

**15th NATIONAL CERTIFICATION EXAMINATION
FOR
ENERGY AUDITORS – August, 2014**

PAPER – 4: Energy Performance Assessment for Equipment and Utility Systems			
Date: 24.8.2013	Timings: 14:00-16:00 Hrs	Duration: 2 Hrs	Max. Marks: 100

Section - I: BRIEF QUESTIONS

Marks: 10 x 1 = 10

- (i) Answer all **Ten** questions
- (ii) Each question carries **One** mark

S-1	Which loss is not considered while evaluating boiler efficiency by “Indirect Method”?
Ans	Blow down loss
S-2	What will be the synchronous speed of a VFD driven 4-pole induction motor operating at 40 Hz ?
Ans	$N_s = 120 \times f/P$ $= 120 \times 40/4 = 1200 \text{ RPM}$
S-3	What is the refrigerant used in a vapour absorption system with lithium bromide as an absorbent?
Ans	Water
S-4	Other than rated kW of motor and the actual power drawn, what other parameter is required to determine the percentage loading of the motor ?
Ans	Motor Efficiency or rated motor efficiency
S-5	Inclined tube manometer is used for measuring gas flow in a duct when the air velocity is very high: True or False?
Ans	False.
S-6	A pump will cavitate if the $NPSH_{required}$ is _____ than the $NPSH_{available}$.
Ans	More
S-7	To determine the effectiveness of the cooling tower, it is required to measure cooling water inlet, outlet and _____ temperatures.
Ans	Ambient Wet bulb
S-8	The ratio of actual heat transfer to the heat that could be transferred by heat exchanger of infinite size is termed as

Ans	Effectiveness
S-9	If the unit heat rate of a power plant is 3070 kcal/kWh ,what is the power plant efficiency ?
Ans	$(860/3070) \times 100 = 28 \%$
S-10	The difference between GCV and NCV of hydrogen fuel is Zero: True or False
Ans	False

..... **End of Section - I**

Section - II: SHORT NUMERICAL QUESTIONS

Marks: 2 x 5 = 10

- (i) Answer all **Two** questions
- (ii) Each question carries **Five** marks

L-1	<p>Hot water at 80 °C is used for room heating in a 5 Star hotel for 4 months in a year. About 200 litres per minute of hot water is maintained in circulation with the return temperature at 50 °C. The hot water is generated using a 'hot waste stream', through a Plate Heat Exchanger (PHE). The hot stream enters the PHE in counterflow direction at 95 °C and leaves at 60 °C. The area of the heat exchanger is 20 m².</p> <p>Calculate the LMTD and the overall heat transfer coefficient.</p>
Ans	<p>Heat load, $Q = 200 \times 60 \times (80 - 50) = 360000 \text{ Kcals/hr (or) } 418.7 \text{ kW}$</p> $\text{LMTD (for counter flow)} = \frac{(95 - 80)/(60 - 50)}{\ln (15/10)} = 3.7 \text{ }^\circ\text{C}$ <p>Overall Heat Transfer Coefficient, $U = Q/(A \times \text{LMTD})$</p> $= 418.7/(20 \times 3.7) = 5.66 \text{ kW/m}^2 \cdot ^\circ\text{C}$ <p>(OR)</p> $= 4864.8 \text{ kcal/hr.m}^2 \cdot ^\circ\text{C}$
L-2	<p>A gas turbine generator is delivering an output of 20 MW in an open cycle with a heat rate of 3440 kcal/kWh. It is converted to combined cycle plant by adding heat recovery steam generator and a steam turbine raising the power generation output to 28 MW. However, with this retrofitting and increased auxiliary consumption, the fuel consumption increases by 5% in the gas turbine.</p>

