

PRACTICE PAPER
NATIONAL CERTIFICATION EXAMINATION FOR
ENERGY MANAGERS & ENERGY AUDITORS
PAPER – 3: ENERGY EFFICIENCY IN ELECTRICAL UTILITIES
ANSWER KEY, EXPLANATIONS AND MODEL ANSWERS

Duration: 3 HRS Max. Marks: 150

General instructions:

- 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
- Use of a non-programmable scientific calculator is permitted

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

1. Answer all 50 questions
2. Each question carries one mark
3. Choose the most appropriate option (a, b, c or d)

1 A cooling tower circulates 3,600 m³/h with a range of 7 °C and is operated at 4 cycles of concentration. Using the guidebook evaporation loss formula, the blowdown required is about:

[1P3CEM001 | Chapter 7: Cooling Towers | 7.2 Cooling tower performance – evaporation and blowdown]

- a) 12.9 m³/h
- b) 7.7 m³/h
- c) 9.6 m³/h
- d) 115.7 m³/h

Answer & explanation

Correct answer: (a) $\approx 12.9 \text{ m}^3/\text{h}$.

Given: circulation rate = 3,600 m³/h; range $T_1 - T_2 = 7 \text{ }^\circ\text{C}$; COC = 4.

Formula: evaporation loss $E \text{ (m}^3/\text{h)} = 0.00085 \times 1.8 \times \text{circulation rate (m}^3/\text{h)} \times (T_1 - T_2)$; blowdown $B = E / (\text{COC} - 1)$.

Substitution: $E = 0.00085 \times 1.8 \times 3,600 \times 7 = 38.56 \text{ m}^3/\text{h}$; $B = 38.56 / (4 - 1)$.

Result: **$B \approx 12.9 \text{ m}^3/\text{h}$** . Make-up = $E + B + \text{drift} \approx 38.6 + 12.9 + \text{drift} \approx 51.5 \text{ m}^3/\text{h}$ plus drift.

Why the others are wrong: (b) divides by (COC + 1); (c) divides by COC; (d) multiplies E by (COC – 1). Raising COC through better water treatment reduces blowdown and make-up, but scaling risk must be controlled.

Ref: BEE Guidebook Paper 3, Ch. 7 (7.2 Cooling tower performance – evaporation loss, COC, blowdown).

2 In a vapour compression cycle, refrigerant enthalpies are 400 kJ/kg at evaporator outlet, 430 kJ/kg at compressor outlet and 250 kJ/kg after the expansion valve. For a 100 TR plant (1 TR = 3.517 kW), the refrigerant mass flow is about:

[1P3CEM002 | Chapter 4: HVAC and Refrigeration System | 4.3 Vapour compression cycle – refrigerant mass flow]

- a) 0.82 kg/s
- b) 1.95 kg/s
- c) 11.72 kg/s
- d) 2.34 kg/s**

Answer & explanation

Correct answer: (d) ≈ 2.34 kg/s.

Given: h_1 (evaporator outlet) = 400 kJ/kg; h_2 (compressor outlet) = 430 kJ/kg; h_4 (after expansion = h_3) = 250 kJ/kg; capacity = 100 TR = 351.7 kW.

Formula: refrigerating effect $RE = h_1 - h_4$; $m = \text{Capacity} / RE$; compressor work = $h_2 - h_1$; $COP = RE / \text{work}$.

Substitution: $RE = 400 - 250 = 150$ kJ/kg; $m = 351.7 / 150 = 2.345$ kg/s; work = 30 kJ/kg; $COP = 150 / 30 = 5.0$.

Result: **$m \approx 2.34$ kg/s; ideal COP = 5.0; compressor power ≈ 70.3 kW.**

Why the others are wrong: (a) divides capacity by the absolute enthalpy 430; (b) uses the condenser heat ($h_2 - h_4 = 180$ kJ/kg) as the refrigerating effect; (c) divides by compressor work (30 kJ/kg).

Ref: BEE Guidebook Paper 3, Ch. 4 (4.3 Types of refrigeration system – vapour compression cycle).

3 A 90 kW (full-flow power) ID fan is run at 70 % flow by outlet damper, drawing 78 kW. If a VFD (efficiency 97 %) is used instead and the affinity laws apply, the annual energy saving over 6,000 h is about:

[1P3CEM003 | Chapter 5: Fans and Blowers | 5.5 Flow control – damper vs VFD]

- a) 78,300 kWh
- b) 1,95,200 kWh
- c) 2,77,100 kWh**
- d) 2,82,800 kWh

Answer & explanation

Correct answer: (c) $\approx 2,77,100$ kWh/year.

Given: full-flow power $P_1 = 90$ kW; flow ratio = 0.70; damper power = 78 kW; $\eta_{\text{VFD}} = 0.97$; 6,000 h/year.

Formula: affinity law $P_2 = P_1 \times (N_2/N_1)^3$ with $N \propto Q$; input with VFD = P_2 / η_{VFD} .

Substitution: $P_2 = 90 \times 0.7^3 = 90 \times 0.343 = 30.87$ kW; input = $30.87 / 0.97 = 31.82$ kW; saving = $(78 - 31.82) \times 6,000 = 46.18 \times 6,000$.

Result: **$\approx 2,77,100$ kWh/year ($\approx ₹ 22$ lakh at ₹ 8/kWh).**

Why the others are wrong: (a) applies a linear power-flow relation; (b) uses the square law (head relation) for power; (d) ignores VFD losses. In systems with significant fixed (static) pressure the cube law overstates savings and should be corrected.

Ref: BEE Guidebook Paper 3, Ch. 5 (5.3 Fan laws; 5.5 Flow control strategies).

4 During rewinding of a burnt 90 kW motor, which workshop practice is MOST likely to raise its core (iron) loss permanently?

[1P3CEM004 | Chapter 2: Electrical Motors | 2.8 Rewinding effects on efficiency]

- a) Rewinding with the original wire gauge and number of turns

- b) Cleaning the stator with solvent and drying it in a low-temperature oven
- c) Stripping old windings by heating the stator above about 350 °C**
- d) Replacing worn bearings with bearings of the original specification

Answer & explanation

Correct answer: (c).

Burning out the old insulation at high temperature (above about 350 °C) damages the inter-laminar insulation of the stator core. Eddy currents can then flow between laminations, raising core (iron) loss permanently; hammering or grinding slots has a similar effect. The guidebook notes that poor rewinding can reduce motor efficiency by about 1–2 % or more per rewind, so controlled-temperature stripping and core-loss testing before and after rewinding are recommended.

Why the others are wrong: (a) keeping the original gauge and turns preserves copper loss and the magnetic design and is good practice (a smaller gauge would raise I^2R loss); (b) low-temperature cleaning protects the core; (d) correct bearings maintain friction loss and air gap and do not raise iron loss.

Ref: BEE Guidebook Paper 3, Ch. 2 (2.8 Rewinding effects on energy efficiency).

5 A designer needs a fan whose power demand does NOT keep rising as system resistance falls and flow increases, to avoid motor overloading. The guidebook recommends:

[1P3CEM005 | Chapter 5: Fans and Blowers | 5.2 Fan types – power characteristic]

- a) Backward-curved centrifugal fan with non-overloading power**
- b) Forward-curved centrifugal fan with a rising power curve
- c) Radial-blade centrifugal fan used for material handling
- d) Forward-curved multi-vane fan with a large hub-to-tip ratio

Answer & explanation

Correct answer: (a).

Backward-curved (backward-inclined and aerofoil) centrifugal fans have a non-overloading characteristic: shaft power peaks near the best-efficiency point and then falls as flow increases, so a motor sized for the peak cannot be overloaded if system resistance turns out lower than expected. They also have the highest efficiency among centrifugal fans.

Why the others are wrong: (b) and (d) forward-curved fans have power that rises steadily with flow (overloading), and their large hub-to-tip ratio gives lower pressure; they suit low-pressure HVAC duties; (c) radial-blade fans also have rising power with flow; they are rugged and suit dusty, erosive or material-handling service but are less efficient.

Ref: BEE Guidebook Paper 3, Ch. 5 (5.2 Fan types; 5.3 Fan performance characteristics).

6 A plant's circulating water carries high suspended solids and oil traces. Which statement about the choice of cooling tower fill is CORRECT?

[1P3CEM006 | Chapter 7: Cooling Towers | 7.2 Fill media – splash vs film]

- a) Film fill gives more heat transfer per volume but fouls easily in dirty water**
- b) Splash fill gives more heat transfer per volume and also fouls easily
- c) Film fill is the best choice for dirty water, as it never clogs at all
- d) Fill type does not affect performance, only the drift loss from the tower

Answer & explanation

Correct answer: (a).

Film fill spreads water into thin films over closely spaced sheets, giving a large air-water contact area and higher heat transfer per unit volume, so towers can be smaller and fan power lower. Its narrow passages, however, clog with suspended solids, oil, algae and scale. With dirty water, splash fill (bars that break water into droplets) or low-clog film fill is preferred, accepting a larger tower.

Why the others are wrong: (b) splash fill has lower heat transfer per volume and tolerates dirty water better; (c) film fill is the most fouling-prone type; (d) the fill is the most important component for thermal performance, as it governs water–air contact; drift eliminators, not fill, control drift loss.

Ref: BEE Guidebook Paper 3, Ch. 7 (7.2 Cooling tower performance – fill media).

7 An internal LT feeder has I²R loss of 18 kW while supplying a load at 0.75 PF. If tail-end capacitors raise the PF to 0.95 at the same kW, the new feeder loss will be about:

[1P3CEM007 | Chapter 1: Electrical Systems | 1.6 Distribution losses – effect of tail-end PF correction]

- a) 6.8 kW
- b) 11.2 kW**
- c) 10.1 kW
- d) 14.2 kW

Answer & explanation

Correct answer: (b) 11.2 kW.

Given: initial loss = 18 kW at PF₁ = 0.75; PF₂ = 0.95; kW and voltage unchanged.

Formula: $I = kW / (\sqrt{3} \times V \times PF)$, so $I \propto 1/PF$ and $loss \propto I^2 \propto (PF_1/PF_2)^2$.

Substitution: new loss = $18 \times (0.75 / 0.95)^2 = 18 \times 0.6233$.

Result: $\approx$ **11.2 kW** (a reduction of 6.8 kW, i.e. 37.7 %).

Why the others are wrong: (a) 6.8 kW is the saving, not the new loss; (c) multiplies 18 by 0.75² and forgets to divide by 0.95²; (d) applies a linear ratio (0.75/0.95), forgetting that copper loss varies with the square of current.

Note that only capacitors installed at the load (tail end) reduce losses in the plant's own cables; a bank at the main incomer does not.

Ref: BEE Guidebook Paper 3, Ch. 1 (1.4 PF improvement; 1.6 Distribution losses in industrial system).

8 Line voltages at a motor terminal are measured as 415 V, 405 V and 395 V. Which statement about this condition is CORRECT?

[1P3CEM008 | Chapter 2: Electrical Motors | 2.7 Voltage unbalance – effect on motors]

- a) Unbalance is about 2.5 %, causing negative-sequence currents and extra winding heating**
- b) Unbalance is about 4.9 %, but with no effect on winding temperature
- c) Unbalance is about 2.5 % and reduces slip, so efficiency improves slightly
- d) Unbalance is about 1.2 % and only affects the starting torque of the motor

Answer & explanation

Correct answer: (a).

