIVERSITY (GTU)

Competency-focused Outcome-based Green Curriculum-2021 (COGC-2021)
Semester-VI
Course Title: THERMAL SYSTEM AND ENERGY EFFICIENCY
(Course Code: 4361908)

Diploma programmer in which this course is offered	Semester in which offered
MECHANICAL ENGINEERING	6^{th} Semester

1. RATIONALE

Thermal systems play a pivotal role in the industrial sector, and their effective operation and maintenance are crucial for achieving economic energy use and environmental conservation. Without proper oversight, managing energy efficiently while minimizing environmental impact becomes challenging. This course is designed to impart foundational knowledge and skills related to the principles, types, and functioning of thermal systems, including boilers, heat exchangers, furnaces, HVAC, and other high-energy consumption devices. By studying this course, students will gain insights enabling them to make informed decisions about the design and specifications of these energy-intensive devices. This, in turn, contributes to energy savings, resulting in lower production costs and reduced environmental impact. Consequently, this course serves as a cornerstone for aspiring 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:

- **Operate and maintain thermal systems for energy efficiency**

3. COURSE OUTCOMES (COs)

The theory should be taught and practical 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.

CO1	Acquire the concept of energy conservation and improve efficiencies of various thermal systems.
CO2	Suggest remedies to improve boiler efficiency after computing the boiler performance and analyzing the effect of parameters
CO3	Evaluate the performance of various furnaces by adopting energy efficiency measures
CO4	Determine the performance of heat exchangers and air compressors based on operating conditions
CO5	Assessment of Energy Performance of HVAC systems.

4. TEACHING AND EXAMINATION SCHEME

Teaching Scheme (In Hours)			Total Credits (L+T+P/2)					
L	T	P	C	Theory Marks		Practical Marks		Total Marks
				ESE(Th)	CA(Th)	CA(Pr)	ESE(Pr)	
03	00	02	04	70	30	25	25	150

5. SUGGESTED PRACTICAL EXERCISES:

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 (PrOs)	Approx Hours. required
1	I	**Preparatory activity:** a. Visit laboratory/ workshop and identify various thermal systems such as heat exchangers, boilers, furnaces, air compressors, pump, motors, etc. Write down technical specifications of the same along with manufactures. b. Compare price of various fuels on common parameter. c. Interpret terms and equations of data sheets provided with the curriculum.	04
2	II	**Case study of Boiler (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	06

3	III	**Case study of Furnace (based on real life example):** 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	04
4	IV	**Case study of Heat Exchangers (based on real life example):** a. Calculate efficiency and over all heat transfer coefficient of **heat exchanger** based on given data. Use LMTD methods. b. List various instrumentation required to measure the required data. **OR** 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	**Case study of Air Conditioning (based on real life example):** a. Calculate **air conditioning** load of given class room or laboratory (Class teacher need to give values related to calculation such as U, TETD, shading coefficient, Allowance for lighting, SHGF, standard electric equipment load, etc. required data - Refer BEE guide books if necessary) b. List various instrumentation required to measure the required data.	06
6	V	**Case study of Refrigerator (based on real life example):** a. Calculate load of domestic **refrigerator /other suitable refrigeration equipment**. Use standard data sheets.(Class teacher need to provide necessary data to students for the calculation- Refer BEE guide books if necessary) b. Calculate Fan / Blower Efficiency	04

Notes:

a. It is compulsory to provide real life data for calculation purpose to students. It is also required to get each exercise recorded in logbook, checked and duly dated signed by teacher.
b. Term work report must not include any photocopy/ies, printed manual/pages, litho, etc..

The following are some **sample** 'Process' and 'Product' related skills (more may be added/deleted depending on the course) that occur in the above-listed **Practical Exercises** of this course required, which are embedded in the COs and, ultimately, the competency.

