25th NATIONAL CERTIFICATION EXAMINATION FOR ENERGY MANAGERS & ENERGY AUDITORS - SEPTEMBER, 2025

PAPER - 3: ENERGY EFFICIENCY IN ELECTRICAL UNTILITIES

Date : 28.09.2025 Timings: 09:30-12:30 HRS Duration: 3 HRS Max. Marks: 150

General instructions:

- *Please check that this question paper contains **8** printed pages*
- *Please check that this question paper contains **64** questions*
- *The question paper is divided into three sections*
- *All questions in all three sections are compulsory*
- *All parts of a question should be answered at one place*

Section – I: OBJECTIVE TYPE **Marks: 50 x 1 = 50**

(i) Answer all **50** questions
(ii) Each question carries **one** mark
(iii) Please shade the appropriate oval in “SECTION-I” of “MAIN ANSWER BOOKLET” with **BLUE/BLACK ball point pen**

1	Which lamp is most suitable for color-critical applications? a) **Halogen lamps** b) LED lamps c) CFLs d) Metal halide lamps
2	Iron losses in an electric motor can be reduced by using a) More copper and large conductors b) **Use of thinner gauge lower loss core steel** c) Use of low loss fan design d) Optimised design and strict quality control
3	A cooling tower has an evaporation loss of 12 m^3/hr and COC of 2.5. What will be the blowdown loss in m^3/hr ? a) 5.2 b) **8.0** c) 9.6 d) 10.2
4	Energy savings by motor replacement can be worked out by: a) KW output ($\eta_{old} - \eta_{new}$) b) KW output ($\eta_{new} - \eta_{old}$) c) **KW output ($1/\eta_{old} - 1/\eta_{new}$)** d) KW output ($1/\eta_{new} - 1/\eta_{old}$)
5	Stray losses in a motor are mainly caused by: a) **Leakage flux induced by load currents** b) Hysteresis and eddy currents c) Frictional losses d) Copper winding losses
6	In a vapor compression refrigeration system, enthalpy changes occur across: a) Compressor b) Condenser c) Evaporator d) **All of the above**
7	The purpose of inter-cooling in a multistage compressor is to: a) Increase final pressure b) **Reduce compression work** c) Separate oil vapour d) Remove all moisture
8	When air is cooled by evaporation in an air washer: a) Humidity ratio decreases b) **Dry bulb temperature decreases** c) Dry bulb temperature increases d) Enthalpy increases
9	Amorphous core transformers primarily reduce: a) Load loss b) **No-load loss** c) Stray loss d) None of the above
10	If a pump delivery valve is throttled to 30% of rated flow, best energy efficiency measure is: a) Replacing the motor b) Installing a larger impeller c) Increasing pump speed d) **None of the above**
11	Calculate the FAD in CFM for an air compressor with a cylinder displacement of 150 CFM and volumetric efficiency of 90%:

	a) 165 b) **135** c) 150 d) None of the above
12	If pump speed is reduced to 2/3rd of its original speed, power consumption will: a) Decrease by half b) Decrease to one-fourth **c) Decrease to approx. 30% of original** d) Remains same
13	At higher altitudes, for same FAD, air compressors: a) Consume less power **b) Consume more power** c) Show no difference d) Work without lubrication
14	In a 4-stroke diesel engine, fuel is injected during: a) Induction stroke b) Compression stroke **c) Ignition and Power stroke** d) Exhaust stroke
15	Voltage unbalance in motors: a) Reduces motor temperature b) Increases motor slip c) **Causes excessive heating and reduces life** d) Improves torque
16	Soft starters are used to: a) Increase motor speed b) **Reduce inrush current** c) Convert AC to DC d) Improve efficiency
17	An air compressor is driven by an IE3 premium efficiency motor. Compared to an IE2 motor of the same rating, which of the following statements is most accurate? A) The IE3 motor will always consume less power under all load conditions. **B) The IE3 motor achieves higher efficiency mainly by reducing copper and iron losses.** C) The IE3 motor has lower inrush current during starting compared to IE2. D) The IE3 motor achieves efficiency by increasing slip.
18	Scale in condenser tubes: a) Increases energy use b) Reduces heat transfer c) Can lead to higher operating pressure d) **All of the above**
19	Larger diameter ducts in fans: a) Increase system resistance b) **Reduce system resistance** c) No effect d) Increase static pressure
20	Which of the following is a common symptom indicating that a pump is oversized? a) High discharge pressure **b) Throttle valve-controlled systems** c) Low suction pressure d) High motor power consumption
21	Reducing the diameter of an impeller in a centrifugal pump will: a) Increase head b) **Decrease head** c) No effect on head d) Increase flow
22	The main function of fill media in a cooling tower is to: a) Reduce drift losses b) **Increase water–air contact** c) Reduce fan noise d) Filter suspended solids
23	Energy-saving opportunities in cooling towers include: a) Optimizing fan blade angle seasonally b) Maintaining correct water chemistry c) Cleaning fill media regularly d) **All of the above**
24	The L/G ratio in a cooling tower is: a) **Ratio of liquid water mass flow to gas (air) mass flow** b) Ratio of drift loss to make-up water c) Ratio of cooling load to fan power d) Ratio of TDS in blowdown to TDS in make-up water
25	Increasing chilled water leaving temperature in a centrifugal chiller: a) **Increases efficiency** b) Decreases efficiency c) No effect d) Increases refrigerant flow
26	Luminaires are used to: a) Store electrical energy b) **Distribute and control light from lamps** c) Produce light directly d) Increase lamp wattage
27	The Envelope Performance Factor (EPF) in ECBC is used to: a) **Compare energy efficiency of proposed and baseline building designs** b) Determine cooling tower sizing c) Calculate lighting power density d) Measure indoor air quality