Given: V = 415, 405, 395 V. Average = 405 V; maximum deviation from average = 10 V.

Formula: % voltage unbalance = (maximum deviation from average / average voltage) $\times$ 100.

Substitution: $10 / 405 \times 100 = 2.47 \%$.

Result: **≈ 2.5 % unbalance**. The unbalanced voltages produce negative-sequence currents that set up a reverse-rotating field, so current unbalance is several times the voltage unbalance, losses rise and winding temperature increases disproportionately; motors may need derating and life falls.

Why the others are wrong: (b) takes the full spread (20 V) as deviation and wrongly claims no heating; (c) unbalance increases slip and losses, it never improves efficiency; (d) the arithmetic is wrong and the effect is continuous, not limited to starting.

Ref: BEE Guidebook Paper 3, Ch. 2 (2.7 Factors affecting energy efficiency – voltage unbalance).

9 Select the WRONG statement on energy conservation in pumping systems:

[1P3CEM009 | Chapter 6: Pumps and Pumping System | 6.6 / 6.11 Pumping energy conservation – wrong statement]

- a) Throttling raises system resistance and shifts the operating point left
- b) Impeller trimming suits a pump that is steadily over-sized for its duty
- c) Cube-law VFD savings apply unchanged to systems with large static head**
- d) VFD savings are highest when friction head dominates the system curve

Answer & explanation

Correct answer: (c) – this statement is wrong.

The affinity laws (flow $\propto N$, head $\propto N^2$, power $\propto N^3$) describe the pump at the same relative operating point. In a system with large static head (e.g. lifting water to an overhead tank) the system curve does not pass through the origin, so reducing speed moves the pump to a different, often less efficient point; flow falls sharply for a small speed drop and actual savings are much less than the cube law predicts.

The other statements are correct: (a) closing a delivery valve adds artificial resistance, moving the operating point to lower flow and higher head and wasting energy in the valve; (b) trimming suits a constant over-design margin; (d) friction-dominated circuits such as closed chilled-water loops give the largest VFD savings.

Ref: BEE Guidebook Paper 3, Ch. 6 (6.2 System characteristics; 6.6 Flow control strategies).

10 An office of 260 m² has an average maintained illuminance of 320 lux with total circuit watts of 2,600 W. If the target installed load efficacy for the room index is 46 lux/W/m², the ILER and the guidebook assessment are:

[1P3CEM010 | Chapter 8: Lighting System | 8.6 Installed load efficacy ratio (ILER)]

- a) ILER 0.70 – satisfactory to good
- b) ILER 1.44 – satisfactory to good
- c) ILER 0.70 – review is suggested**
- d) ILER 0.70 – urgent action required

Answer & explanation

Correct answer: (c).

Given: A = 260 m²; average lux = 320; circuit watts = 2,600 W; target ILE = 46 lux/W/m².

Formula: W/m² = circuit watts / area; actual ILE = average lux / (W/m²); ILER = actual ILE / target ILE.

Substitution: W/m² = 2,600 / 260 = 10 W/m²; ILE = 320 / 10 = 32 lux/W/m²; ILER = 32 / 46 = 0.696.

Result: **ILER ≈ 0.70 → 'review suggested'**. Guidebook bands: 0.75 or over = satisfactory to good; 0.51–0.74 = review suggested; 0.50 or less = urgent action required.

Why the others are wrong: (a) 0.70 is below 0.75, so it is not satisfactory; (b) inverts the ratio (46/32); (d) urgent action applies only at 0.50 or less. A review would check lamp efficacy, luminaire optics, cleaning schedule and room reflectances.

Ref: BEE Guidebook Paper 3, Ch. 8 (8.6 General energy saving opportunities – ILER).

11 A 37 kW motor (efficiency 89 %) delivers 29.6 kW shaft output for 6,000 h/year. Replacing it with an IE3 motor of 93.5 % efficiency at the same output, with tariff ₹ 8/kWh, saves about:

[1P3CEM011 | Chapter 2: Electrical Motors | 2.6 Energy-efficient motor replacement savings]

- a) ₹ 63,900 per year
- b) ₹ 76,800 per year**
- c) ₹ 71,800 per year
- d) ₹ 96,000 per year

Answer & explanation

Correct answer: (b) ≈ ₹ 76,800 per year.

Given: shaft output = 29.6 kW (80 % load); $\eta_{old} = 0.89$; $\eta_{new} = 0.935$; 6,000 h/year; ₹ 8/kWh.

Formula: kW saved = Output $\times (1/\eta_{old} - 1/\eta_{new})$.

Substitution: $29.6 \times (1/0.89 - 1/0.935) = 29.6 \times (1.1236 - 1.0695) = 29.6 \times 0.05408 = 1.60$ kW; energy = $1.60 \times 6,000 = 9,604$ kWh; cost = $9,604 \times 8$.

Result: ≈ **₹ 76,800 per year (9,604 kWh)**.

Why the others are wrong: (a) multiplies output by the efficiency difference (0.045) instead of the reciprocal difference; (c) applies the efficiency difference to the old input power, still not the correct relation; (d) uses the 37 kW rating instead of the actual 29.6 kW load. Also check that the IE3 motor's higher speed (lower slip) does not raise centrifugal load power.

Ref: BEE Guidebook Paper 3, Ch. 2 (2.6 Energy efficient motors).

12 A cooling water pump delivers 300 m³/h. The suction gauge reads -0.3 kg/cm² and the discharge gauge 4.2 kg/cm² (gauges at the same level). The motor draws 52 kW at 93 % efficiency. Pump efficiency is about:

[1P3CEM012 | Chapter 6: Pumps and Pumping System | 6.4 Pump performance – operating efficiency]

- a) 65.9 %
- b) 70.7 %
- c) 81.8 %
- d) 76.1 %**

Answer & explanation

Correct answer: (d) ≈ 76.1 %.

Given: $Q = 300$ m³/h = 0.0833 m³/s; suction head = -0.3 kg/cm² (≈ -0.294 bar) = -3 m; discharge head = 4.2 kg/cm² (≈ 4.12 bar) = 42 m; motor input = 52 kW; $\eta_m = 0.93$; $\rho = 1,000$ kg/m³.

Formula: total head H = discharge head – suction head; hydraulic power (kW) = $Q \times H \times \rho \times g / 1,000$; $\eta_{pump} = \text{hydraulic power} / (\text{motor input} \times \eta_m)$.

Substitution: $H = 42 - (-3) = 45$ m; hydraulic power = $0.0833 \times 45 \times 1,000 \times 9.81 / 1,000 = 36.79$ kW; shaft power = $52 \times 0.93 = 48.36$ kW; $\eta = 36.79 / 48.36$.

Result: **$\eta_{pump} \approx 76.1$ %**.

Why the others are wrong: (a) subtracts the suction head the wrong way ($H = 39$ m); (b) divides by motor input, giving combined pump-motor efficiency; (c) applies motor efficiency twice. A negative suction reading means suction lift; it adds to the head.

Ref: BEE Guidebook Paper 3, Ch. 6 (6.4 Factors affecting pump performance; pump efficiency).

13 In lumen-method design, which of the following is NOT a component of the maintenance (light loss) factor?

- a) Lamp lumen maintenance (lumen depreciation over burning hours)
- b) Luminaire maintenance factor, due to dirt on the luminaire optics
- c) Utilisation factor, which depends on room index and reflectances**
- d) Room surface maintenance factor, due to dirt on walls and ceiling

Answer & explanation

Correct answer: (c).

The utilisation factor (coefficient of utilisation) is a separate term in the lumen method: it is the fraction of lamp lumens that reaches the working plane and depends on luminaire distribution, room index (room dimensions and mounting height) and surface reflectances. It does not change with time.

The maintenance factor accounts for the fall in illuminance over time, and is the product of: (a) lamp lumen maintenance factor (output falls with burning hours); (b) luminaire maintenance factor (dirt on reflectors, diffusers and lamps); (d) room surface maintenance factor (dirt on walls and ceiling lowers reflected light). Lamp survival factor is also included where failed lamps are not replaced promptly. Group re-lamping and regular cleaning raise the maintenance factor and allow fewer luminaires.

Ref: BEE Guidebook Paper 3, Ch. 8 (8.5 Methods of calculating illuminance).

14 A building's design does not meet some prescriptive ECBC envelope and lighting requirements. The architect wants to show compliance by comparing its simulated annual energy use with that of a standard design. This route is the:

- a) Prescriptive method with all requirements met
- b) Whole building performance method using simulation**
- c) Envelope trade-off method using the EPF value
- d) Mandatory provisions route without any modelling

Answer & explanation

Correct answer: (b).

ECBC allows compliance through: (i) the prescriptive method, where each component meets the specified values; (ii) the trade-off method, where the building envelope is compared using the Envelope Performance Factor (EPF) so that a weaker element can be offset by a better one within the envelope only; and (iii) the whole building performance method, where annual energy use of the proposed design is simulated and must not exceed that of a standard design built to the prescriptive requirements. Mandatory provisions must be met under every route.

Why the others are wrong: (a) the design already fails some prescriptive requirements; (c) EPF trade-off is limited to the envelope and is not an annual whole-building simulation covering lighting; (d) mandatory provisions alone are never sufficient for compliance.

Ref: BEE Guidebook Paper 3, Ch. 10 (10.4 Compliance approaches).

15 A 600 kW induction-motor load operates at 0.75 lagging PF. The capacitor rating needed to raise the PF to 0.95 lagging is closest to:

- a) 332 kVAr**
- b) 168 kVAr
- c) 197 kVAr

d) 529 kVAr

Answer & explanation

Correct answer: (a) 332 kVAr.

Given: $P = 600 \text{ kW}$; $PF_1 = 0.75$ ($\phi_1 = 41.41^\circ$); $PF_2 = 0.95$ ($\phi_2 = 18.19^\circ$).

Formula: $\text{kVAr required} = \text{kW} \times (\tan \phi_1 - \tan \phi_2)$.

Substitution: $\tan \phi_1 = 0.8819$; $\tan \phi_2 = 0.3287$; $\text{kVAr} = 600 \times (0.8819 - 0.3287) = 600 \times 0.5532$.

Result: $\approx 332 \text{ kVAr}$ (choose the next standard bank, e.g. 350 kVAr, with APFC steps).

Why the others are wrong: (b) is the fall in kVA ($800 - 631.6 = 168$), which is not the reactive compensation; (c) is only the kVAr remaining after correction ($600 \times 0.3287 = 197$); (d) is the total initial kVAr ($600 \times 0.8819 = 529$), which would push the PF to unity and risks leading PF at light load.

Ref: BEE Guidebook Paper 3, Ch. 1 (1.4 Power factor improvement and benefits).

16 Which of the following actions will INCREASE the specific power consumption (kW/TR) of a water-cooled chiller?

[1P3CEM016 | Chapter 4: HVAC and Refrigeration System | 4.16 Energy saving opportunities – chiller kW/TR]

- a) Cleaning scaled condenser tubes to bring down the condenser approach temperature
- b) Raising the chilled water set point where the process permits it
- c) Raising the condenser water set point to cut cooling tower fan power**
- d) Running the chiller near its best-efficiency part load with sequencing

Answer & explanation

Correct answer: (c).