Sr. No.	Sample Performance Indicators for the PrOs	Weightage in %
For Demonstration type PrOs (PrOs Number: 1)		
1	Knowledge	30
2	Quality of Report	20
3	Observation Skills	15
4	Participation	15
5	Punctuality	20
Total		100

Sr. No.	Sample Performance Indicators for the PrOs	Weightage in %
For Demonstration type PrOs (PrOs Number: 2, 3, 4, 5, 6, 7)		
1	Knowledge	20
2	Quality of Report	15
3	Observation Skills	15
4	Analysis	20
5	Participation	15
6	Punctuality	15
Total		100

Sample Rubrics Performance Indicators for the PrOs

For all PrOs					
Criteria	**%**	**10**	**9-8**	**7-6**	**5**
Knowledge	**For all**	Students give the correct answers 90% or more.	Student give the correct answers between 70-89%.	Student give the correct answers between 50-69%.	Student give the correct answers less than 50%.
Quality of Report	**For all**	Neat Handwriting, figure, and table. Complete labeling of figure and table.	Only formatting is improper (Location of figures/tabl es, use of pencil and scale).	A few required elements (labeling/ notations) are missing.	Several elements are missing (content in paragraph, labels, figures, tables).
Observation Skill	**For all**	Excellent focused attention in the exercise	Moderately focused attention on exercise	Focused limited attention in the exercise.	Participation is minimum

Participation	**For all**	Excellent focused attention in the exercise.	Moderately focused attention on exercise.	Focused limited attention in the exercise.	Participation is minimum.
Punctuality	**For all**	Timely Submission.	Submission late by one laboratory.	Submission late by two laboratories.	Submission late by more than two laboratories.
Analysis	**For all**	Student understand the data and analyze correctly the obtained test results.	Student understand most of the data and analyze the obtained test results with help or support.	Student need help to understand some of the data and also in analyzing the obtained test results.	Student always need help to understand the data and also in analyzing the obtained test results.

6. MAJOR EQUIPMENT/ INSTRUMENTS REQUIRED

Sr.No.	Equipment Name with Broad Specifications	PrO. No.
1	Boilers/ furnaces/ air compressor system/ heat exchangers/ HVAC/ Refrigeration, Pump, Motors, Lighting, etc. available within institute OR nearby area and industries	1 to 6

7. AFFECTIVE DOMAIN OUTCOMES

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.*

The following ***sample*** Affective Domain Outcomes (ADOs) are embedded in many of the above COs and PrOs. More can be added to fulfill the development of this course competency.

a. Work as a leader/ team member.
b. Follow safety practices.
c. Follow ethical practices.
d. Maintain tools and equipment.
e. Practice environment-friendly methods and processes. (Environment related)

8. UNDERPINNING THEORY: (Refer attached data sheet also. Data sheet is allowed for students in examination hall).

Based on the higher-level UOs of Revised Bloom's taxonomy formulated for developing COs and competency, the primary underpinning theory is given below. If required, more such UOs could be included by the course teacher to focus on attaining COs and competency.

Unit	Major Unit Outcomes (in cognitive domain)	Topics and Sub-topics
Unit – I. **Basic Concepts of Energy Conservations and Thermal Systems**	1a. Importance of Energy Conservation 1b. Explain Energy conservation in Domestic appliances 1c. Describe basic concepts of energy savings in various thermal systems 1d. Role of Energy Audit	1.1 Energy conservation and its importance. 1.2 Energy Conservation in Domestic Applications: - Refrigerator & Air-Conditioning - Water heater (Electric/Gas), Pressure Cooker - Light & Fan - Washing machine, Oven, Television 1.3 Introduction to Energy Conservation Act 2001 and schemes of Bureau of Energy Efficiency under EA-2001. 1.4 Introduction of energy efficiency in various thermal systems such as steam generation, heat exchanger, HVAC (Heating, Ventilating and Air Conditioning), refrigeration system, air compressor, pumps, etc. 1.5 Introduction to energy audit and walk through audit for energy.
Unit – II. **Steam Generation & Steam Distribution System**	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): i. Indirect method. ii. Direct method. 2.2 Energy efficiency measures in boiler system. 2.3 Introduction and understanding of steam distribution system. 2.4 Steam traps-working principal, operation and need of: 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 of furnaces. 3b. Determine the performance of heat treatment furnaces. 3c. Derive energy efficiency parameters.	3.1 General structure of furnace, working of general furnace and its applications. 3.2 Factors affecting furnace efficiency. 3.3 Performance evaluation of typical heat treatment furnace system (Attached data sheets are allowed in exams). i. Indirect method. ii. Direct Method. 3.4 General fuel economy/ Energy efficiency measures in furnace systems.
Unit – IV **Heat Exchangers and Air Compressor.**	4a. Concept of LMTD in Heat Exchanger 4b. Determine performance of Heat exchangers 4c. Describe energy saving measures in Heat exchangers & air compressor.	4.1 Energy savings measures in general in a heat exchanger 4.2 Concept of LMTD and its calculation without derivation for parallel and cross flow type heat exchangers. 4.3 Performance evaluation of heat exchangers based on LMTD (Attached data sheets are allowed in exams). ~~4.4~~ Air compressor: Understanding of free air delivery and energy saving measures in compressed air system 4.5 Field testing of compressor by nozzle and by pump up method (Attached data sheets are allowed in exams).
Unit – V **HVAC systems.**	5a. Use concept of HVAC and refrigeration system. 5b. Assessment of Energy Performance of HVAC System	5.1 Concept of HVAC and refrigeration system. 5.2 Energy Performance assessment of HVAC System - Concept of Tons of refrigeration (TR), Net Refrigerating Capacity, kW/ton rating, Coefficient of Performance (COP), Energy Efficiency Ratio (EER) - Calculations of COP, EER & kW/Ton - Heat load evaluation based on enthalpy difference by using psychrometric chart. Simple Numerical on it. 5.3 Simple Load calculation for