	Calculate the combined cycle gross heat rate and efficiency.	
Ans	Gas turbine output	= 20 MW
	Combined cycle output	= 28 MW
	Heat rate in GT open cycle for 20 MW	= 3440 kcal/kwh
	Increase in fuel consumption in combined cycle operation	= 5%
	Combined cycle heat rate	= (3440 X 1.05) X(20 / 28) = 2580 kcal/kwh
	Combined cycle plant efficiency	= (860 / 2580) X 100 = 33.33%

..... **End of Section - II**

Section - III: LONG NUMERICAL QUESTIONS

Marks: 4 x 20 = 80

(i) Answer all **Four** questions

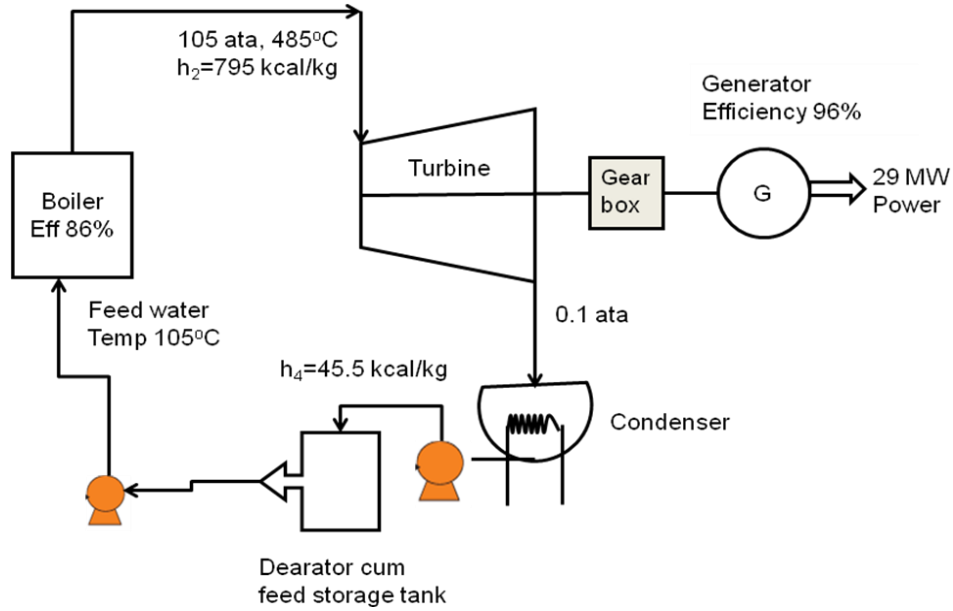
N-1	<p>The steam requirement of an export oriented unit is met by a 6 TPH oil fired package boiler generating steam at 10 kg/cm². The monthly steam consumption of the unit is 3000 tonnes.</p> <p>Other data are given below:</p> <p>Fuel oil composition: Carbon = 86%; Hydrogen = 12%; Oxygen= 0.5%; Sulphur =1.5%</p> <p>Specific heat of flue gases, Cp = 0.27 kcal/kg°C G.C.V. of fuel oil = 10,000 kcal/kg Sp.heat of super heated water vapour = 0.45 kcal/kg°C Enthalpy of steam at 10 kg/cm² = 665kcal/kg Feed water temperature = 85 °C % O₂ in dry flue gas = 6% Flue gas temperature at boiler outlet = 240 °C Ambient temperature = 30°C Cost of fuel oil = Rs.43 per kg. Radiation and other unaccounted losses = 2.45%</p> <p>The export oriented unit is costing its steam cost based on the fuel consumption cost with additional 15% to account for the auxiliary and consumables.</p> <p>A neighbouring continuous process plant now offers to supply the required steam at 10</p>
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	<p>kg/cm² to the export oriented unit at a cost of Rs 3300 per tonne with a condition that all the condensate will be returned back.</p> <p>Calculate the following:</p> <p>a) Boiler efficiency</p> <p>b) Cost advantage per tonne of availing steam from neighbouring plant in place of in-house generation and also monthly monetary saving.</p>
<p>Ans</p>	<p><u>First calculate the efficiency of Boiler (in EOU)</u></p> <p>Theoretical air required = = 11.6 C + 34.8 (H – O/8) + 4.35 S = [11.6 X 86 + 34.8 (12 – 0.5/8) + 4.35 X 1.5] x 1/100 = 14.195 = Say 14.2</p> <p>% Excess Air = $\frac{[\% O_2 / (21 - \% O_2)] \times 100}{[6 / (21 - 6)] \times 100} = 40\%$</p> <p>AAS = Actual amount of air supplied = 14.2 X 1.4 = 19.88 kg per kg. of fuel oil</p> <p>Mass of dry flue gas m_{dfg} = Mass of combustion gases due to presence of C,H,S +Mass of N₂ supplied = (0.86 X 44/12) + (0.015 X 64 / 32) + [(19.88 – 14.2) X 23 / 100] + (19.88 X 77/100) = 19.797</p> <p>Mass dry flue gas ,say = 19.8 Kg / kg fuel</p> <p>Or</p> <p>Alternatively mass of dry flue gas = (AAS + 1) – 9 H = (19.88 + 1) – 9 X 0.12 = 19.8 Kg./Kg. fuel</p> <p>L1 = % heat loss in dry flue gas = $\frac{[m_{dfg} \times C_p \times (T_q - T_a) / GCV] \times 100}{19.8 \times 0.27 \times (240 - 30)} \times 100$ = $\frac{19.8 \times 0.27 \times (240 - 30)}{10,000} \times 100$ L1 = 11.23%</p> <p>L2 = Loss due to presence of hydrogen forming water vapour $\frac{9 \times H [584 + C_{ps} (T_g - T_a)]}{GCV} \times 100$ = $\frac{9 \times 0.12 [584 + 0.45 (240 - 30)]}{10000} \times 100$ L2 = 7.33%</p> <p>L3 = Radiation and other unaccounted losses = 2.45%</p> <p>Total losses = L1 + L2 + L3</p>