Raising the condenser water temperature raises the condensing temperature and pressure, so the compressor works against a higher lift and kW/TR rises (roughly 2–3 % per °C of condensing temperature). The small saving in cooling tower fan power is normally much less than the extra compressor power, so the cooling tower should deliver the coldest water the chiller can accept.

Why the others are wrong: (a) scale removal lowers the condensing temperature and kW/TR; (b) a higher chilled water set point raises evaporator temperature and lowers kW/TR (about 3 % per °C); (d) correct sequencing keeps chillers near their most efficient loading. Other measures in the guidebook include clean evaporator tubes, correct refrigerant charge, VFD on compressors and reducing heat ingress.

Ref: BEE Guidebook Paper 3, Ch. 4 (4.8 Factors affecting performance; 4.16 Energy saving opportunities).

17 An ID fan handles $20 \text{ m}^3/\text{s}$ at a static pressure rise of 180 mmWC. The motor input is 52 kW and motor efficiency is 92 %. The fan static efficiency is about:

[1P3CEM017 | Chapter 5: Fans and Blowers | 5.6 Fan static efficiency]

- a) 62.4 %
- b) 67.9 %
- c) 80.2 %
- d) 73.8 %**

Answer & explanation

Correct answer: (d) $\approx 73.8 \%$.

Given: $Q = 20 \text{ m}^3/\text{s}$; static pressure rise $\Delta p_s = 180 \text{ mmWC}$ ($\approx 1.77 \text{ kPa}$); motor input = 52 kW; $\eta_{\text{motor}} = 0.92$.

Formula: $\eta_{\text{static}} (\%) = Q (\text{m}^3/\text{s}) \times \Delta p_s (\text{mmWC}) / (102 \times \text{shaft power kW}) \times 100$; shaft power = motor input $\times \eta_{\text{motor}}$.

Substitution: shaft power = $52 \times 0.92 = 47.84 \text{ kW}$; $\eta = 20 \times 180 / (102 \times 47.84) \times 100 = 3,600 / 4,880 \times 100$.

Result: $\eta_{\text{static}} \approx 73.8 \%$ (1 mmWC = 9.81 Pa, so air power = $20 \times 1,766 \text{ Pa} = 35.3 \text{ kW}$).

Why the others are wrong: (a) divides motor input by 0.92 instead of multiplying; (b) uses motor input (52 kW) as shaft power; (c) applies the motor efficiency twice. Use total pressure (static + velocity) when total efficiency is required.

Ref: BEE Guidebook Paper 3, Ch. 5 (5.6 Fan performance assessment – fan efficiency).

18 During a leak test with all end-users closed, a compressor (loaded power 110 kW) is on-load for 18 s and off-load for 42 s in each cycle. Ignoring unload power, the annual energy wasted on leaks over 8,000 h is about:

[1P3CEM018 | Chapter 3: Compressed Air System | 3.5 Leakage test – energy wasted]

- a) 3,77,100 kWh
- b) 6,16,000 kWh
- c) 8,80,000 kWh
- d) 2,64,000 kWh**

Answer & explanation

Correct answer: (d) 2,64,000 kWh/year.

Given: on-load time $T = 18 \text{ s}$; off-load time $t = 42 \text{ s}$; loaded power = 110 kW; 8,000 h/year.

Formula: % leakage = $T / (T + t) \times 100$; energy lost = leakage fraction $\times$ loaded power $\times$ hours.

Substitution: leakage = $18 / (18 + 42) = 0.30$ (30 %); energy = $0.30 \times 110 \times 8,000$.

Result: **2,64,000 kWh/year ($\approx \text{₹ } 21.1 \text{ lakh at ₹ } 8/\text{kWh}$)}**. Leakage quantity = 30 % of the compressor FAD.

Why the others are wrong: (a) divides on-load by off-load time ($18/42 = 42.9 \%$); (b) uses the off-load fraction ($42/60$); (c) assumes the full loaded power is wasted for all hours. A 30 % leakage is far above the well-maintained level of about 5–10 %.

Ref: BEE Guidebook Paper 3, Ch. 3 (3.5 Efficient operation – leakage test).

19 A 1,000 kVA distribution transformer has a no-load loss of 1.8 kW and a full-load copper loss of 11.0 kW. The load at which its efficiency is maximum is about:

[1P3CEM019 | Chapter 1: Electrical Systems | 1.5 Transformer – load for maximum efficiency]

- a) 164 kVA
- b) 405 kVA**
- c) 500 kVA
- d) 595 kVA

Answer & explanation

Correct answer: (b) 405 kVA.

Given: rating $S = 1,000 \text{ kVA}$; no-load (core) loss $P_o = 1.8 \text{ kW}$; full-load load (copper) loss $P_{\text{c}} = 11.0 \text{ kW}$.

Formula: maximum efficiency occurs when variable copper loss equals fixed core loss, i.e. $x^2 \times P_{\text{c}} = P_o$, so $x = \sqrt{P_o / P_{\text{c}}}$.

Substitution: $x = \sqrt{1.8 / 11.0} = \sqrt{0.1636} = 0.4045$; load = $0.4045 \times 1,000$.

Result: **$\approx 405 \text{ kVA}$ (40.5 % loading)**. At this load copper loss = $11.0 \times 0.4045^2 = 1.8 \text{ kW}$.

Why the others are wrong: (a) uses the loss ratio without the square root ($0.164 \times 1,000$); (c) assumes maximum efficiency always occurs at half load, true only when $P_{\text{c}} = 4P_o$; (d) is $1 - 0.405$, an arithmetic slip. This is why modern low-loss transformers are chosen for the actual expected loading, not the nameplate.

Ref: BEE Guidebook Paper 3, Ch. 1 (1.5 Transformers – losses and efficiency).

20 Select the WRONG statement regarding energy efficient operation of DG sets:

[1P3CEM020 | Chapter 9: Diesel / Natural Gas Power Generating System | 9.5 DG set energy saving – wrong statement]

- a) A choked intake air filter raises the fuel consumption of the engine
- b) A lower load power factor reduces alternator losses and fuel per kWh**
- c) Higher intake air temperature raises the specific fuel consumption of the engine
- d) Turbocharged and after-cooled engines generally give better fuel economy at load

Answer & explanation

Correct answer: (b) – this statement is wrong.

For the same kW, a lower power factor means more current (kVA) through the alternator, so its copper losses rise and alternator efficiency falls; the set may also hit its kVA limit before its kW limit. Hence the guidebook advises maintaining a high load PF (via capacitors on the load side where appropriate) to get more kWh per litre. The other statements are correct: (a) a choked filter restricts air, causing incomplete combustion, black smoke and higher fuel use; (c) hot intake air is less dense, reducing the air mass for combustion, so intake air should be drawn from a cool, clean source; (d) turbocharging with after-cooling increases air density and engine output, improving SFC.

Ref: BEE Guidebook Paper 3, Ch. 9 (9.3 Operational factors; 9.5 Energy saving measures for DG sets).

21 Select the WRONG statement about energy-efficient (IE2/IE3) induction motors compared with standard motors of the same rating:

[1P3CEM021 | Chapter 2: Electrical Motors | 2.6 Energy-efficient motors – wrong statement]

- a) They run at lower slip, so a centrifugal load may draw a little more power
- b) Lower losses come from more copper, better steel and thinner laminations
- c) Their starting (inrush) current is always lower than that of standard motors**
- d) Their efficiency stays high over a wider band, roughly 50 % to 100 % load

Answer & explanation

Correct answer: (c) – this statement is wrong.

Energy-efficient motors are built with more active material (more copper, better grade and thinner laminations of low-loss steel), longer cores, smaller air gaps and optimised fan design. Their lower resistance usually means equal or higher starting current, so starters and protection settings must be checked; they do not inherently reduce inrush.

The other statements are true: (a) lower rotor resistance gives lower slip and slightly higher speed, and since centrifugal pump/fan power varies with speed cubed part of the expected saving can be lost; (b) reduced copper, iron and stray losses are the source of higher efficiency; (d) the efficiency curve of an EE motor is flatter, so part-load efficiency remains high.

Ref: BEE Guidebook Paper 3, Ch. 2 (2.6 Energy efficient motors; 2.10 Star labelling of motors).

22 A chiller runs at 0.70 kW/TR. The process allows the chilled water set point to be raised by 2 °C, raising the evaporator temperature by 2 °C. Using the guidebook thumb rule, the new specific power will be about:

[1P3CEM022 | Chapter 4: HVAC and Refrigeration System | 4.8 Factors affecting performance – evaporator temperature]

- a) 0.66 kW/TR**
- b) 0.56 kW/TR

- c) 0.69 kW/TR
- d) 0.74 kW/TR

Answer & explanation

Correct answer: (a) ≈ 0.66 kW/TR.

Given: present specific power = 0.70 kW/TR; rise in evaporator temperature = 2 °C.

Formula (guidebook thumb rule): each 1 °C rise in evaporator temperature lowers compressor power by about 3 %, because suction pressure rises and the compression ratio (lift) falls. Saving $\approx 3 \% \times \Delta T$.

Substitution: saving $\approx 3 \times 2 = 6 \%$; new kW/TR = $0.70 \times (1 - 0.06) = 0.658$.

Result: ≈ 0.66 kW/TR (about 6 % less compressor power).

Why the others are wrong: (b) assumes 10 % per °C (20 % in total), which is unrealistic; (c) assumes only about 1 % saving in total; (d) moves in the wrong direction, because a higher evaporator temperature improves COP.

Lower condensing temperature (clean tubes, better cooling tower approach) gives a similar benefit.

Ref: BEE Guidebook Paper 3, Ch. 4 (4.8 Factors affecting performance and energy efficiency).

23 A 750 kVA DG set is run for long periods at about 25–30 % load to supply a small night load. The main consequence is:

[1P3CEM023 | Chapter 9: Diesel / Natural Gas Power Generating System | 9.3 Operational factors – low load operation]

- a) Lower specific fuel consumption since the engine runs cooler
- b) Improved alternator efficiency because copper loss is reduced
- c) No change in fuel per kWh, since the governor adjusts the fuel
- d) Higher specific fuel consumption and carbon build-up in the engine**

Answer & explanation

Correct answer: (d).

Diesel engines achieve their best specific fuel consumption (lowest litres per kWh, highest kWh per litre) at roughly 60–80 % of rated load. At very light loads, fixed losses (friction, auxiliaries, alternator core loss) form a larger share of output, so SFC rises sharply. Low cylinder temperatures also cause incomplete combustion, carbon deposits, 'wet stacking' (unburnt fuel in the exhaust) and higher maintenance. The guidebook recommends matching the set size to the load, running fewer sets at higher loading, or using a smaller set for night loads.

Why the others are wrong: (a) cooler running worsens combustion and raises SFC; (b) although copper loss falls, fixed losses dominate, so alternator efficiency falls at light load; (c) the governor holds speed by adjusting fuel, but fuel per kWh still rises.

Ref: BEE Guidebook Paper 3, Ch. 9 (9.3 Operational factors; 9.4 Energy performance assessment of DG sets).