28	In a cooling tower, if any three of the four parameters: heat load, range, approach, and wet-bulb temperature, are kept constant, the required tower size will vary a)Directly with the heat load b)Inversely with the range c)Inversely with the approach **d) All the above**
29	A system resistance curve of a fan changes with: a) Inlet guide vanes b) **Discharge dampers** c) Speed change with VFD d) Any of the above
30	A centrifugal pump has BEP efficiency of 65%. At shut-off head, efficiency is: a) **0%** b) 65% c) 50% d) 30%
31	A pump with 200 mm impeller delivers 120 m^3/h. To deliver 100 m^3/h by trimming, impeller size will be approximately: a) 240 mm **b) 167 mm** c) 60 mm d) 276 mm
32	If tail-end power factor is improved from 0.80 to 0.95, distribution loss reduction is: a) 13.33% b) 21% c) **29%** d) 16%
33	In a vapour compression system, refrigerant changes from vapour to liquid in the: a) Compressor b) Evaporator c) **Condenser** d) Expansion valve
34	Unity power factor means: a) **No reactive power is drawn from the supply** b) Current leads voltage c) Current lags voltage d) Reactive power is maximum
35	Examples of lighting controls include: a) Dimmer switches b) Timers c) Photo-sensors **d) All of the above**
36	A 4-pole, 50 Hz induction motor runs at 1470 rpm. Slip is: a) **0.02** b) 0.20 c) 0.25 d) 0.30
37	Which type of compressed air dryer consumes the least power for capacities higher than 250 CFM? a) Refrigeration type b) Blower reactivated type c) **Heat of compression type** d) Heatless purge type
38	A DG set operates at 1250 kVA, 0.8 PF, with specific fuel consumption of 0.23 L/kWh. Quantity of fuel used is____________. a) 175 L/h **b) 230 L/h** c) 250 L/h d) 300 L/h
39	In a UPS, DC to AC conversion is carried out by: a) Converter b) Charger c) Battery **d) Inverter**
40	If a plant receives 96 Million Units (MU) with a T&D efficiency of 80%, generation required is: a) 101.2 MU b) 76.9 MU **c) 120 MU** d) 68.1 MU
41	Synchronous speed of a motor is inversely proportional to: a) **Number of poles** b) Frequency c) Voltage d) Temperature
42	If 27,216 kcal of heat is removed per hour, refrigeration tonnage is: a) 10 TR b) 7 TR c) 11 TR d) **None of the above**
43	The most influential component for cooling tower performance is: a) **Fill media** b) Drift eliminator c) Casing d) Fan motor
44	An equipment room measures 12 × 8 × 3.5 m. Ventilation required for 15 ACH is: a) 5060 m^3/h b) 5020 m^3/h c) **5040 m^3/h** d) 5080 m^3/h
45	Luminous efficacy is: a) **Ratio of lumens to watts** b) Measured in candela c) Same as luminance d) Measures reflection of light
46	If dew point temperature equals air temperature, relative humidity is: a) 0% b) 45% c) 50% **d) 100%**
47	In a DG set, the component causing maximum energy loss is: a) Coolant loss b) Alternator loss c) Radiation loss d) **Flue gas loss**
48	The Energy Conservation Act applies to buildings with connected load: a) All HT connections **b) Commercial building having ≥ 100** kW c) Residential buildings only d) Government buildings having ≥ 100 kW
49	A 750 kVA transformer has 1200 W no-load loss and 7200 W full-load copper loss. At 60% load, total loss is:

	a) 4320 W b)5520 W c) 7632 W **d) 3792 W**
50	In vapour compression and vapour absorption systems, the common refrigerant is: a) Lithium bromide b) R-134a c) **Ammonia** d) None of the above

.... End of Section I ....