	<p style="text-align: center;">= 11.23 + 7.33 + 2.45 = 21.05 %</p> <p>Efficiency of the EOU boiler by indirect method</p> <p style="text-align: center;">= 100 – 21.05 = 78.99 %</p> <p style="text-align: center;">= Say 79 %</p> <p><u>Secondly calculate the cost of steam in the EOU plant</u></p> <p>Evaporation Ratio = $[(n \times GCV) / (h_g - h_f)] \times 100$ = $[(0.79 \times 10000) / (665 - 85)] \times 100$ = 13.62 kg Steam / kg. Fuel</p> <p>Fuel oil consumption = 1000 / 13.62 kg. per tonne of steam Fuel oil consumption = 73.42 kg./tonne of steam gen</p> <p>Cost of fuel oil. = Rs. 43 per kg Cost of steam in EOU = Fuel cost + 15% fuel cost = 73.42 x 1.15 x 43 = Rs.3,599 per tonne Say = Rs 3600 per tonne</p> <p>Selling cost of steam from neighboring plant = Rs 3300 per tonne</p> <p>Cost advantage = 3600 – 3300 = Rs.300 per tonne</p> <p>Annual Savings = Rs.300 per tonne x 3000tonne/month X 12 month = Rs.108 Lacs</p>															
N-2	<p>a) The operating parameters of a Vapour Compression Refrigeration system are indicated below.</p> <table border="1" style="margin-left: auto; margin-right: auto; border-collapse: collapse; text-align: center;"> <thead> <tr> <th style="width: 40%;">Parameter</th> <th style="width: 20%;">Chiller side</th> <th style="width: 20%;">Condenser side</th> </tr> </thead> <tbody> <tr> <td>Water Flow (m³/hr)</td> <td>89</td> <td>87</td> </tr> <tr> <td>Inlet Temperature (°C)</td> <td>10.1</td> <td>32.3</td> </tr> <tr> <td>Outlet Temperature (°C)</td> <td>6.8</td> <td>36.6</td> </tr> <tr> <td>Density (kg/m³)</td> <td>1000</td> <td>990</td> </tr> </tbody> </table> <p>Find the COP of the Refrigeration system ignoring heat losses.</p> <p>b) A 6 pole, 415 volt, 3 Φ, 50 Hz induction motor delivers 22 kW power at rotor shaft at a speed of 950 rpm with PF of 0.88. The total loss in the stator including core, copper and other losses, is 2 kW. Calculate the following.</p> <ol style="list-style-type: none"> i) Slip ii) Rotor Copper Loss iii) Total Input to motor iv) Line current at 415 V and motor pf of 0.88 v) Motor operating efficiency 	Parameter	Chiller side	Condenser side	Water Flow (m ³ /hr)	89	87	Inlet Temperature (°C)	10.1	32.3	Outlet Temperature (°C)	6.8	36.6	Density (kg/m ³)	1000	990
Parameter	Chiller side	Condenser side														
Water Flow (m ³ /hr)	89	87														
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Outlet Temperature (°C)	6.8	36.6														
Density (kg/m ³)	1000	990														
	<p>a) Refrigeration Effect = 89 x 1000 x (10.1 – 6.8)</p>															