24 An assembly hall of 30 m × 15 m needs 400 lux. LED luminaires of 4,000 lm and 36 W are used with UF 0.60 and maintenance factor 0.80. Rounding up the number of luminaires, the resulting lighting power density is about:

[1P3CEM024 | Chapter 8: Lighting System | 8.5 Lumen method and lighting power density]

- a) 3.6 W/m²
- b) 4.8 W/m²
- c) 6.0 W/m²
- d) 7.5 W/m²**

Answer & explanation

Correct answer: (d) $\approx 7.5 \text{ W/m}^2$.

Given: $A = 30 \times 15 = 450 \text{ m}^2$; $E = 400 \text{ lux}$; $\Phi = 4,000 \text{ lm per luminaire}$; $UF = 0.60$; $MF = 0.80$; $36 \text{ W per luminaire}$.

Formula: $N = (E \times A) / (\Phi \times UF \times MF)$; $LPD = N \times W / A$.

Substitution: $N = (400 \times 450) / (4,000 \times 0.60 \times 0.80) = 1,80,000 / 1,920 = 93.75 \rightarrow 94 \text{ luminaires}$; $\text{load} = 94 \times 36 = 3,384 \text{ W}$; $LPD = 3,384 / 450$.

Result: **$N = 94$; $LPD \approx 7.5 \text{ W/m}^2$** .

Why the others are wrong: (a) ignores both UF and MF (45 luminaires); (b) multiplies by MF instead of dividing (60 luminaires); (c) omits the maintenance factor (75 luminaires), so the design would fall below 400 lux as lamps age and luminaires get dirty. Compare the LPD with ECBC limits for the space type.

Ref: BEE Guidebook Paper 3, Ch. 8 (8.5 Methods of calculating illuminance – lumen method).

25 A data room UPS supplies a steady 120 kW load round the clock at 88 % efficiency. Replacing it with a UPS of 95 % efficiency at the same load, with tariff ₹ 9/kWh, saves about:

[1P3CEM025 | Chapter 10: Energy Conservation in Buildings and ECBC | 10.11 Uninterruptible power supply – efficiency]

- a) ₹ 6.62 lakh per year
- b) ₹ 7.92 lakh per year**
- c) ₹ 7.53 lakh per year
- d) ₹ 11.88 lakh per year

Answer & explanation

Correct answer: (b) $\approx ₹ 7.92 \text{ lakh per year}$.

Given: $\text{load} = 120 \text{ kW}$; $\eta_{\text{old}} = 0.88$; $\eta_{\text{new}} = 0.95$; $8,760 \text{ h/year}$; ₹ 9/kWh.

Formula: $\text{input} = \text{output} / \eta$; $\text{saving (kW)} = \text{output} \times (1/\eta_{\text{old}} - 1/\eta_{\text{new}})$.

Substitution: $\text{input}_{\text{old}} = 120 / 0.88 = 136.36 \text{ kW}$; $\text{input}_{\text{new}} = 120 / 0.95 = 126.32 \text{ kW}$; $\text{saving} = 10.05 \text{ kW}$; $\text{energy} = 10.05 \times 8,760 = 88,019 \text{ kWh}$; $\text{cost} = 88,019 \times 9 = ₹ 7,92,172$.

Result: **$\approx 88,000 \text{ kWh}$ and $₹ 7.92 \text{ lakh per year}$** , plus a lower cooling load in the UPS room.

Why the others are wrong: (a) multiplies output by the efficiency difference ($7 \% \times 120 \text{ kW}$); (c) applies the 7 % difference to the old input; (d) uses 180 kW ($\text{kVA} \times \text{PF}$ of a 200 kVA rating) instead of the actual 120 kW load. UPS efficiency falls at light load, so right-sizing and modular units also matter.

Ref: BEE Guidebook Paper 3, Ch. 10 (10.11 Uninterruptible power supply).

26 Select the INCORRECT statement regarding maximum demand (MD) control and power factor in an industrial plant:

[1P3CEM026 | Chapter 1: Electrical Systems | 1.3 / 1.4 Maximum demand control and PF – wrong statement]

- a) The MD recorded by the trivector meter is the average kVA over each demand integration period
- b) A capacitor bank at the main HT incomer cuts the I^2R losses in the plant's own LT cables**
- c) Rescheduling large batch loads away from peak hours lowers MD and the energy bill under a TOD tariff
- d) Automatic load shedding of non-essential loads near the MD limit avoids crossing the contract demand

Answer & explanation

Correct answer: (b) – this statement is incorrect.

A capacitor bank improves the PF only upstream of its point of connection. A bank at the HT incomer reduces the kVA drawn from the utility (and so the kVA-based demand charge and PF penalty), but the plant's internal transformers and LT cables still carry the same reactive current, so their I^2R losses do not fall. To cut internal distribution losses the capacitors must be placed at the load end (tail end), e.g. at motor terminals or MCCs.

The other statements are correct: (a) trivector meters record MD as the average kVA over the integration period (typically 15 or 30 minutes); (c) load rescheduling under time-of-day tariffs reduces both peak demand and energy cost; (d) automatic load shedding through an MD controller prevents demand exceeding the contract limit.

Ref: BEE Guidebook Paper 3, Ch. 1 (1.3 Load management and MD control; 1.4 PF improvement).

27 Air passes over a cooling coil whose surface temperature stays above the air's dew point. Which statement correctly describes the process on the psychrometric chart?

[1P3CEM027 | Chapter 4: HVAC and Refrigeration System | 4.2 Psychrometrics – sensible cooling]

- a) **Humidity ratio stays constant while dry bulb falls and relative humidity rises**
- b) Humidity ratio falls while dry bulb temperature remains constant throughout
- c) Dry bulb and relative humidity both fall at a constant wet bulb temperature
- d) Enthalpy stays constant while the humidity ratio rises along the line

Answer & explanation

Correct answer: (a).

If the coil surface is above the dew point, no moisture condenses, so the process is sensible cooling: a horizontal line to the left on the psychrometric chart. Moisture content (humidity ratio, kg water per kg dry air) and dew point remain constant, dry bulb temperature falls, enthalpy falls, and relative humidity rises because cooler air can hold less moisture at saturation.

Why the others are wrong: (b) a falling humidity ratio at constant dry bulb describes chemical dehumidification, not a coil above dew point; (c) dry bulb and RH cannot both fall in pure cooling, and constant wet bulb describes adiabatic (evaporative) processes; (d) constant enthalpy with rising moisture is evaporative cooling (air washer), where dry bulb falls and humidity ratio rises.

Ref: BEE Guidebook Paper 3, Ch. 4 (4.2 Psychrometrics and air conditioning processes).

28 A 1.2 m diameter duct carries air at 60 °C. The average velocity pressure is 25 mmWC and the pitot tube constant is 0.85. Taking air density at 0 °C as 1.293 kg/m³, the air flow is about:

[1P3CEM028 | Chapter 5: Fans and Blowers | 5.6 Fan performance assessment – flow by pitot tube]

- a) 18.7 m³/s
- b) 24.3 m³/s
- c) 82.7 m³/s
- d) **20.7 m³/s**

Answer & explanation

Correct answer: (d) $\approx 20.7 \text{ m}^3/\text{s}$.

Given: $D = 1.2 \text{ m}$; $t = 60 \text{ }^\circ\text{C}$; $\Delta p = 25 \text{ mmWC}$ ($\approx 245 \text{ Pa}$); $C_p = 0.85$; density at $0 \text{ }^\circ\text{C} = 1.293 \text{ kg/m}^3$.

Formula: $\gamma = 273 \times 1.293 / (273 + t)$; $v = C_p \times \sqrt{(2 \times 9.81 \times \Delta p / \gamma)}$; $Q = v \times A$, with $A = \pi D^2/4$.

Substitution: $\gamma = 273 \times 1.293 / 333 = 1.060 \text{ kg/m}^3$; $v = 0.85 \times \sqrt{(2 \times 9.81 \times 25 / 1.060)} = 0.85 \times 21.51 = 18.28 \text{ m/s}$; $A = 1.131 \text{ m}^2$; $Q = 18.28 \times 1.131$.

Result: **$Q \approx 20.7 \text{ m}^3/\text{s}$ ($\approx 74,400 \text{ m}^3/\text{h}$).**

Why the others are wrong: (a) uses 1.293 kg/m^3 without temperature correction; (b) omits the pitot coefficient; (c) takes the area as $\pi \times 1.2^2$ (diameter used as radius). The guidebook recommends averaging point velocities from a traverse, not averaging velocity pressures.

Ref: BEE Guidebook Paper 3, Ch. 5 (5.6 Fan performance assessment).

29 A plant replaces a heatless purge desiccant dryer on its 600 cfm compressor with a blower-reactivated dryer. The main energy benefit comes from:

[1P3CEM029 | Chapter 3: Compressed Air System | 3.4 Compressed air dryers – purge losses]

- a) Dew point rising to +3 °C, which reduces the regeneration load
- b) Elimination of all heaters, since blower dryers need no heat
- c) Higher discharge pressure becoming available at all the user points
- d) Purge loss falling from 12–15 % to about 1–2 % of flow**

Answer & explanation

Correct answer: (d).

A heatless purge dryer regenerates the saturated tower by expanding dry compressed air through it, losing about 12–15 % of the dried air; the guidebook recommends it only for capacities below about 250 cfm. A blower-reactivated dryer uses an external heater and blower for regeneration, with a purge loss of only about 1–2 %, and is used above 250 cfm. For a 600 cfm compressor this recovers roughly 60–80 cfm of compressed air that was being generated only to be vented.

Why the others are wrong: (a) +3 °C dew point is typical of refrigeration dryers, not desiccant dryers; (b) blower-reactivated dryers do use heaters (electric or steam); only heat-of-compression dryers avoid them; (c) the dryer type does not raise delivery pressure.

Ref: BEE Guidebook Paper 3, Ch. 3 (3.4 System components – dryers).

30 Which condition MOST increases the risk of cavitation in a centrifugal pump drawing water from a sump?

[1P3CEM030 | Chapter 6: Pumps and Pumping System | 6.4 Factors affecting performance – NPSH and cavitation]

- a) Raising the sump level and cooling the incoming water
- b) A falling sump level combined with a higher water temperature**
- c) Reducing the pump speed by a VFD at the same suction
- d) Opening the suction valve fully and enlarging suction pipe

Answer & explanation

Correct answer: (b).

Cavitation occurs when the net positive suction head available (NPSHa) falls below that required by the pump (NPSHr), so liquid flashes into vapour bubbles at the impeller eye which then collapse, causing noise, vibration, pitting and loss of head and efficiency. $NPSHa = \text{atmospheric head} \pm \text{static suction head} - \text{friction loss} - \text{vapour pressure head}$. A falling sump level increases suction lift, and hotter water has a higher vapour pressure; both reduce NPSHa.

Why the others are wrong: (a) a higher sump level and cooler water both raise NPSHa; (c) lower speed reduces NPSHr (roughly with speed squared), lowering cavitation risk; (d) a fully open suction valve and larger suction pipe reduce suction friction loss and raise NPSHa. Never throttle on the suction side.

Ref: BEE Guidebook Paper 3, Ch. 6 (6.4 Factors affecting pump performance).

31 A heat pump water heater supplies 12.0 kW of heat while drawing 3.4 kW of electrical power. Which pair correctly gives its heating COP and the equivalent cooling COP of the same cycle?