Section – II: SHORT DESCRIPTIVE QUESTIONS **Marks: 8 x 5 = 40**

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

S-1

A steel manufacturing facility is powered by a 3-phase, 6.6 kV, 50 Hz supply and operates the following electrical loads:

An electric arc furnace consumes 1.2 MW at a lagging power factor of 0.65, a bank of induction motors for rolling operations consumes 800 kW at a 0.80 lagging power factor, and the lighting and instrumentation systems consume 100 kW at unity power factor.

Due to utility regulations, the overall plant power factor must be improved to 0.95 lagging. A capacitor bank will be installed for compensation. As an energy auditor evaluate the following:

a. Total active power consumption. (1 Mark)
b. Total initial apparent power drawn by the facility. (1 Mark)
c. The operating power factor. (1 Mark)
d. Determine the total reactive power required to achieve the desired power factor. (2 Mark)

S-1 Ans

Load	Real Power (KW)	PF	KVA = KW/PF	Reactive Power (KVAr) = $\sqrt{(KVA)^2-(KW^2)}$
Arc furnace	1200	0.65	1846	1402
All Motors	800	0.8	1000	600
Lighting & instruments	100	1	100	0
Total	2100		2946	2002

a. Total active Power = 1200+800+100 = 2100 kW
b. Total apparent power drawn: 1846+1000+100 = 2946 kVA
c. Operating Power factor = 2100/2946 = 0.713
d. KVAR = KW (Tan PF1 -Tan PF2)
= 2100 * (Tan (Cos^{-1}(0.713)- Cos^{-1}(0.95))
= 1376 kVAr

S-2

Determine the difference in heat rejected in kCal/TR to the cooling tower for two different types of air conditioning system operating at same capacity.

Parameter	Centrifugal chiller	VAM
Chilled water flow (m^3/h)	-	180
Condenser water flow (m^3/h)	-	340
Chiller inlet temp (°C)	13.0	14.6
Condenser water inlet temp (°C)	-	33.5
Chiller outlet temp (°C)	7.7	9.0
Condense water outlet temp (°C)	-	39.1
Specific power consumption (kW/TR)	0.6	-

S-2 Ans

1 TR = 3024 kcal/h
Centrifugal chiller:
Power input = 0.6 × 860 = 516 kcal/TR
Heat rejected = 3024 + 516 = 3540 kcal/TR

	VAM: Chilled water flow = 180 m^3/h = 180000 kg/h $\Delta T = 14.6 - 9.0 = 5.6°C$ Cooling load = 180000 × 1 × 5.6 = 1008000 kcal/h TR = 1008000 / 3024 = 333.33 TR Heat Rejected = 340000 kg/hr x 1 kcal/kg x (39.1-33.5) = 1904000 kcal/hr Heat Rejected per TR = 1904000 / 333.33 = 5712 kcal/TR Difference per TR = 5712 - 3540 = 2172 kcal/TR
S-3	An energy audit in an industrial unit revealed a fan directly coupled with motor was operating at 37 Hz through VFD for 500 hours/month and supplying air through a 150 mm diameter duct. The fan is designed to deliver an air flow of 1300 m^3/h with a rated input power of 3 kW at 50 Hz. Calculate the air velocity and annual energy savings ignoring the motor losses.
S-3 Ans	Given: Design air flow rate = 1300 m^3/h at 50 Hz Operating frequency = 37 Hz Power drawn at 50 Hz = 3 kW Operating hours = 500 hours/month Duct diameter = 150 mm = 0.15 m Flow rate at 37 Hz: Q2 = 1300 × (37 / 50) = 962 m^3/h Q2 = 962 / 3600 = 0.2672 m^3/s Duct area: $A = \pi/4 \times (0.15)^2 = 0.01767\ m^2$ Air velocity: V = Q / A = 0.2672 / 0.01767 = 15.12 m/s Power at 37 Hz: $P2 = 3 \times (37 / 50)^3 = 3 \times 0.405 = 1.215$ kW Monthly energy savings: (3 - 1.215) × 500 = 892.5 kWh/month Annual energy savings: 892.5 × 12 = 10710 kWh/year Answers: Air velocity = 15.12 m/s Annual energy savings = 10710 kWh/year
S-4	A pump is used to fill a rectangular overhead tank measuring 5 m × 3.5 m with a height of 10 m. The inlet pipe to the tank is positioned at a height of 25 m above ground level. The following additional data is available: The pump draws water from an underground sump situated 4 meters below the pump level and delivers it to a tank whose overflow line is positioned 8 meters above the tank bottom. The motor driving the pump draws 7.5 kW of power. The operating efficiencies of the motor and the pump are 90% and 70% respectively. Calculate the time taken by the pump to fill the tank up to the overflow level.