Ans	<p>= 293700 kcal/hr</p> <p>Condenser load = $87 \times 990 \times (36.6 - 32.3)$ = 370359 kcal/hr</p> <p>Compressor work = Condenser load – Refrigeration effect = $370359 - 293700$ = 76659 Kcal/hr</p> <p>C.O.P. = Refrigeration Effect/ Compressor work = $293700/76659 = 3.83$</p> <p>b) Synchronous Speed = $(120 \times 50 / 6) = 1000$ rpm Motor Speed = 950 rpm</p> <p>(i) Slip = $(1000 - 950) / 1000 = 5\%$ Power input to rotor = $\{ (22 / (1 - 0.05)) \} = 23.16$ kW</p> <p>(ii) Rotor Copper Loss = $(0.05 \times 23.16) = 1.158$ kW Or = $23.16 - 22 = 1.16$ kW</p> <p>(iii) Total Input to motor = $(23.16 + 2) = 25.16$ kW</p> <p>(iv) Line Current = $(25.16 \times 1000) / (\sqrt{3} \times 415 \times 0.88) = 39.75$ Amps</p> <p>(v) Motor Efficiency = $(22 / 25.16) = 87.44\%$</p>
N-3	<p>A common plant facility is installed to provide steam and power to textile and paper plant with a co-generation system. The details and operating parameters are given below:</p> <p>Boiler efficiency- 80% GCV of Coal-5000 kcal/kg Boiler feed water temp.- 80°C</p> <p>Other data:</p> <ul style="list-style-type: none"> - Turbine, alternator and other losses = 8% - Specific steam consumption in paper industry= 5 Tons/Ton of paper - Specific power consumption in paper industry= 600 kWh/Ton of paper <p>Calculate:</p>