[1P3CEM031 | Chapter 4: HVAC and Refrigeration System | 4.11 Heat pumps – COP relationships]

- a) Heating COP 2.53 and cooling COP 3.53
- b) Heating COP 3.53 and cooling COP 4.53**

c) Heating COP 3.53 and cooling COP 2.53

d) Heating COP 0.28 and cooling COP 1.28

Answer & explanation

Correct answer: (c).

Given: heat delivered $Q_H = 12.0$ kW; work input $W = 3.4$ kW.

Formula: $COP_{\text{heating}} = Q_H / W$; heat extracted from the source $Q_L = Q_H - W$; $COP_{\text{cooling}} = Q_L / W = COP_{\text{heating}} - 1$.

Substitution: $COP_H = 12.0 / 3.4 = 3.53$; $Q_L = 12.0 - 3.4 = 8.6$ kW; $COP_C = 8.6 / 3.4 = 2.53$.

Result: **$COP_H \approx 3.53$ and $COP_C \approx 2.53$** . One kWh of electricity delivers about 3.5 kWh ($\approx 3,035$ kcal; 12.7 MJ) of heat, compared with under 1 kWh from a resistance heater.

Why the others are wrong: (a) swaps the two values; (b) adds 1 instead of subtracting it; (d) inverts the heating ratio (W/Q_H). Heat pumps are most attractive where simultaneous heating and cooling can both be used, e.g. hotels and dairies.

Ref: BEE Guidebook Paper 3, Ch. 4 (4.11 Heat pumps and their applications).

32 For the same heat load, circulating water flow and ambient wet bulb temperature, which observation indicates that a cooling tower's thermal performance has IMPROVED after fill replacement?

[1P3CEM032 | Chapter 7: Cooling Towers | 7.2 Cooling tower performance – approach as indicator]

a) Higher range with the same hot water temperature

b) Lower approach to wet bulb and higher effectiveness

c) Higher approach and a cold water temperature rise

d) Lower range together with a lower effectiveness

Answer & explanation

Correct answer: (b).

Approach = cold water temperature – wet bulb temperature, and effectiveness = $\text{range} / (\text{range} + \text{approach}) \times 100$. With the heat load and flow fixed, the range (hot – cold water) is fixed by the process (heat load = flow $\times$ range). So a better tower shows up as colder outlet water: the approach falls and effectiveness rises. The guidebook regards approach as a better indicator of tower performance than range.

Why the others are wrong: (a) at fixed heat load and flow the range cannot rise; any change in range would mean the process changed, not the tower; (c) a higher approach and warmer cold water show deterioration (fouled fill, poor distribution, low air flow); (d) lower range at fixed load is impossible, and falling effectiveness indicates worse performance.

Ref: BEE Guidebook Paper 3, Ch. 7 (7.2 Cooling tower performance – range, approach, effectiveness).

33 A new commercial complex has a connected load of 85 kW and a contract demand of 125 kVA. Under the building definition in the Energy Conservation (Amendment) Act given in the guidebook, ECBC:

[1P3CEM033 | Chapter 10: Energy Conservation in Buildings and ECBC | 10.2 Building definition – applicability of ECBC]

a) Does not apply, since connected load is below 100 kW

b) Applies only after the building is first occupied

c) Applies, because contract demand is 120 kVA or more

d) Applies only if the built-up area exceeds 10,000 m²

Answer & explanation

Correct answer: (c).

The guidebook quotes the Act's definition: a building is a structure used or intended for commercial purposes with a connected load of 100 kW OR a contract demand of 120 kVA and above. The two criteria are alternatives, so meeting either brings the building within the scope of the notified energy conservation building code. Here the contract demand (125 kVA) exceeds 120 kVA, so ECBC applies even though the connected load is only 85 kW. Why the others are wrong: (a) treats the criteria as 'both required' instead of 'either'; (b) ECBC sets minimum standards at design and construction stage, before occupation; (d) no built-up area threshold appears in the guidebook definition; states may add area-based criteria when they notify the code, but that is not the guidebook definition.

Ref: BEE Guidebook Paper 3, Ch. 10 (10.2 Building definition; 10.3 ECBC).

34 A water-cooled chiller cools $150 \text{ m}^3/\text{h}$ of chilled water through 5.0°C while its compressor draws 175 kW. The COP of the chiller is about:

[1P3CEM034 | Chapter 4: HVAC and Refrigeration System | 4.7 Performance assessment – chiller COP]

- a) 1.42
- b) 3.52
- c) 4.28
- d) 4.98**

Answer & explanation

Correct answer: (d) ≈ 4.98 .

Given: $m = 150 \text{ m}^3/\text{h} = 1,50,000 \text{ kg/h}$; $C_p = 1 \text{ kcal/kg } ^\circ\text{C}$ ($\approx 4.19 \text{ kJ/kg}\cdot\text{K}$); $\Delta T = 5.0^\circ\text{C}$; $P = 175 \text{ kW}$.

Formula: $Q \text{ (kcal/h)} = m \times C_p \times \Delta T$; $\text{TR} = Q / 3,024$; $\text{kW/TR} = P / \text{TR}$; $\text{COP} = \text{refrigeration effect (kW)} / \text{input (kW)} = 3.516 / (\text{kW/TR})$.

Substitution: $Q = 1,50,000 \times 1 \times 5 = 7,50,000 \text{ kcal/h}$ ($= 3,140 \text{ MJ/h}$); $\text{TR} = 7,50,000 / 3,024 = 248.0 \text{ TR}$; $\text{kW/TR} = 175 / 248.0 = 0.706$; refrigeration kW = $7,50,000 / 860 = 872.1 \text{ kW}$; $\text{COP} = 872.1 / 175$.

Result: **COP ≈ 4.98 (0.706 kW/TR).**

Why the others are wrong: (a) is $1/(\text{kW/TR})$, a wrong inversion; (b) uses 3.516 as if kW/TR were 1.0; (c) uses 3.024 (kcal-based TR divided by 1,000) instead of 3.516 kW per TR.

Ref: BEE Guidebook Paper 3, Ch. 4 (4.7 Performance assessment of refrigeration plants).

35 A 4-pole, 50 Hz, 415 V motor has rated speed 1,475 rpm. At site it runs at 1,485 rpm with terminal voltage 400 V. Using the slip method with voltage correction, the motor load is approximately:

[1P3CEM035 | Chapter 2: Electrical Motors | 2.4 Motor loading by slip method with voltage correction]

- a) 55.7 %**
- b) 40.0 %
- c) 60.0 %
- d) 64.6 %

Answer & explanation

Correct answer: (a) 55.7 %.

Given: $N_s = 120f/P = 120 \times 50 / 4 = 1,500 \text{ rpm}$; $N_r \text{ (rated)} = 1,475 \text{ rpm}$; $N \text{ (measured)} = 1,485 \text{ rpm}$; $V = 400 \text{ V}$; $V_r = 415 \text{ V}$.

Formula: $\text{Load} = \text{Slip} / [(N_s - N_r) \times (V_r / V)^2]$, where $\text{Slip} = N_s - N$.

Substitution: Slip = 1,500 – 1,485 = 15 rpm; $N_s - N_r = 25$ rpm; $(415/400)^2 = 1.0764$; Load = $15 / (25 \times 1.0764) = 15 / 26.91$.

Result: ≈ 55.7 % load.

Why the others are wrong: (b) uses $N - N_r$ (10 rpm) as the slip; (c) ignores the voltage correction (15/25), overstating load because slip rises at lower voltage; (d) applies the voltage factor in the numerator instead of the denominator. The slip method is quick but less accurate because nameplate speed tolerance is about ± 20 % of rated slip.

Ref: BEE Guidebook Paper 3, Ch. 2 (2.4 Motor efficiency – slip method).

36 A compressor delivers 1,000 m³/h free air from an intake at 1.013 kg/cm²(a) to 7.0 kg/cm²(g). The theoretical isothermal power is about:

[1P3CEM036 | Chapter 3: Compressed Air System | 3.3 Compressor performance – isothermal power]

- a) 57.1 kW
- b) 24.8 kW
- c) 53.4 kW
- d) 190.7 kW

Answer & explanation

Correct answer: (a) ≈ 57.1 kW.

Given: $Q_1 = 1,000$ m³/h; $P_1 = 1.013$ kg/cm²(a) (≈ 0.993 bar(a)); $P_2 = 7.0 + 1.013 = 8.013$ kg/cm²(a) (≈ 7.86 bar(a)).

Formula: isothermal power (kW) = $P_1 \times Q_1 \times \log_e r / 36.7$, with $r = P_2/P_1$ (absolute).

Substitution: $r = 8.013 / 1.013 = 7.910$; $\ln 7.910 = 2.068$; power = $1.013 \times 1,000 \times 2.068 / 36.7$.

Result: ≈ 57.1 kW. If the measured input is 95 kW, isothermal efficiency = $57.1/95 = 60.1$ %.

Why the others are wrong: (b) uses $\log_{10}$ instead of the natural log; (c) uses gauge pressure in the ratio (7.0/1.013); (d) uses $(r - 1)$ instead of $\ln r$. Isothermal efficiency is the guidebook's basis for comparing compressors at the same FAD and pressure.

Ref: BEE Guidebook Paper 3, Ch. 3 (3.3 Compressor performance – isothermal efficiency).

37 A 75 kW, 415 V motor with full-load efficiency of 93 % draws 98 A at 415 V and 0.84 PF. Its approximate percentage loading is:

[1P3CEM037 | Chapter 2: Electrical Motors | 2.4 Motor loading by input power measurement]

- a) 42.4 %
- b) 73.4 %
- c) 78.9 %
- d) 87.3 %

Answer & explanation

Correct answer: (b) 73.4 %.

Given: rated output $P_r = 75$ kW; $\eta_r = 0.93$; $V = 415$ V; $I = 98$ A; PF = 0.84.

Formula: input power $P_i = \sqrt{3} \times V \times I \times \text{PF} / 1000$; % load = $P_i / (P_r / \eta_r) \times 100$.

Substitution: $P_i = 1.732 \times 415 \times 98 \times 0.84 / 1000 = 59.17$ kW; rated input = $75 / 0.93 = 80.65$ kW; load = $59.17 / 80.65 \times 100$.

Result: ≈ 73.4 % loading (shaft output ≈ 55 kW).

Why the others are wrong: (a) omits $\sqrt{3}$ in the 3-phase power; (c) compares input power with rated output (59.17/75), ignoring motor losses; (d) omits the power factor and so uses kVA (70.4) instead of kW. Note: this method assumes efficiency near rated; at low loads the slip or current method is used to cross-check.

Ref: BEE Guidebook Paper 3, Ch. 2 (2.4 Motor efficiency – determining motor load).

38 An HT consumer records a maximum demand of 2,400 kVA at 0.80 PF. Capacitors raise the PF to 0.96 with the same kW demand. If the demand charge is ₹ 450/kVA/month, the monthly saving in demand charges is:

[1P3CEM038 | Chapter 1: Electrical Systems | 1.4 Power factor improvement – kVA demand saving]

- a) ₹ 1,80,000
- b) ₹ 1,72,800
- c) ₹ 2,16,000
- d) ₹ 3,96,000

Answer & explanation

Correct answer: (a) ₹ 1,80,000.