		refrigeration/ air conditioning systems such as class room or laboratory or conference/seminar hall, etc. to understand the methods and procedure with the help of data sheet. 5.4 Energy efficiency measures in refrigeration/ air conditioning systems. 5.5 Energy Performance Assessment of Fans and Blowers - Determination of Fan Pressure, Power Input & Fan Efficiency - Factors affecting the Performance of Fans/Blowers

9. SUGGESTED SPECIFICATION TABLE FOR QUESTIONPAPER DESIGN: NA

Table for details of hours distribution is as follows for the given units.

Unit No.	Unit Title	Teaching Hours	Distribution of Theory Marks			
			R Level	U Level	A Level	Total Marks
I	Basic Concepts of Energy Conservations and Thermal Systems.	08	04	04	02	10
II	Steam Generation & Steam Distribution	10	02	05	11	18
III	Furnaces.	06	02	02	06	10
IV	Heat Exchangers and Air Compressors.	08	02	03	09	14
V	HVAC systems.	10	04	04	10	18
	Total	42	14	18	38	70

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

Notes:

a. 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.
b. Duration of End Semester Examination (Theory) is 3 hours.
c. 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.
d. Use of enclosed data sheets are to be allowed to student during examination (They should be provided by the examining agency).

10. SUGGESTED STUDENT ACTIVITIES:

Sr. No.	Unit	Unit Name	Activities and Strategies
1	I	Basic Concepts of Energy Conservations and Thermal Systems.	Demonstration of systems, movies, industrial visits, on-hand practice on available thermal systems.
2	II	Steam Generation & Steam Distribution	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.
5	V	HVAC systems.	Standard data of load calculation to compare with the calculated load calculations, industrial visits, demonstration of plants having HVAC systems.

11. SUGGESTED SPECIAL INSTRUCTIONAL STRATEGIES (if any)

Walk through audits must be carried out with understanding and knowledge sharing where expert in the field can be invited who have degree of energy manager or energy auditor or other field experts.

12. SUGGESTED MICRO-PROJECTS

Only one micro-project is planned to be undertaken by a student that needs to be assigned to him/her at the beginning of the semester. The number of students in the group should not exceed five. Each student must maintain a dated work diary (Logbook) consisting of individual contributions to the project work and give a seminar presentation before submission. The duration of the micro project should be about **4-5** ***(four to five) student engagement hours*** during the course. The students ought to submit a micro-project by the end of the semester to develop the industry-oriented COs.

Walk through audit for thermal equipments available in thermal laboratory or walk through audit of mechanical department including class rooms and laboratories or conference/seminar hall of the institute.

(Students should understand basics of audit and prepare report related to actual observations. They must suggest measures for energy conservation based on the audit carried out in the department.)