	<p>i. Coal consumption in boiler per hour or per day.</p> <p>ii. Power generation from co-generation plant</p> <p>iii. If 10% is auxiliary power consumption in co-generation plant, how much power is consumed by the textile industry per hour?</p> <p>iv. What is the gross heat rate of turbine?</p>
<p>Ans</p>	<p>i) Boiler efficiency = Steam production (steam enthalpy- Feed water enthalpy) / Quantity of coal x G.C.V. of coal Quantity of coal = 60,000 (810-80)/ 0.8 x 5000 = 10.95 tons/hr.</p> <p>ii) Gross power generation from co-generation plant</p> <p>Total enthalpy input to turbine = 60,000 x 810 = 48.6 Million kcal. Total enthalpy out put through back pressure= 60,000* 660 = 39.6 Million kcal Enthalpy difference = 48.6- 39.6 = 9 Million kcal/hr Turbine, alternator and other losses =8% or 9x0.08 = 0.72 Million kcal/hr Useful energy for power generation = 9- 0.72 = 8.28 Million kcal/hr Power generation from co-generation plant = 8.28 x 10⁶/860 = 9628kWh</p> <p>iii) If 10% is auxiliary power consumption in co-generation plant, power consumed by textile industry</p> <p>10% of total power generation = 9628 x 0.10 = 962.8kWh</p> <p>Total power consumed by industries = 9628 – 962.8 = 8665.2kWh</p> <p>Total steam consumption in paper plant 40 tons/hr. and specific steam consumption 5 ton/ton of paper. So Paper production per hour is 8 tons.</p> <p>Specific power consumption = 600kWh/ton. Total power consumption in paper industry = 8 x 600 = 4800kWh Total power consumption in textile industry = 8665.2- 4800 = 3865.2 kWh</p> <p>iv) Gross heat rate= Input enthalpy – output enthalpy/ gross generation =(48.6- 39.6) 10⁶/ 9628 = 934.7 kCal/kWh</p>
<p>N-4</p>	<p>To attempt ANY ONE OF THE FOLLOWING among A, B, C and D</p>
<p>A</p>	<p>A captive thermal plant is delivering an output of 29 MW at the generator terminal. The generator efficiency is 96%. The steam generated in a utility boiler with an efficiency of 86% at 105 ata and 485°C is fed to the turbine. The turbine exhausts steam to condenser maintained at 0.1 ata and 45.5°C. The feed water temperature at inlet to the boiler is 105°C.</p>



The other data pertaining to captive power plant are,

- Enthalpy of steam at 105 ata 485°C = 795 kcal/kg.
- Dryness fraction of steam at inlet to condenser = 0.9
- Enthalpy of dry saturated steam at 0.1ata = 618 kcal/Kg.
- Enthalpy of water at 0.1 ata & at 45.5°C = 45.5 kcal/Kg.
- Loss in the gear box connecting turbine and generator = 1100 kW
- Enthalpy of feed water at inlet to the boiler , = 105 kcal/Kg.

Based on the above data determine:

- i. Output of the steam turbine in kW
- ii. Steam flow through the turbine
- iii. Turbine heat rate
- iv. Unit heat rate

Ans

- Enthalpy of steam at turbine exhaust
i.e. h_3 = $45.5 + 0.9 (618 - 45.5)$
= 560.75 Kcal/Kg.
- Generator electric output = 29000 KW
- Generator input = $29000 / 0.96 = 30208.33$ KW
- Loss in gear box = 1100 KW
- Output of steam turbine = Generator input + Gear box loss
= $30208.33 + 1100$
= 31308.33 KW
- i) Output of the steam turbine **Say = 31308 KW**
- ms = Steam flow through turbine