Given: $MD_1 = 2,400$ kVA; $PF_1 = 0.80$; $PF_2 = 0.96$; demand charge = ₹ 450/kVA/month; kW unchanged.

Formula: $kW = kVA_1 \times PF_1$; $kVA_2 = kW / PF_2$; Saving = $(kVA_1 - kVA_2) \times \text{tariff}$.

Substitution: $kW = 2,400 \times 0.80 = 1,920$ kW; $kVA_2 = 1,920 / 0.96 = 2,000$ kVA; reduction = $2,400 - 2,000 = 400$ kVA; saving = 400×450 .

Result: ₹ 1,80,000 per month ($\approx$ ₹ 21.6 lakh per year).

Why the others are wrong: (b) multiplies 2,400 kVA by the PF difference (0.16), which has no physical meaning; (c) takes kVA – kW ($2,400 - 1,920 = 480$), confusing demand with active power; (d) bills the kVAr reduction ($1,440 - 560 = 880$ kVAr) at the kVA rate, but the utility bills kVA, not kVAr.

Ref: BEE Guidebook Paper 3, Ch. 1 (1.2 Electricity billing; 1.4 Power factor improvement).

39 A second identical pump is started in parallel with a running pump on a system with a steep (friction-dominated) system curve. The combined flow will be:

[1P3CEM039 | Chapter 6: Pumps and Pumping System | 6.5 Pumps in parallel]

- a) Less than twice the single-pump flow, at a higher head
- b) Exactly twice the single-pump flow at the same head
- c) Unchanged, because parallel pumps only add extra head
- d) More than twice the single-pump flow at a lower head

Answer & explanation

Correct answer: (a).

For pumps in parallel, the combined pump curve is obtained by adding flows at the same head. The operating point is where this combined curve meets the system curve. Because extra flow raises friction head ($\text{head} \propto \text{flow}^2$), the operating point moves up the system curve to a higher head, where each pump delivers less than it did alone. On a steep, friction-dominated system the gain can be small, e.g. only 20–40 % more flow, and each pump may operate far from its best efficiency point.

Why the others are wrong: (b) doubling occurs only on a flat system curve with no friction rise; (c) adding head is the role of series pumps, not parallel; (d) flow can never exceed double, and head rises rather than falls.

Ref: BEE Guidebook Paper 3, Ch. 6 (6.5 Efficient pumping system operation – parallel operation).

40 A VFD reduces the supply frequency of a 415 V, 50 Hz induction motor to 35 Hz for a centrifugal pump. To keep the air-gap flux nearly constant, the drive output voltage should be about:

[1P3CEM040 | Chapter 2: Electrical Motors | 2.9 Speed control – VFD V/f principle]

- a) 415 V, since voltage must stay at nameplate value
- b) 203 V, reducing voltage with the square of frequency
- c) 290 V, keeping the V/f ratio constant**
- d) 593 V, raising voltage to maintain the rated torque

Answer & explanation

Correct answer: (c) ≈ 290 V.

Given: $V_{\text{rated}} = 415$ V at 50 Hz; $f_2 = 35$ Hz.

Formula: constant flux requires constant V/f; $V_2 = V_{\text{rated}} \times f_2 / f_{\text{rated}}$.

Substitution: $V_2 = 415 \times 35 / 50 = 290.5$ V.

Result: ≈ 290 V (**V/f = 8.3 V/Hz**). Synchronous speed falls to $120 \times 35 / 4 = 1,050$ rpm for a 4-pole machine, and pump power falls roughly with the cube of speed.

Why the others are wrong: (a) keeping 415 V at 35 Hz would over-flux and saturate the core, increasing magnetising current and heating; (b) a quadratic V/f profile is an optional energy-optimising mode for variable-torque loads, but 'V $\propto f^2$ ' (203 V) is not the constant-flux condition asked; (d) the drive cannot exceed its input voltage, and over-voltage would saturate the motor.

Ref: BEE Guidebook Paper 3, Ch. 2 (2.9 Speed control of AC induction motors).

41 Which statement is CORRECT for a single-effect lithium bromide–water vapour absorption chiller?

[1P3CEM041 | Chapter 4: HVAC and Refrigeration System | 4.3 Vapour absorption chillers]

- a) Lithium bromide is the refrigerant, so sub-zero brine temperatures are possible
- b) No cooling tower is needed because the absorber rejects no heat at all
- c) It rejects less heat per TR to the cooling tower than an electric chiller
- d) Water is the refrigerant, so chilled water is limited to about 5 °C**

Answer & explanation

Correct answer: (d).

In a LiBr–water absorption machine, water is the refrigerant and LiBr solution is the absorbent. Water evaporates at very low pressure (vacuum) in the evaporator, but because it freezes at 0 °C the chilled water temperature is practically limited to about 5 °C or higher. The machine is driven by low-grade heat (steam, hot water, exhaust gas) and uses electricity only for small pumps.

Why the others are wrong: (a) LiBr is the absorbent, not the refrigerant; sub-zero duties need ammonia–water systems; (b) both the absorber and the condenser reject heat, so a cooling tower is essential; (c) a single-effect machine rejects much more heat per TR (roughly the cooling load plus the heat input at a COP of about 0.7) than a vapour compression chiller, so its cooling tower is larger.

Ref: BEE Guidebook Paper 3, Ch. 4 (4.3 Vapour absorption refrigeration system).

42 A harmonic analyser at a VFD feeder shows fundamental current 200 A, 5th harmonic 40 A, 7th harmonic 28 A and 11th harmonic 12 A. The current THD is:

[1P3CEM042 | Chapter 1: Electrical Systems | 1.10 Harmonics – current THD calculation]

- a) 20.0 %

- b) 24.4 %
- c) 40.0 %
- d) **25.1 %**

Answer & explanation

Correct answer: (d) 25.1 %.

Given: $I_1 = 200$ A; $I_5 = 40$ A; $I_7 = 28$ A; $I_{11} = 12$ A.

Formula: $\text{THD}(I) = \sqrt{I_2^2 + I_3^2 + \dots + I_n^2} / I_1 \times 100$.

Substitution: $\sqrt{40^2 + 28^2 + 12^2} = \sqrt{1,600 + 784 + 144} = \sqrt{2,528} = 50.28$ A; $\text{THD} = 50.28 / 200 \times 100$.

Result: **$\text{THD}(I) \approx 25.1$ %.**

Why the others are wrong: (a) uses only the 5th harmonic (40/200); (b) divides by the total RMS current $\sqrt{200^2 + 2,528} = 206.2$ A instead of the fundamental; (c) adds harmonic magnitudes arithmetically (80/200), but harmonics of different frequency combine as root-sum-square. A THD of 25 % at a drive feeder typically calls for line reactors or a passive/active filter, and detuned reactors with any PF capacitors.

Ref: BEE Guidebook Paper 3, Ch. 1 (1.10 Harmonics).

43 Under the BEE star labelling programme for existing commercial buildings described in the guidebook, the star rating of an office building is primarily based on its:

[1P3CEM043 | Chapter 10: Energy Conservation in Buildings and ECBC | 10.14 Star rating of buildings]

- a) Installed chiller capacity per m^2 of built-up area
- b) Contract demand in kVA per m^2 of conditioned area
- c) **Energy Performance Index in kWh per m^2 per year**
- d) Peak lighting load in watts per m^2 of carpet area

Answer & explanation

Correct answer: (c).

The BEE star rating for buildings (offices, BPOs, shopping malls, hospitals and others) uses the Energy Performance Index (EPI): the annual electricity consumption (grid plus captive/DG generation) divided by the built-up area, in $\text{kWh}/\text{m}^2/\text{year}$. The EPI is compared with bands set for the building type, climatic zone and the share of air-conditioned area; a lower EPI earns more stars, with 5 stars for the most efficient band.

Why the others are wrong: (a) installed TR per m^2 reflects design capacity, not actual energy use; (b) contract demand is a tariff parameter and says nothing about annual consumption; (d) lighting power density is an ECBC design check for one end-use, not the basis of the whole-building star label. EPI also lets owners benchmark year-on-year improvement.

Ref: BEE Guidebook Paper 3, Ch. 10 (10.14 Star rating of buildings).

44 A 160 kW compressor draws air from inside its compressor house at 42°C , while outside air is at 30°C . Using the guidebook thumb rule, relocating the intake outdoors would save, for 7,000 h/year at ₹ 8/kWh, about:

[1P3CEM044 | Chapter 3: Compressed Air System | 3.5 Effect of intake air temperature]

- a) ₹ 89,600 per year
- b) **₹ 2,68,800 per year**
- c) ₹ 5,37,600 per year
- d) ₹ 10,75,200 per year

Answer & explanation

Correct answer: (b) ₹ 2,68,800 per year.

Given: inlet temperature drop = $42 - 30 = 12\text{ }^{\circ}\text{C}$; power = 160 kW; 7,000 h/year; ₹ 8/kWh.

Formula (guidebook thumb rule): every $4\text{ }^{\circ}\text{C}$ rise in inlet air temperature raises energy consumption by about 1 % for the same output. Saving % = $\Delta T / 4$.

Substitution: $12 / 4 = 3\%$; saving = $0.03 \times 160 \times 7,000 = 33,600\text{ kWh}$; cost = $33,600 \times 8$.

Result: **≈ 33,600 kWh and ₹ 2,68,800 per year.** Cooler air is denser, so more mass is delivered per stroke or revolution.

Why the others are wrong: (a) takes only 1 % in total; (c) assumes 1 % per $2\text{ }^{\circ}\text{C}$ (6 %); (d) assumes 1 % per $^{\circ}\text{C}$ (12 %). The intake should also be dust-free and away from hot exhausts.

Ref: BEE Guidebook Paper 3, Ch. 3 (3.5 Efficient operation – cool air intake).

45 Select the WRONG statement about basic lighting terms:

[1P3CEM045 | Chapter 8: Lighting System | 8.2 Basic lighting terms – wrong statement]

- a) Illuminance of one lux equals one lumen per square metre
- b) Colour rendering index of low pressure sodium lamps is very poor
- c) Luminous efficacy of a lamp is expressed in lux per watt**
- d) Luminous intensity in a given direction is measured in candela

Answer & explanation

Correct answer: (c) – this statement is wrong.

Luminous efficacy is the ratio of light output to electrical input, expressed in lumens per watt (lm/W). Lux is a unit of illuminance at a surface, which depends on mounting height, room geometry and reflectances, so it cannot express a lamp property. When control gear (ballast or driver) losses are included, the term 'system efficacy' (lm per circuit watt) is used.

The other statements are correct: (a) $1\text{ lux} = 1\text{ lm/m}^2$; (b) LPSV lamps emit near-monochromatic yellow light, so their CRI is very poor even though their efficacy is very high; they suit street or security lighting, not colour-critical tasks; (d) luminous intensity is measured in candela, the basis of luminaire polar diagrams.

Ref: BEE Guidebook Paper 3, Ch. 8 (8.2 Basic parameters and terms in lighting system).