S-4 Ans

Step 1: Volume of water filled
Volume = 5 × 3.5 × 8 = 140 m³
Mass of water = 140 × 1000 = 140000 kg

Step 2: Total head (H)
Total head = 25 + 4 = 29 m

Step 3: Shaft power (output of motor)
Shaft Power = 7.5 × 0.90 = 6.75 kW

Step 4: Water power (hydraulic power output of pump)
Water Power = 6.75 × 0.70 = 4.725 kW = 4725 W

Step 5: Time taken
Pump efficiency = Mass flow × g × Head / Shaft Power
0.7 = mass flow x 9.81 x 29 /(6.75x1000)

Mass flow = 16.6 kg/sec = 59791 kg/hr = 59.79 m3/hr

Time = 140 / 59.79 = 2.34 hrs = 140.5 minutes

S-5

A commercial training hall with dimensions 18 m × 12 m is being planned. Calculate the number of 18 W LED lamps, each providing 1800 lumens, required to achieve an illuminance level of 300 Lux. The lamps will be installed at a height of 3 meters from the working plane. The utilisation factor (UF) of the system is 0.70, and the light loss factor (LLF) is 0.80.

S-5 Ans

Area of room (A): 18 × 12 = 216 m^2
Total lumens required (Φ_total): Φ_total = E × A = 300 × 216 = 64800 lumens
Effective lumens per lamp (Φ_lamp_effective): Φ_lamp_effective = Lumen Output × UF × LLF = 1800 × 0.70 × 0.80 = 1008 lumens
Number of lamps required (N): N = Φ_total / Φ_lamp_effective = 64800 / 1008 = 64.3 ≈ **65 lamps**

S-6

A private power distribution company has implemented new digital metering and billing systems to improve efficiency in a residential zone. After six months of operation, the following data was recorded:

- Input energy to the system = 75 MU
- Metered billed energy = 56 MU
- Unmetered average billing = 4 MU
- Amount billed = ₹680 million
- Total amount received = ₹600 million
- Arrears collected = ₹90 million
- Purchased energy cost = ₹8.50 per kWh

i) Estimate the Aggregate Technical and Commercial (AT&C) loss (%) and the revenue realized per kWh – 4 Marks

ii) Calculate the revenue loss per kWh to the company due to AT&C loss. – 1 Mark

S-6 Ans	Input Energy = 75 MU = 75,000,000 kWh Metered Billed Energy = 56 MU Unmetered Average Billing = 4 MU Total Energy Billed = 56 + 4 = 60 MU Amount Billed = ₹680 million Arrears Collected = ₹90 million Amount Received = ₹600 million Purchased Energy Cost = ₹8.50/kWh i) AT&C Loss (%) and Revenue Realized (₹/kWh) Billing Efficiency = (60 / 75) × 100 = 80.0% Collection Efficiency = ((600 - 90) / 680) × 100 = (510 / 680) × 100 = 75.0% AT&C Loss (%) = 1 - (Billing Efficiency × Collection Efficiency) = 1 - (0.80 × 0.75) × 100 = 1 - 0.60 × 100 = 40.0% Revenue Realized per kWh = (600 - 90) / 75 = 510 / 75 = ₹6.80/kWh ii) Revenue Loss per kWh Revenue Loss = ₹8.50 - ₹6.80 = ₹1.70/kWh
S-7	List five energy saving measures in compressed air system.
S-7 Ans	**Energy-Saving Measures in a Compressed Air System (Headings Only)** 1. Fixing Air Leaks 2. Reducing Compressor Discharge Pressure 3. Proper Sizing of Compressors 4. Using Variable Speed Drives (VSDs) 5. Avoiding Artificial Demand 6. Heat Recovery from Compressor 7. Reducing Air Intake temperature 8. Optimizing Piping Layout and Size 9. Using Efficient Air Dryers 10. Eliminating Inappropriate Uses of Compressed Air 11. Using Automatic Drain Traps 12. Implementing Demand-Side Control 13. Operating Compressors at Full Load 14. Performing Regular Maintenance and Monitoring
S-8	Match the Following: 1. Solar Heat Gain Coefficient (SHGC) — a. Coefficient of Performance (COP) 2. U-value — b. Solar Reflectance 3. HVAC System Efficiency — c. Fenestration Heat Gain 4. Cool Roof — d. Building Insulation 5. Thermal Bridging — e. Conductive path for unwanted heat transfer
S-8 Ans	**Answer Key:** 1 → **c. Fenestration Heat Gain** 2 → **d. Building Insulation**