	$= \frac{\text{(Turbine output x 860)}}{(h_2 - h_3) \text{ Turbine enthalpy drop}}$ $h_2 = \text{Enthalpy at turbine inlet} = 795 \text{ kcal/kg}$ $h_3 = \text{Enthalpy at turbine exhaust} = 560.75 \text{ kcal/Kg.}$ $m_s = 31308 \times 860 / (795 - 560.75) = 114940.78 \text{ kg/Hr.}$ $= 114.94 \text{ TPH}$ <p>ii) Steam flow through the turbine Say = 115 TPH</p> <p>iii) Turbine heat rate = Heat input to turbine / Generator output $= [m_s (h_2 - h_1)] / 29000$ $= 115000 (795 - 105) / 29000$ $= 2736.2 \text{ kcal/ kWh}$</p> <p>iv) Unit heat rate = Turbine heat rate / Efficiency of boiler Unit heat rate = $2736.2 / 0.86 = 3181.63 \text{ kcal/ kWh}$</p>
	Or
B	<p>In a textile unit a stenter is delivering 80 meters/min of dried cloth at 5% moisture. The moisture of wet cloth at inlet is 50%. The stenter is heated by steam at 7 kg/cm² with inlet enthalpy of 660 kcal/kg. and condensate exits the stenter at 135 kcal/kg.</p> <p>Other data</p> <ul style="list-style-type: none"> • Latent heat of water evaporated from the wet cloth = 540 kcal/kg • Weight of 10 meters of dried cloth = 1 kg • Inlet temperature of wet cloth = 27°C • Outlet temperature of dried cloth at stenter outlet = 80°C. <p>i) Estimate the steam consumption in the stenter considering a dryer efficiency of 48%.</p> <p>ii) Determine the specific steam consumption kg/kg of dried cloth</p>
Ans	<p>Output of stenter = 80 mts/min. = 80 x 60 / 10 = 480 Kg/hr.</p> <p>Moisture in the dried output cloth = 5% Wt of bone dry cloth = 480 X (1 - 0.05) i.e. W = 456 Kg/hr.</p> <p>m_o = moisture in outlet cloth $= (480 - 456) / 456 = 0.0526 \text{ Kg./Kg. of bone dried cloth}$</p> <p>Inlet moisture = 50% Wt of inlet cloth = 456 / (1 - 0.50) = 912 Kg./hr.</p> <p>m_i = moisture in inlet cloth = 912 X 0.5 / 456 = 1.00 Kg./Kg. bone dried cloth</p> <p>Inlet temperature of cloth = 27°C</p>

	<p>Final temperature of cloth = 80°C</p> <p>Heat load on the dryer = $w \times (m_i - m_o) \times [(T_{out} - T_{in}) + 540]$ Kcal/hr.</p> <p>Heat load on the dryer = $456 (1 - 0.0526) \times [(80 - 27) + 540]$ = 2,56,184.5 Kcal/hr</p> <p>Efficiency of the dryer = 48%</p> <p>Heat input to the stenter = $2,56,184.5 / 0.48 = 5,33,717.71$ Kcal/hr</p> <p>Steam consumption in the stenter = $5,33,717.71 / (660 - 135)$ = 1016.61 Kg/hr</p> <p>Steam consumption per Kg. of dried at stenter outlet cloth = $1016.61 / 480$ = 2.12 Kg./Kg. dried cloth</p>
	Or
C	<p>Determine the cooling load of a commercial building for the following given data.</p> <p><u>Outdoor conditions :</u> DBT = 35°C ; WBT = 25°C; Humidity = 18 g of water / kg of dry air</p> <p><u>Desired indoor conditions :</u> DBT = 25.6°C ; RH = 50 %; Humidity = 10 g of water / kg of dry air</p> <p>Total area of wall = 40 m² Total area of window = 20m² U – Factor (Wall) = 0.33 W / m²K U – Factor (Roof) = 0.323 W / m²K U – factor [fixed windows with aluminum frames and a thermal break] = 3.56 W / m²K</p> <ul style="list-style-type: none"> • 15 m x 25 m roof constructed of 100 mm concrete with 90 mm insulation & steel decking. • CLTD at 17:00 h :Details : Wall = 12°C Roof = 44°C Glass Window = 7°C • SCL at 17 : 00 h :Details : Glass Window = 605 W/ m² • Shading coefficient of Window = 0.74 • Space is occupied from 8:00 to 17:00 h by 25 people doing moderately active work. • Sensible heat gain / person = 75 W ; Latent heat gain / person = 55 W ; CLF for people = 0.9