13. SUGGESTED LEARNING RESOURCES

S. No.	Title of Book	Author	Publication
1.	A Text book of Thermal	R S Khurmi& J.K. Gupta	S Chand & Co.
2.	Refrigeration and air conditioning	Arora & Domkundwar	Khanna publication

3.	Guide book for NCE for EM & EA (Vol I to IV)	--	Bureau of Energy Efficiency
4.	The Efficient Use of Energy	The Rt Hon Tony Benn, MP	BSI, 2 Park street, London

14. SOFTWARE/LEARNING WEBSITES

a. http://nptel.ac.in/courses/112101005/downloads/Module_4_Lecture_7_final.p df
b. http://btech.mit.asia/downloads/svlomte/HT2011.pdf
c. http://powermin.nic.in/acts_notification/pdf/ecact2001.pdf
d. www.energymanagertraining.com (register for free guide book downloads)
e. http://www.ureda.uk.gov.in/upload/downloads/Download-7.pdf
f. http://www.fao.org/docrep/t0269e/t0269e05.htm
g. http://energy.gov/eere/government-energy-management
h. http://www.sari

15. PO-COMPETENCY-CO MAPPING:

Semester VI	Mechanical Engineering TS&EE (Course Code:4361908)						
	POs						
Competency & Course Outcomes	PO-1	PO-2	PO-3	PO-4	PO-5	PO-6	PO-7
	Basic & Discipline specific knowledge	Problem Analysis	Design/ development of solutions	Engineering Tools, Experimentation& Testing	Engineering practices for society, sustainability & environment	Project Management	Life-long Learning
Competency	**Identify various energy sources availability; analyze performance of boiler, furnace, heat exchanger and compressor. Calculate variety of refrigeration and air-conditioning loads.**						
CO1- Acquire the concept of energy conservation and improve efficiencies of various thermal systems.	2	-	-	-		-	2
CO2- Suggest remedies to improve boiler efficiency after computing the boiler performance and	2	3	2	1	2	-	2

analyzing the effect of parameters							
CO3- Evaluate the performance of various furnaces by adopting energy efficiency measures	2	3	2	1	2	-	2
CO4- Determine the performance of heat exchangers and air compressors based on operating conditions	2	3	2	1	2	-	2
CO5- Assessment of Energy Performance of HVAC systems	2	3	2	-	2	-	2

*Legend: '**3**' for high, '**2**' for medium, '**1**' for low and '**-**' for no correlation of each CO with PO.*

16. COURSE CURRICULUM DEVELOPMENT COMMITTEE

GTU Resource Persons

Sr. No.	Name and Designation	Institute	Contact No	Email
1.	Dr. Pinkesh R. Shah (Ph.D. IIT Bombay)	Government Polytechnic Kheda	9825472703	pinkeshrshah@gmail.com
2.	Mehulkumar N Patel (Energy Auditor – EA10615)	R C Technical Institute, Sola, Ahmedabad	7621048748	mehulmnp@gmail.com
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17. BOS Resource Persons

Sr.No.	Name and Designation	Institute	Contact No.	Email

1	Dr. S. H. Sundarani, BOS Chairman & HOD Mechanical	Government Polytechnic, Ahmadabad	9227200147	gpasiraj@gmail.com
2	Dr. Rakesh D. Patel, BOS Member & HOD Mechanical	B. & B. Institute of Technology, V. V. Nagar	9825523982	rakeshgtu@gmail.com
3.	Dr. Atul S. Shah, BOS Member & Principal	B. V. Patel Institute of Technology, Bardoli	7567421337	asshah97@yahoo.in

GUJARAT TECHNOLOGICAL UNIVERSITY, AHMEDABAD, GUJARAT

Course Curriculum

THERMAL SYSTEMS AND ENERGY EFFICIENCY

(Code: 4361908)

[Allowed in examination hall]

Diploma Programme in which this course is offered	Semester in which offered
Mechanical Engineering	6th Semester

DATA SHEET IS ALLOWED IN EXAMINATIONS:

1. **BOILERS:**

Direct method:

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

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

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,

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

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

Theoretical air required for combustion:

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

$$\%Excess\ air\ supplied(EA) = \frac{O_2\%}{21 - O_2\%} \times 100 = \frac{7900[(CO_2\%)_t - (CO_2\%)_a}{(CO_2\%)_a[100 - (CO_2\%)_t]} \rightarrow From\ flue\ gas\ analysis$$

$$(CO_2\%)_t = Theoretical\ CO_2 = \frac{Moles\ of\ C}{Moles\ of\ N_2 + Moles\ of\ C}$$

$$(CO_2\%)_a = Actual\ CO_2\%\ measured\ in\ flue\ gas$$

$$Moles\ of\ N_2 = \frac{Wt\ of\ N_2\ in\ theoretical\ air}{Mol.wt\ of\ N_2} + \frac{Wt\ of\ N_2\ in\ fuel}{Mol.wt\ of\ N_2}$$

$$Moles\ of\ C = \frac{Wt\ of\ C\ in\ fuel}{Molecular\ Wt\ of\ C}$$

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

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

OR $\text{Total mass of dry flue gas} = \text{Total AAS} + 1$

$$\%Loss\ due\ to\ dry\ flue\ gas = L_1 = \frac{m_d \times Cp \times (T_f - T_a)}{GCV\ of\ fuel} \times 100$$

Cp=0.23 kCal/kg Degree C

Where,	m_d	=	Mass of dry flue gas in kg/ kg of fuel
		=	Combustion product from fuel: CO_2+SO_2+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)
	Cp	=	Specific heat of flue gas in kCal/ kg degree C
	Tf	=	Flue gas temperature in degree C
	Ta	=	Ambient temperature in degree C

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

Cp=0.45 kCal/kg Degree C

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

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

where (for L_3 to L_4),

H_2	=	kg of hydrogen present in fuel on 1 kg basis
Cp	=	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

$$\%Heat\ loss\ due\ to\ incomplete\ combustion = L_5 = \frac{\%CO \times C}{\%CO + \%CO_2} \times \frac{5744}{GCV\ of\ fuel} \times 100$$

Where,

L5	=	%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

<u>OR</u>

When CO is obtained in ppm during the flue gas analysis

CO formation(Mco) = CO(in ppm)*M_f*28*10^{-6}

M_f = Fuel consumption in kg/ hr

L_5 = Mco*5744

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

Where,

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

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

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

Boiler Efficiency in % η = 100 -(Addition of %L_1 to %L_8)

2. <u>Furnace:</u>

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

Direct Method:

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

$$Heat\ imparted\ to\ stock\ Q = mCp(t_2 - t_1)$$

Where, Q	=	Quantity of heat in kCal
m	=	Mass of material in kg
Cp	=	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:

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

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

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

$$Total\ mass\ of\ dry\ flue\ gas = Mass\ of\ C + Mass\ of\ N_2\ in\ fuel + Mass\ of\ SO_2 + Mass\ of\ N_2\ in\ Combustion\ air\ supplied + Mass\ of\ O_2\ in\ flue\ gas$$

or

$$= (C \times \frac{44}{12}) + (AAS \times \frac{77}{100}) + [(AAS - Theoretical\ Air) \times \frac{23}{100}] + (S \times \frac{64}{32}) + N_2$$

$$OR\ \ Total\ mass\ of\ dry\ flue\ gas = Total\ AAS + 1$$

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

<u>Heat input calculation for furnace heat balance sheet (one tonne basis):</u>

Heat Input = Combustion heat of fuel Q_1+ Sensible heat of fuel Q_2

= (fuel consumption per tonne of billet*GCV)+ (fuel consumption per tonneof billet*Cp of fuel*Temperature difference of flue gas to atmosphere)

= Q_1 + Q_2inkCal per tonne of billet.

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

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

Where, To = Temperature of billet at outlet of furnace in degree C

Ti = Temperature of atmosphere at outlet

Cp = Specific heat of billets in lCal/ kg/degree C

Sensible heat loss in flue gases:

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

Where, m = Amount of fuel consumped 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

Ta = Temperature of atmosphere at base in degree C

Assumption: 1 kg of oil require 14 kg of air to burn fully.

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

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

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

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

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/ m^2 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 m^2
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/ m^2 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 m^2
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/ m^2 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 m^2
	ε	=	emissivity of furnace body surface
	D	=	Outside diameter of flue gas duct

Q_8 = q1+ q2+ q3+ q4 kCal per hour/ Amount of billet (t/ hr)

$$Radiation\ heat\ loss\ through\ furnace\ opening = Q_9 = hr \times A \times \varphi \times 4.88[(\frac{T_f}{100})^4 - (\frac{T_0}{100})^4]/t$$

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 m^2
	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.