	3 → **a. Coefficient of Performance (COP)** 4 → **b. Solar Reflectance** 5 → **e.** Conductive path for unwanted heat transfer

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

Section – III: LONG DESCRIPTIVE QUESTIONS **Marks: 6 x 10 = 60**

(i) Answer all **<u>Six</u>** questions
(ii) Each question carries **<u>Ten</u>** marks

L-1	A distribution company (DISCOM) plans to implement a comprehensive Demand Side Management (DSM) initiative to reduce its peak load and overall energy procurement cost. The program targets two consumer categories Residential consumers and Industrial consumers. For residential consumers, DISCOM has taken LED replacement as a DSM intervention whereas for industrial consumers load shifting strategy has been adopted through peak and off-peak electricity pricing. The DISCOM supplies electricity to 10,000 households, each using 4 CFL bulbs (30 W each). These bulbs are used for 5 hours per day during evening peak hours. The DISCOM replaces each CFL bulb with a 9 W LED bulb. Procurement cost of each LED bulb costs ₹100, however the DISCOM provides the LED bulbs in place of CFL to consumers at a subsidized rate of ₹70/bulb. Administrative cost per household for the program Rs.10/-. DISCOM also serves 50 industrial consumers, each with a shiftable evening load of 100 kW, used from 6 PM to 10 PM. DISCOM incentivizes these consumers to shift their load from 10 PM to 2 AM by offering an incentive of ₹2 per kWh shifted. Eighty percent of industrial consumers agree to take advantage of the tariff incentive scheme. Power purchase cost for DISCOM: o Evening Peak (5–10 PM): ₹7/kWh o Late Night (10 PM–6 AM): ₹3/kWh Calculate the following: a) For the residential consumers: i) Calculate the total daily energy savings in kWh/day from the LED replacement program. 2 Marks ii) Determine the daily cost savings for the DISCOM from the LED program. 1 Mark iii) Calculate the total one-time cost to the DISCOM for the LED program, including subsidies and administrative costs. 2 Marks iv) Estimate the simple payback period in days for the LED program. 1 Mark b) For the industrial consumers: i) Calculate the total energy shifted in kWh/day. 1 Mark ii) Compute the net daily savings for DISCOM, considering power cost reduction and incentive payout. 1 Mark c) Estimate the carbon emission avoidance due to above two DSM activity, if emission factor of grid electricity is 0.716 tCO2/MWh. 2 Marks
L-1 Ans	Daily energy savings from LED replacement: (10000*4*5) * (30 – 9) /1000 = 4200 kWh Daily cost savings for DISCOM = 4200 *(7) = Rs.29400 One time cost to DISCOM: Subsidy for LED replacement = 10000 * 4 * (100-70) = Rs. 12 Lakh Administrative cost = 10000*10 = Rs. 1.0 Lakh Total One-time cost to DISCOM = 12+ 1.0 = Rs. 13.0 Lakh Simple Payback = 1300000 / (16800*365) = 44 Days Energy Shifted by industrial consumers = 50*100*4*0.8 = 16000 kWh per Day Net daily savings = 1600 *(Purchase cost savings – incentive cost) = 16000* (7-3-2) = Rs 32000/ Day Energy Savings achieved only by the LED program, hence emission reduction = 4200*0.716/1000 = 3.0 tCO_2 per day.