	<ul style="list-style-type: none"> • Fluorescent light in space = 21.5 W/m² FLF for lighting = 0.9 • Ballast factor details = 1.2 for fluorescent lights & 1.0 for incandescent lights • Computers and office equipment in space produces 5.4 W/m² of sensible heat • One coffee maker produces 1050 W of sensible heat and 450 W of latent heat. • Air changes / hr of infiltration = 0.3 • Height of building = 3.6 m
<p>Ans</p>	<p>I External Heat Gain</p> <p>(i) Conduction heat gain through the wall = U – factor x net area of wall x CLTD =[0.33 x 40 x 12] = 158.4 W</p> <p>(ii) Conduction heat gain through the roof =U – factor x net area of roof x CLTD =0.323 x (15 x 25) x 44 = 5 329.5 W</p> <p>(iii) Conduction heat gain through the windows =U – factor x net area of windows x CLTD = (3.56 x 20 x 7) = 498.4 W</p> <p>(i) Solar radiation through glass = Surface area c Shading coefficient x SCL =(20 x 0.74 x 605) = 8 954 W</p> <p>II Internal Heat Gain</p> <p>(i) Heat gain from people =Sensible heat gain + Latent heat gain</p> <p>Sensible heat gain =(No.of people x Sensible heat gain / person x CLF) =(25 x 75 x 0.9) = 1 687.5 W</p> <p>Latent heat gain =No.of people x Latent heat gain / person =(25 x 55) = 1 375 W</p> <p>Therefore, Heat gain from people=(1687.5 + 1375) = 3 062.5 W</p> <p>(ii) Heat gain from lighting =(Energy input x Ballast factor x CLF)</p> <p>Energy input =(Amount of lighting in space / unit area) x Floor area =21.5 x (15 x 25) =8 062.5 W</p> <p>Therefore, heat gain from lighting =(8062.5 x 1.2 x 0.9) =8 707.5 W</p>

(iii) Heat generated by equipment :

Sensible heat generated by coffee maker =1050 W

Latent heat generated by coffee maker =450 W

Sensible heat gain by computers and office equipment = 5.4 x 375 = 2025 W

Therefore, Heat generated by equipment = **3 525 h**

(iv) Heat gain through air infiltration=(Sensible heat gain + Latent heat gain)

Sensible heat gain =(1210 x airflow x ΔT)

Airflow =(Volume of space x air change rate) / 3600

={ (15 x 25 x 3.6) x 0.3 } / 3600

=0.1125 m³ / s

Therefore, sensible heat gain =1210 x 0.1125 x (35 – 25.6) =1 279.58 W

Latent heat gain =3010 x 0.1125 x (18 – 10) = 2 709 W

No	Space Load Components	Sensible Heat Load (W)	Latent Heat Load (W)
1	Conduction through exterior wall	158.4	-----
2	Conduction through roof	5 329.5	-----
3	Conduction through windows	498.4	-----
4	Solar radiation through windows	8954	-----
5	Heat gained from people	1 687.5	1 375
6	Heat gained from lighting	8 707.5	-----
7	Heat gained from equipment	3 075	450
8	Heat gained by air infiltration	1 279.58	2 709
Total space cooling load		29 689.88	4 534

Or

D During heat balance of a 5 stage preheater Kiln in a cement plant, the following data was measured at Preheater (PH) Fan Inlet and clinker cooler vent air fan inlet:

Parameter measured	Temperature	Static Pressure	Avg. Dynamic Pressure	Specific heat	Gas Density at STP	Duct Area
Unit	°C	(P _s) mm WC	(P _d) mm WC	kcal/kg °C	kg/m ³	m ²
PH Exit Gas at PH fan Inlet	316	-650	28.6	0.248	1.4	2.27
Clinker cooler vent air at cooler Stack Fan Inlet	268	-56	9.7	0.24	1.29	2.01

Note: take Pitot tube constant as 0.85, reference temperature 20 °C and atmospheric pressure 9908 mm WC.

Other Data

Clinker Production	Designed specific volume of PH gas	NCV of Coal	Cost of coal	Annual Operation
TPH	Nm ³ /kg clinker	kcal/kg	Rs./ton	hrs
45.16	1.75	5500	6500	8000

Calculate the following:

- i. Specific volume of PH gas as well as cooler vent air (Nm³/kg clinker)
- ii. Heat loss in pre-heater exit gas (kcal/kg clinker)
- iii. Heat loss in cooler vent air (kcal/kg clinker)
- iv. If the measured specific volume of PH gas (Nm³/kg clinker) exceeds the design value, calculate the heat loss (kcal/kg clinker) and annual monetary loss due to excessive specific volume of PH gas.