46 In a pump-up test, a compressor fills a 9.5 m^3 receiver-plus-piping volume from 0.5 to $7.5\text{ kg/cm}^2(\text{g})$ in 4 min 10 s. With atmospheric pressure $1.026\text{ kg/cm}^2(\text{a})$, the free air delivery is about:

[1P3CEM046 | Chapter 3: Compressed Air System | 3.6 Compressor capacity assessment – pump-up (FAD) test]

- a) $13.1\text{ Nm}^3/\text{min}$
- b) $16.0\text{ Nm}^3/\text{min}$
- c) $16.7\text{ Nm}^3/\text{min}$
- d) $15.6\text{ Nm}^3/\text{min}$**

Answer & explanation

Correct answer: (d) $\approx 15.6\text{ Nm}^3/\text{min}$.

Given: $V = 9.5\text{ m}^3$ (receiver + delivery piping); $P_1 = 0.5\text{ kg/cm}^2(\text{g})$ ($\approx 0.490\text{ bar(g)}$); $P_2 = 7.5\text{ kg/cm}^2(\text{g})$ ($\approx 7.35\text{ bar(g)}$); $P_o = 1.026\text{ kg/cm}^2(\text{a})$ ($\approx 1.01\text{ bar(a)}$); $T = 4\text{ min } 10\text{ s} = 4.167\text{ min}$.

Formula: FAD, $Q = [(P_2 - P_1) / P_o] \times (V / T)\text{ Nm}^3/\text{min}$.

Substitution: $Q = (7.0 / 1.026) \times (9.5 / 4.167) = 6.823 \times 2.280$.

Result: **$Q \approx 15.6\text{ Nm}^3/\text{min}$ ($\approx 933\text{ Nm}^3/\text{h}$).** Compare with rated FAD to judge capacity loss (wear, valve leakage).

Why the others are wrong: (a) ignores the pipe volume and uses only 8 m³ of receiver; (b) omits P₀, treating the pressure rise in kg/cm² as atmospheres; (c) uses P₂ alone (7.5) instead of the pressure rise (P₂ – P₁). The test needs the receiver outlet closed, the drain shut and the compressor started from the lower pressure.

Ref: BEE Guidebook Paper 3, Ch. 3 (3.6 Compressor capacity assessment).

47 A process plant increases its circulating water flow by 25 % while the process heat load stays unchanged. What happens to the cooling tower range, other factors constant?

[1P3CEM047 | Chapter 7: Cooling Towers | 7.2 Range determined by the process]

- a) Range rises by 25 % because more water is cooled
- b) Range falls to about 80 % of its earlier value**
- c) Range stays the same since it is fixed by tower size
- d) Range falls to 75 % of its earlier value exactly

Answer & explanation

Correct answer: (b).

Given: heat load Q unchanged; new flow m₂ = 1.25 m₁.

Formula: heat load = m × Cp × Range, so Range ∝ 1 / m at constant load.

Substitution: Range₂ / Range₁ = m₁ / m₂ = 1 / 1.25 = 0.80.

Result: **Range falls to 80 % (a 20 % reduction)**. The guidebook stresses that range is determined not by the cooling tower but by the process it serves (heat load and water flow).

Why the others are wrong: (a) more flow at the same load lowers, not raises, the temperature drop; (c) range is not a property of tower size; tower size affects approach; (d) a 25 % flow increase gives 1/1.25 = 0.80, not 0.75 (that would follow from a 33 % increase). Higher flow also raises pumping power and may exceed the tower's design water loading.

Ref: BEE Guidebook Paper 3, Ch. 7 (7.2 Cooling tower performance – range).

48 A pump with a 320 mm impeller develops 62 m at the required flow, but the system needs only 52 m at that flow. Using the affinity relation for trimming (head ∝ D²), the trimmed impeller diameter is about:

[1P3CEM048 | Chapter 6: Pumps and Pumping System | 6.6 Flow control – impeller trimming]

- a) 225 mm
- b) 293 mm**
- c) 268 mm
- d) 302 mm

Answer & explanation

Correct answer: (b) ≈ 293 mm.

Given: D₁ = 320 mm; H₁ = 62 m; H₂ = 52 m; flow treated as approximately unchanged at the operating point (a simplification for small trims).

Formula: H₂ / H₁ = (D₂ / D₁)², so D₂ = D₁ × √(H₂ / H₁); power ∝ D³.

Substitution: D₂ = 320 × √(52 / 62) = 320 × √0.8387 = 320 × 0.9158.

Result: **D₂ ≈ 293 mm (≈ 8.4 % trim)**. Power falls roughly to (0.916)³ = 77 % of the original if flow follows the trim, less where static head dominates.

Why the others are wrong: (a) squares the head ratio instead of taking the root; (c) treats head as directly proportional to diameter; (d) uses the cube root (power relation). Trimming is permanent, suits a steady over-sized duty, and should normally stay within about 75 % of the original diameter.

Ref: BEE Guidebook Paper 3, Ch. 6 (6.6 Flow control strategies – impeller trimming).

49 In a 3-phase, 4-wire LT system feeding many SMPS-based computer loads, the neutral conductor is found overheated. Which harmonic orders add arithmetically in the neutral and cause this?

[1P3CEM049 | Chapter 1: Electrical Systems | 1.10 Harmonics – triplen harmonics in neutral]

- a) **Triplen harmonics such as the 3rd and 9th**
- b) Fifth and eleventh harmonics from VFD rectifiers
- c) Seventh and thirteenth positive-sequence harmonic currents
- d) Even harmonics such as the 2nd and 4th

Answer & explanation

Correct answer: (a) triplen harmonics (3rd, 9th, 15th ...).

Triplen harmonic currents of the three phases are in phase with each other (zero-sequence), so instead of cancelling in the neutral as balanced fundamental currents do, they add. With single-phase non-linear loads such as computers, UPS and LED drivers the neutral current can exceed the phase current, causing overheating, and transformer delta windings carry circulating triplen currents.

Why the others are wrong: (b) 5th and 11th are negative-sequence characteristic harmonics of 6-pulse drives; they cancel in the neutral; (c) 7th and 13th are positive-sequence and also cancel in a balanced neutral; (d) even harmonics are normally negligible in symmetrical waveforms.

Remedies: oversized neutral, K-rated transformers, zig-zag or active filters.

Ref: BEE Guidebook Paper 3, Ch. 1 (1.10 Harmonics).

50 A 1,250 kVA DG set runs at 850 kW with exhaust gas at 470 °C after the turbocharger. Using the guidebook relation (8 kg gas per kWh, Cp 0.25 kcal/kg °C, exit limited to 180 °C), the waste heat recovery potential is about:

[1P3CEM050 | Chapter 9: Diesel / Natural Gas Power Generating System | 9.4 / 9.5 DG waste heat recovery potential]

- a) **4,93,000 kcal/h**
- b) 5,95,000 kcal/h
- c) 7,25,000 kcal/h
- d) 7,99,000 kcal/h

Answer & explanation

Correct answer: (a) 4,93,000 kcal/h.

Given: output = 850 kWh per hour; flue gas = 8 kg/kWh; Cp = 0.25 kcal/kg °C (≈ 1.05 kJ/kg·K); $t_g = 470$ °C; minimum exit = 180 °C.

Formula: WHR potential (kcal/h) = (kWh output per hour) $\times 8 \times 0.25 \times (t_g - 180)$.

Substitution: $850 \times 8 \times 0.25 \times (470 - 180) = 1,700 \times 290$.

Result: $\approx 4,93,000$ kcal/h (≈ 573 kW thermal; 2,064 MJ/h). The 180 °C limit avoids acid dew point corrosion.

Why the others are wrong: (b) cools the gas to 120 °C, below the safe exit limit; (c) uses the 1,250 kVA rating instead of the actual 850 kW output; (d) cools the gas to 0 °C (uses 470 °C instead of 470 – 180). Actual recoverable heat also depends on loading, running hours and allowable back pressure on the engine.

Ref: BEE Guidebook Paper 3, Ch. 9 (9.5 Energy saving measures – waste heat recovery).

..... End of Section I

Section – II: SHORT DESCRIPTIVE QUESTIONS

Marks: 8 x 5 = 40

4. Answer all Eight questions
5. Each question carries Five marks

S-1 A chemical unit has an HT connection with a contract demand of 1,500 kVA. Its tariff and one month's metered data are:

Item	Value
Recorded maximum demand	1,180 kVA
Billing demand	Higher of recorded MD or 75 % of contract demand
Demand charge	₹ 420 per kVA per month
Energy charge (base)	₹ 7.20 per kWh
Normal-hour consumption	3,00,000 kWh
Peak-hour consumption (surcharge 20 % on base rate)	1,40,000 kWh
Off-peak consumption (rebate ₹ 1.00 per kWh)	1,80,000 kWh
Average power factor	0.88
PF penalty	1 % of energy charges for every 0.01 below 0.90

Calculate:

- (a) Billing demand and demand charges. (1 Mark)
- (b) Energy charges including TOD surcharge and rebate. (2 Marks)
- (c) PF penalty. (1 Mark)
- (d) Total monthly bill and average cost per kWh. (1 Mark)

[1P3CEM051 | Chapter 1: Electrical Systems | 1.2 Electricity billing – HT tariff with TOD and PF penalty]

S-1 – Model answer (5 marks)

Given: CD = 1,500 kVA; MD = 1,180 kVA; demand rate ₹ 420/kVA; base energy rate ₹ 7.20/kWh; normal 3,00,000 kWh; peak 1,40,000 kWh (+20 %); off-peak 1,80,000 kWh (–₹ 1.00); PF = 0.88.

(a) Billing demand (1 Mark)

Formula: Billing demand = max (MD, 0.75 × CD)

Substitution: $0.75 \times 1,500 = 1,125$ kVA; MD = 1,180 kVA > 1,125 kVA

Result: **Billing demand = 1,180 kVA; demand charge = $1,180 \times 420 = ₹ 4,95,600$**

(b) Energy charges (2 Marks)

Normal: $3,00,000 \times 7.20 = ₹ 21,60,000$

Peak: $1,40,000 \times 7.20 \times 1.20 = 1,40,000 \times 8.64 = ₹ 12,09,600$

Off-peak: $1,80,000 \times (7.20 - 1.00) = 1,80,000 \times 6.20 = ₹ 11,16,000$

Result: **Energy charges = ₹ 44,85,600** (total energy 6,20,000 kWh)

(c) PF penalty (1 Mark)

Shortfall = $(0.90 - 0.88) / 0.01 = 2$ steps → 2 % of energy charges

Penalty = $0.02 \times 44,85,600 = ₹ 89,712$

(d) Total bill and average cost (1 Mark)

Total = $4,95,600 + 44,85,600 + 89,712 = ₹ 50,70,912$

Average cost = $50,70,912 / 6,20,000 = ₹ 8.18$ per kWh

Auditor's note: correcting PF to above 0.90 with APFC removes the ₹ 89,712 monthly penalty ($\approx ₹ 10.8$ lakh/year) and, by lowering kVA, also reduces demand charges.

Marking: (a) 1; (b) 0.5 + 0.5 + 0.5 + 0.5 for the three slabs and total; (c) 1; (d) 0.5 + 0.5.

S-2 A 55 kW, 4-pole, 415 V pump motor has been rewound twice. A pump test shows the pump needs 44.0 kW at its shaft, while the motor input measured with a power analyser is 49.5 kW. The plant is considering an IE3 motor of the same rating with 94.5 % efficiency at this load, costing ₹ 3,40,000 installed. The pump runs 7,200 h/year and the tariff is ₹ 7.50/kWh.