L-2

A) A clear water pump with rated flow of 125 m^3/hr, head 55 m at rated speed of 1460 rpm and 79% efficiency is being used for supplying clarified water to a residential colony's water treatment facility. The daily water requirement is for 3000 M^3. The pump is directly coupled and driven by a three phase 50 Hp, 415 V, 64A, 0.9 pf, 1460 rpm induction motor with 90.5% full load efficiency.

During an internal energy audit, it has found that the motor is designed to operate with only 65% loading at pump rated conditions, therefore compromising on motor efficiency. The plant management has considered replacing the standard motor with a 30 kW IE3 motor. The following are operating parameters before and after motor replacement:

Parameters	Before motor replacement	After motor replacement
Flow (m^3/hr)	130	?
Head (m)	52	51
Supply Voltage (V)	415	415
Current (Amp)	42	39
Power Factor	0.9	0.92
Motor Eff (%)	0.88	0.932

As an external auditor, you observed that although the plant has reduced the size of the induction motor to improve loading and enhance motor efficiency, the slip of the new IE3 motor has decreased by 20 rpm. This raises concerns about the actual energy savings achieved. Validate the savings claimed, calculate the following:

i) % Loading of motor after replacement. (1 Mark)
ii) Flow after replacing the standard motor with 30 kW IE 3 motor. (1 Mark)
iii) Operating Pump Efficiency before and after motor replacement. (2 Marks)
iv) Daily energy saving during operation due to motor replacement. (1 Marks)

B) Mark the following statements as True/False

i) Totally enclosed, fan cooled (TEFC) motors are less efficient than screen-protected, drip-proof (SPDP) motors.
ii) Stray loss in induction motors is inversely proportional to load current.
iii) As per BIS standard, the motor output should not be affected with voltage variation up to +/- 6%.
iv) Motor life doubles for each 10^0C reduction in operating temperature.
v) Starting torque of energy efficient motors is higher than standard motors.

L-2 Ans

A)

i) Loading of the IE3 Motor: = (1.732*0.415*39*0.92*0.932)/30 = 80.12%
ii) Flow after replacement = 130 m^3/hr * 1480/1460 = 131.8 m^3/hr
iii) Operating Pump Efficiency:

Power Consumption before replacement = 1.732*0.415*42*0.9 = 27.17 kW
Power Consumption after replacement = 1.732*0.415*39*0.92 = 25.79 kW

Before replacement = [(130 m3/hr /3600) * 52 *9.81] / (27.17*0.88) = 77%
After replacement = [(131.8 m3/hr/3600) * 51 *9.81] / (25.79*0.932) = 76.2%

Daily Operating Hour before Pump replacement = 3000 /130 = 23.08 Hrs
Daily Operating Hour after Pump replacement = 3000 /131.8 = 22.77 Hrs

iv) Daily Energy Savings = (23.08*27.17) – (25.79*22.77) = 39.9 kWh

B) True/False:

i) False
ii) False
iii) True
iv) True
v) False

L-3

A Commercial Office building accommodates two government departments. The total employees working in both the departments is 250 out of which 70% average number of employees present at any time. Being a government office, the building is operational 6 days a week with 10 working Hrs a day. The building receives Electricity supply from local electricity Distribution company through a 33KV feeder, and it is distributed after stepping down to 415 V. The building does not have separate parking, lawn, internal roads etc.
The building information sheet is as below:

Office Building			Annual Data (April 24-March 25)
1.	Contract Demand (kW)		130
2.	Installed capacity: Diesel Generating (DG) Set(s) (kVA)		160
3.	a) Annual Electricity Consumption, purchased from Utilities (kWh)		105753
	b) Annual Electricity Consumption, through DG Set(s) (kWh)		2136
4.	a) Annual Cost of Electricity, purchased from Utilities (Rs.)		1043557
	b) Annual Cost of Electricity generated through DG Set(s) (Rs.)		54405
5.	Area of the Building	Built Up Area (sq.m)	3591.96
		Conditioned Area (sq.m)	2155.18
6.	Installed capacity of Chiller of Air Conditioning System (TR)		137.5
7.	Installed lighting load (kW)		8.11
8.	Officer Appliances (kW)		11.0
9.	Other Loads (kW)		12.5
10.	HSD Consumption in DG (GCV 10800 Kcal/kg and density of 0.85)		585 Litres