$Q_{heat\ balance}$: $(Q_1+Q_2) = (Q_3+Q_4+Q_5+Q_6+Q_7+Q_8+Q_9+Q_{10})$

3. <u>Heat Exchanger</u>

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/ m^2/ degree C
	A	=	Heat transfer area in m2
	LMTD	=	Logarithmic Mean Temperature difference in degree C

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

Where,	Cmin	=	Lower of two fluid heat capacities in kCal/ hr degree C
	ΔTmax	=	Max. temp. difference from terminal stream temperature. in degree C

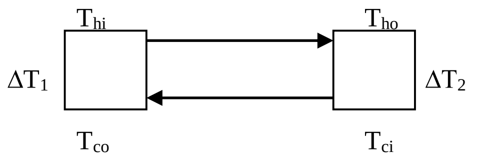
$$Heat\ duty\ of\ hot\ fluid = Q_h = W \times C_{ph} \times (T_{hi} - T_{ho})$$
$$Heat\ duty\ of\ cold\ fluid = Q_c = w \times C_{pc} \times (T_{co} - T_{ci})$$

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.

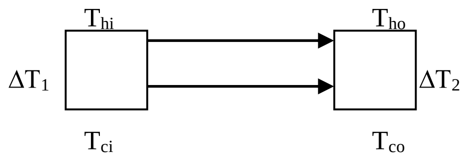
$$\text{Heat duty of heat exchanger } Q = \text{Sensible heat } q_s + \text{Latent heat } q_l$$
$$q_s = W \times C_{ph} \times (T_{hi} - T_{ho})/3600 = w \times C_{pc} \times (T_{co} - T_{ci})/3600 \ldots\ldots in\, kW$$
$$q_l = W \times \lambda_h / 3600 = w \times \lambda_c / 3600 \ldots. in\, kW$$

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

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

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

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

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

<u>For R≠1, compute as following:</u>

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

<u>For R=1, compute as following:</u>

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

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. Air Compressor and free air delivery:

Load unload test of compressor for compressed air system leakage:

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

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

Free air delivery by nozzle method:

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

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 = [Free air delivery (in m^3/ min) / Compressor displacement (in m^3/ hr)]*100
= [Free air delivery (in m^3/ min)/ (0.785*D^2*L*N*X*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 m^3/ hr

5. Refrigeration and air conditioning Load Calculations: (Use standard Refrigeration Tables for values of different factors)

a. External roof and walls (sensible):

$$\boxed{Q = UA[(TETD_P \times F_C) + (TETD_A \times F_R)]}$$

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):

$$\boxed{Q = UA\Delta T}$$

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):

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

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):

$$\boxed{Q = UA\Delta T}$$

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):

$$\boxed{\begin{aligned} Q_s &= No\ of\ occupants\ in\ space \times Sensible\ heat\ gain\ factor\ per\ occupant \\ Q_s &= No\ of\ occupants\ in\ space \times Latent\ heat\ gain\ factor\ per\ occupant \end{aligned}}$$

e. **Lights (sensible):**

$$Q = Input \times Allowance \times Use$$

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):**

$$Q = Power of\, motor \times Load\ \ factor \times Use\ \ factor$$

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):**

$$Q_s = No\ appliances\ in\ space \times Sensible\ heat\ \ factor$$
$$Q_s = No\ of\ \ appliances\ in\ space \times Latent\ heat\ \ factor$$

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 respcetively in degree K.
W = Humidity ratio difference of outside and inside in gms/ kg

i. **Ventilation and Infiltration (latent):**

$$Infiltration\ \ for\ room = HLWG / 60$$
$$Door \inf\ iltration = door\ opening \times Factor / 60$$

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

6. Fan & Blower Efficiency:

Determination of Flow

Once the cross-sectional area of the duct is measured, the flow can be calculated as follows:

Flow, (m^3/s) = Area (m^2) x Velocity (m/s)

$$\text{Volume(flow)} = \text{A x C}_p\ x \frac{\sqrt{2\,x\,9.81\,x\,\Delta p\,x\,\gamma}}{\gamma}$$

Power Measurement:

$$P = \sqrt{3} \text{ x V x I x Cos}\Phi$$

$$\textit{Power Input to fan shaft} = \textit{Power input to the motor} * \eta \textit{ of motor at the corresponding loading} * \textit{transmission system } \eta$$

$$\textit{Fan efficiency} = \frac{\textit{Volume in } m^3/\sec * \textit{total pressure in mmWC}}{102 * \textit{power input to fan shaft in kW}}$$