Ans

- i. Density of Pre-heater gas at PH Fan Inlet at prevailing temp., pressure conditions:

$$\rho_{T,P} = \rho_{STP} \times \frac{273 \times (9908 + P_s)}{(273 + T) \times 10334}$$

$$\rho_{T,P} = 1.40 \times \frac{273 \times (9908 - 650)}{(273 + 316) \times 10334} = 0.581 \text{ kg/m}^3$$

Velocity of PH gas

$$v = P_t \sqrt{\frac{2gP_d}{\rho_{T,P}}}$$

$$v = 0.85 \sqrt{\frac{2 \times 9.8 \times 28.6}{0.581}} = 26.4 \text{ m/sec}$$

Volumetric flow rate of PH gas = velocity X duct cross-sectional area
 = 26.4 X 2.27
 = 59.9 m³/sec
 = 59.9 X 3600
 = 215640 m³/hr

Specific volume of PH gas = 215640 X 0.58/1.4
 = 89491 Nm³/hr
 = 89491/45160 = **1.98 Nm³/kg clinker**

Similarly density of cooler vent air at cooler vent air fan Inlet at prevailing temp., pressure conditions:

$$\rho_{T,P} = \rho_{STP} \times \frac{273 \times (9908 + P_s)}{(273 + T) \times 10334}$$

$$\rho_{T,P} = 1.29 \times \frac{273 \times (9908 - 56)}{(273 + 268) \times 10334} = 0.62 \text{ kg/m}^3$$

Velocity of cooler vent air in the fan inlet duct

$$v = P_t \sqrt{\frac{2g P_d}{\rho_{T,P}}}$$

$$v = 0.85 \sqrt{\frac{2 \times 9.8 \times 9.7}{0.62}} = 14.88 \text{ m/sec}$$

Volumetric flow rate of PH gas = velocity X duct cross-sectional area
 = 14.88 X 2.01
 = 29.9 m³/sec
 = 29.9 X 3600
 = 107640 m³/hr

Specific volume of cooler vent air = 107640 X 0.62/1.29
 = 51734 Nm³/hr
 = 51734/45160 = **1.15 Nm³/kg clinker**

ii) Heat loss in PH exit gas

$$Q1 = m_{ph} c_p \Delta T \quad (C_p \text{ of PH gas} = 0.248 \text{ kcal/kg } ^\circ\text{C})$$

$$Q1 = 1.98 \times 1.4 \times 0.248 \times (316-20)$$

$$= \mathbf{203.5 \text{ kcal/kg clinker}}$$

iii) Heat loss in cooler vent air

$$Q2 = m_{CA} c_p \Delta T \quad (C_p \text{ of cooler vent air} = 0.24 \text{ kcal/kg } ^\circ\text{C})$$

$$Q2 = 1.15 \times 1.29 \times 0.24 \times (268-20)$$

$$= \mathbf{88.3 \text{ kcal/kg clinker}}$$

iv) Heat Loss due to excess specific volume of PH gas

$$V_{\text{excess}} = 1.98 - 1.75 = 0.23 \text{ Nm}^3/\text{kg clinker}$$
$$\text{Heat loss } Q = 0.23 \times 1.4 \times 0.248 \times (316-20) = 23.6 \text{ kcal/kg clinker}$$

Equivalent coal saving = $23.6/5500 = 0.0043$ kg coal/kg clinker or ton of coal/ton of clinker

Coal saving in one hour = $0.0043 \times 45.16 = 0.194$ TPH

Annual Coal Saving = $0.194 \times 8000 = 1552$ tons of coal per annum

Annual Monetary Saving = $1552 \times 6500 = \text{Rs. 100.88 lakhs}$

----- End of Section - III -----