Calculate the following:

a. The total electricity consumed by the building and average electricity unit cost. (2 Mark)
b. EPI of the building considering the reported data for past one year. Also recommend the appropriate rating under BEE star rating program for buildings if the bandwidth of the EPI range between 150-50 kWh/sq. m/year. (3 Marks)
c. Calculate the design diversity factor of the building, if the design EER of the chiller is 3.5 and recorded maximum demand is 75% of the contract demand. (2 Marks)
d. Estimate the overall operating efficiency of the DG set (2 Marks)
e. Calculate the lighting power density (1 Marks)

L-3 Ans

a. Total electricity consumed: 105753+2136 =107889 kWh
Average unit cost: (1043557+54405)/107889 = Rs.10.18 per kWh
b. EPI = 107889/3591.96 = 30 kWh/m^2/year, the EPI is below the bandwidth for star rating, hence 5 Star rated.
c. Diversity Factor = Maximum Demand / Connected Load
Maximum Demand = 130 * 0.75 = 97.5 kW
Connected Load = Lighting load + appliances +others+ AC
= 8.11+11.0+12.5+ (137.5*3024/860/3.5) = 169.75 kW
Diversity Factor = 97.5/169.75 = 0.57 (or) 169.75/97.5 = 1.74

d. Overall, DG Set efficiency= (2136*860) / (585*0.85*10800) = 34.2%
e. Lighting Power Density = 8.11*1000/3591.96 = 2.25 W/m^2

L-4

A 5-star business hotel operates a centralized HVAC system operating round the clock with the following configuration. Only one chiller operates at a time, while the other is on standby. Two centrifugal chillers, each rated at 250 TR, with EER varying with load as below:

Load (%)	EER	Operating Days/Year
85%	5.2	180
60%	4.6	120
40%	3.9	65

No change in EER observed above 85% load, assume chiller motor efficiency of 90% at all loading conditions and the energy consumption by the auxiliary systems is as below:

During chiller operation, two pumps run in parallel at an 80% load factor, consuming a total of 19.7 kW. In addition, two cooling tower fans operate continuously with a power consumption of 5.89 kW. Both the

	pumps and fans function 24 hours a day, with overall efficiencies of 75% and 70% respectively. The applicable electricity tariff is ₹6.5 per kWh. Evaluate the following: a. The total annual energy consumption (in MWh) and cost of the HVAC system, considering part-load EERs and auxiliary loads. (4 Marks) b. Heat removal by condenser in (TR) at different loads. (3 Marks) c. The hotel is planning to use the chiller partially as a heat pump by mounting a plate heat exchanger in series between the compressor and condenser (desuperheater for partial heat recovery) for producing hot water. The heat recovery can be only 20% of the condenser heat discharge. If the hot water requirement is 2000 litters/hr with 10^{0}C temperature rise, evaluate whether the hot water requirement can be met at 40% loading conditions. (3 Marks)

L-4 Ans

a. Energy Consumption:

Energy Consumed by Chiller:

Loading (%)	Cooling Load (TR)	EER	Cooling Load (KW)	Input Power (KW)	Days	Mwh
A	B	C	D=B*3024/860	E=D/C	F	G=E*F*24/1000
0.85	212.5	5.2	747.21	143.69	180	620.8
0.6	150	4.6	527.44	114.66	120	330.2
0.4	100	3.9	351.63	90.16	65	140.7

Energy Consumed by auxiliaries: (19.7+5.89) *24*365/1000= 224.5 Mwh

Total Annual Energy Consumption = 620.8+330.2+140.7+224.5 = 1316 Mwh

Annual Cost = 1316000*6.5 = Rs. 85.55 Lakh

b. Heat Removal by Condenser (TR)

Loading (%)	Cooling Load (TR)	Input Power (KW)	Power Input to Compressor (kW)	Condenser Heat Load (TR)
X	Y	Z	P=Z8*0.9	HL =Y+(P*860/3024)
0.85	212.5	143.69	129.32	249.28
0.6	150	114.66	103.20	179.35
0.4	100	90.16	81.14	123.08

c) Heat Hoad at 40% loading = 123.08*3024 = 372194 kCal/Hr

Recovery potential (20%) = 74439 kCal/Hr

Heat requirement for hot water generation = 2000*1*10 = 20000kCal/H

Therefore, the heating requirement can easily be met at 40% loading.

L-5 a)

In a large-scale steel manufacturing facility, a cooling tower is used to reject heat from continuous casting operations. The circulating water flow rate is 2000 m^3/hr. The cooling tower is currently operating at a Cycles of Concentration (COC) of 3. The evaporation loss is estimated at 1.0% of the circulating flow, and the drift loss is 0.1% of the circulating flow.

The facility is planning to improve the COC from 3 to 6 through advanced water treatment. Evaluate the following:

i. Calculate the make-up water requirement at the current COC of 3.
ii. Calculate the revised make-up water requirement if the COC is increased to 6.
iii. Estimate the total water savings per day.
iv. Discuss one limitation or risk associated with increasing the COC.

b) True or False
i. Cooling towers primarily reject heat through evaporative cooling.
ii. The approach temperature in a cooling tower is the difference between the hot water temperature and the

	ambient dry bulb temperature. iii. Blowdown in a cooling tower is required to prevent the build-up of dissolved solids. iv. Drift losses in a cooling tower refer to water carried away with the exhaust air. v. Cooling tower effectiveness improves with higher approach temperatures. vi. Cycles of concentration in a cooling tower relate to how many times the water is reused before discharge.
L-5 Ans	a) Given: Circulating Water Flow (CWF) = 2000 m^3/hr Initial COC = 3 Final COC = 6 Evaporation Loss (E) = 1% of 2000 = 20 m^3/hr Drift Loss (D) = 0.1% of 2000 = 2 m^3/hr i) Current Make-up Water Requirement at COC = 3 B = 20 / (3 - 1) = 10 m^3/hr Make-up Water = E + D + B = 20 + 2 + 10 = 32 m^3/hr ii) Revised Make-up Water Requirement at COC = 6 B = 20 / (6 - 1) = 4 m^3/hr Make-up Water = E + D + B = 20 + 2 + 4 = 26 m^3/hr iii) Water Savings Hourly Savings = 32 - 26 = 6 m^3/hr Daily Savings = 6 × 24 = 144 m^3/day iv) Limitation of Higher COC Increasing COC can lead to higher concentrations of dissolved solids in the water, which may cause scaling, corrosion, and microbiological fouling in the system. Effective water treatment and frequent monitoring are necessary to avoid operational issues. b) True or False i) True ii) False *(It is the difference between the cold-water temperature and the wet bulb temperature.)* iii) True iv) True v) False *(Lower approach means better effectiveness.)* vi) True
L-6	a) A manufacturing plant operates a 180 kVA diesel generator set rated at 0.8 lagging PF. The prime mover is a diesel engine rated 240 BHP. The alternator has total losses (including exciter power) of 5.44 kW. Assume no derating for site conditions. The generator is required to supply a mixed industrial load at its full kVA rating. The plant manager wishes to improve system efficiency by operating at a higher power factor. The diesel engine operates at a brake thermal efficiency of 32% when loaded near its rated capacity. The calorific value of the diesel fuel is 10,500 kCal/kg, and the specific gravity of the fuel is 0.85. Calculate the following: i) Maximum power factor that can be maintained at full kVA load without exceeding the engine capacity. (3 Marks) ii) Corresponding diesel fuel consumption (litres per hour) at this maximum power factor. (2 Marks) b) True or False Question: i) Improving power factor of the load on a DG set reduces the apparent power drawn and increases the system's overall fuel efficiency.

	ii) Alternator losses are independent of the load power factor. iii) Turbocharger in a diesel engine helps to reduce engine noise. iv) A diesel generator set must always be operated at unity power factor for maximum efficiency. v) DG sets are designed to handle unbalanced load between phases to 25% of their capacity.
L-6 Ans	**a)** i. Convert BHP to kW (shaft power): 240 BHP × 0.746 = 179.04 kW Net electrical power available = 179.04 kW - 5.44 kW = 173.6 kW At full load (180 kVA), maximum PF = Real Power / Apparent Power PF = 173.6 / 180 = 0.964 ii. Thermal Input Required = Electrical Output / Efficiency = 179.04 / 0.32 = 559.5 kW Convert kcal to kW: 1 kg diesel = 10,500 kcal = 10,500 × 4.1868 = 43,961.4 kJ/kg Fuel consumption (kg/hr) = (559.5 × 3600) / 43961.4 = 45.8 kg/hr In litres per hour = 45.8 / 0.85 = 53.88 L/hr **b) True or False Question:** i) Improving power factor of the load on a DG set reduces the apparent power drawn and increases the system's overall fuel efficiency. **True** ii) Alternator losses are independent of the load power factor. **False** iii) Turbocharger in a diesel engine helps to reduce engine noise. **False** iv) A diesel generator set must always be operated at unity power factor for maximum efficiency. **False** v) DG sets are designed to handle unbalanced load between phases to 25% of their capacity. **False**

.... End of Section III ....