- (i) Operating efficiency of the rewound motor. (1 Mark)
- (ii) Percentage loading of the motor. (1 Mark)
- (iii) Input power with the IE3 motor and annual energy and cost savings. (2 Marks)
- (iv) Simple payback period. (1 Mark)

[1P3CEM052 | Chapter 2: Electrical Motors | 2.8 Rewound motor – efficiency, loading and replacement economics]

S-2 – Model answer (5 marks)

Given: shaft demand $P_{out} = 44.0$ kW; present input $P_{in} = 49.5$ kW; rating = 55 kW; $\eta_{IE3} = 0.945$; 7,200 h/year; ₹ 7.50/kWh; investment ₹ 3,40,000.

(i) Operating efficiency (1 Mark)

Formula: $\eta = P_{out} / P_{in} \times 100$

Substitution: $44.0 / 49.5 \times 100$

Result: $\eta \approx 88.9\%$ (well below the 93–94 % expected of a healthy motor of this size, which confirms rewinding losses)

(ii) Loading (1 Mark)

Formula: $\% \text{ load} = P_{out} / \text{rated output} \times 100$

Substitution: $44.0 / 55 \times 100$

Result: **80 % loading** (good loading, so the same rating is retained)

(iii) IE3 input and savings (2 Marks)

Input with IE3 = $44.0 / 0.945 = 46.56$ kW

Saving = $49.5 - 46.56 = 2.94$ kW

Annual energy saving = $2.94 \times 7,200 = 21,162$ kWh/year (≈ 76.2 GJ)

Annual cost saving = $21,162 \times 7.50 = ₹ 1,58,714$ per year

(iv) Payback (1 Mark)

Formula: $SPP = \text{investment} / \text{annual saving}$

Substitution: $3,40,000 / 1,58,714$

Result: ≈ 2.14 years

Note: the IE3 motor runs at lower slip; check pump flow and power after replacement, because the slightly higher speed raises centrifugal load demand.

Marking: (i) 1; (ii) 1; (iii) 0.5 input + 0.5 kW saving + 0.5 kWh + 0.5 ₹; (iv) 1.

S-3 A screw compressor of rated FAD 18 m³/min draws 118 kW when loaded. A leakage test was conducted during a lunch break with all end-uses closed. The average on-load time was 22 s and off-load time 58 s per cycle. The plant runs 8,000 h/year and electricity costs ₹ 8/kWh.

- (a) Calculate the percentage leakage and the leakage quantity. (2 Marks)

(b) Estimate the power lost due to leakage and its annual cost, using the loaded specific power. (2 Marks)

(c) Estimate the annual saving if leakage is brought down to 10 % of FAD. (1 Mark)

[1P3CEM053 | Chapter 3: Compressed Air System | 3.5 Compressed air leakage test – quantity, power and cost]

S-3 – Model answer (5 marks)

Given: $Q = 18 \text{ m}^3/\text{min}$; loaded power = 118 kW; T (on-load) = 22 s; t (off-load) = 58 s; 8,000 h/year; ₹ 8/kWh.

(a) Leakage (2 Marks)

Formula: $\% \text{ leakage} = T / (T + t) \times 100$; leakage quantity = $\% \text{ leakage} \times Q$

Substitution: $22 / (22 + 58) \times 100 = 27.5 \%$; 0.275×18

Result: **Leakage = 27.5 %; quantity = 4.95 m³/min (297 m³/h)**

(b) Power lost and cost (2 Marks)

Specific power = $118 / 18 = 6.556 \text{ kW per m}^3/\text{min}$

Power lost = $4.95 \times 6.556 = \mathbf{32.45 \text{ kW}}$

Annual energy = $32.45 \times 8,000 = 2,59,600 \text{ kWh}$

Annual cost = $2,59,600 \times 8 = \mathbf{₹ 20,76,800 (\approx ₹ 20.8 \text{ lakh})}$

(c) Saving at 10 % leakage (1 Mark)

Target leakage = $0.10 \times 18 = 1.80 \text{ m}^3/\text{min}$; reduction = $4.95 - 1.80 = 3.15 \text{ m}^3/\text{min}$

Power saved = $3.15 \times 6.556 = 20.65 \text{ kW}$; energy = $20.65 \times 8,000 = 1,65,200 \text{ kWh}$

Result: **$\approx ₹ 13.2 \text{ lakh per year}$**

Marking: (a) 1 + 1; (b) 0.5 specific power + 0.5 kW + 0.5 kWh + 0.5 ₹; (c) 1. Leak detection with ultrasonic detectors, tagging and a monthly leak-test routine sustain the saving.

S-4 A pitot-tube traverse was made on the 1.0 m × 1.4 m rectangular suction duct of an ID fan handling flue gas at 85 °C. Velocity pressures at five points were 18, 22, 25, 21 and 19 mmWC. The pitot tube constant is 0.9. Static pressure at fan suction is –145 mmWC and at fan discharge +35 mmWC. The motor draws 68 kW at 93 % efficiency. Take density at 0 °C as 1.293 kg/m³ (sea level).

(a) Gas density at operating temperature. (1 Mark)

(b) Average velocity and volume flow. (2 Marks)

(c) Fan static efficiency. (2 Marks)

[1P3CEM054 | Chapter 5: Fans and Blowers | 5.6 Fan performance assessment – traverse, density, flow and static efficiency]

S-4 – Model answer (5 marks)

Given: duct area $A = 1.0 \times 1.4 = 1.4 \text{ m}^2$; $t = 85 \text{ °C}$; $\Delta p = 18, 22, 25, 21, 19 \text{ mmWC} (\approx 186 \text{ Pa})$; $C_p = 0.9$; $P_{\text{suction}} = -145 \text{ mmWC} (\approx -1,422 \text{ Pa})$; $P_{\text{discharge}} = +35 \text{ mmWC} (\approx 343 \text{ Pa})$; motor input 68 kW; $\eta_m = 0.93$.

(a) Density (1 Mark)

Formula: $\gamma = 273 \times 1.293 / (273 + t)$

Substitution: $273 \times 1.293 / 358$

Result: **$\gamma = 0.986 \text{ kg/m}^3$**

(b) Velocity and flow (2 Marks)

Formula: $v = C_p \times \sqrt{(2 \times 9.81 \times \Delta p / \gamma)}$ for each point; average the velocities, not the pressures.

Velocities: $18 \rightarrow 17.03$; $22 \rightarrow 18.83$; $25 \rightarrow 20.07$; $21 \rightarrow 18.40$; $19 \rightarrow 17.50 \text{ m/s}$

Average velocity = $(17.03 + 18.83 + 20.07 + 18.40 + 17.50) / 5 = 18.37 \text{ m/s}$

Flow $Q = 18.37 \times 1.4 = 25.71 \text{ m}^3/\text{s}$ ($\approx 92,570 \text{ m}^3/\text{h}$)

(c) Static efficiency (2 Marks)

Static pressure rise = $35 - (-145) = 180 \text{ mmWC}$ ($= 1,766 \text{ Pa}$)

Shaft power = $68 \times 0.93 = 63.24 \text{ kW}$

Formula: $\eta_{\text{static}} = Q \times \Delta p_s / (102 \times \text{shaft power}) \times 100$

Substitution: $25.71 \times 180 / (102 \times 63.24) \times 100 = 4,628 / 6,450 \times 100$

Result: $\eta_{\text{static}} \approx 71.7 \%$

Marking: (a) 1; (b) 1 for point velocities + 0.5 average + 0.5 flow; (c) 0.5 ΔP + 0.5 shaft power + 1 efficiency.

Averaging velocity pressures first ($21 \text{ mmWC} \rightarrow 18.40 \text{ m/s}$) gives a slightly different value and is not the guidebook method.

S-5 A $60 \text{ m} \times 24 \text{ m}$ factory bay is lit by 64 HPSV luminaires of 250 W (ballast loss 30 W each), giving an average 210 lux . Management wants 250 lux with 120 W LED high-bay luminaires of $15,600 \text{ lumens}$ each. Take utilisation factor 0.65 and maintenance factor 0.80 . The bay operates $4,800 \text{ h/year}$ and electricity costs $\text{₹ } 8.20/\text{kWh}$.

(a) Number of LED luminaires required. (2 Marks)

(b) Existing and proposed lighting power density. (1 Mark)

(c) Annual energy and cost savings. (2 Marks)

[1P3CEM055 | Chapter 8: Lighting System | 8.5 Lighting retrofit – lumen method, LPD and savings]

S-5 – Model answer (5 marks)

Given: $A = 60 \times 24 = 1,440 \text{ m}^2$; $E = 250 \text{ lux}$; $\Phi = 15,600 \text{ lm}$; $UF = 0.65$; $MF = 0.80$; existing $64 \times (250 + 30) \text{ W}$; LED 120 W ; $4,800 \text{ h/year}$; $\text{₹ } 8.20/\text{kWh}$.

(a) Number of luminaires (2 Marks)

Formula: $N = (E \times A) / (\Phi \times UF \times MF)$

Substitution: $(250 \times 1,440) / (15,600 \times 0.65 \times 0.80) = 3,60,000 / 8,112 = 44.4$

Result: **$N = 45 \text{ LED luminaires}$** (rounded up; arranged e.g. 9×5)

(b) LPD (1 Mark)

Existing load = $64 \times 280 = 17,920 \text{ W} \rightarrow \text{LPD} = 17,920 / 1,440 = 12.4 \text{ W/m}^2$ (at only 210 lux)

Proposed load = $45 \times 120 = 5,400 \text{ W} \rightarrow \text{LPD} = 5,400 / 1,440 = 3.75 \text{ W/m}^2$ (at 250 lux)

(c) Savings (2 Marks)

Load reduction = $17.92 - 5.40 = 12.52 \text{ kW}$

Energy saving = $12.52 \times 4,800 = 60,096 \text{ kWh/year}$ ($\approx 216 \text{ GJ}$)

Cost saving = $60,096 \times 8.20 = \text{₹ } 4,92,787 \text{ per year}$ ($\approx \text{₹ } 4.93 \text{ lakh}$)

Note: illuminance rises by about 19% while load falls by 70% ; adding daylight/occupancy controls would increase savings.

Marking: (a) 1 formula + 1 result; (b) $0.5 + 0.5$; (c) $0.5 \text{ kW} + 1 \text{ kWh} + 0.5 \text{ ₹}$.

S-6 (a) Briefly explain the three compliance approaches available under ECBC. (1.5 Marks)

(b) List five energy efficiency measures for a new air-conditioned commercial building, covering envelope, HVAC and lighting. (2.5 Marks)

(c) Using the building definition given in the guidebook, state whether ECBC applies to each of the following and why: (1 Mark)

Building	Use	Connected load	Contract demand
A	Office	90 kW	110 kVA
B	Hotel	140 kW	100 kVA
C	Private residential apartments	250 kW	280 kVA

[1P3CEM056 | Chapter 10: Energy Conservation in Buildings and ECBC | 10.4 / 10.15 ECBC compliance approaches, building EE measures and applicability]

S-6 – Model answer (5 marks)

(a) Compliance approaches (0.5 Mark each)

1. **Prescriptive method** – every envelope, HVAC, service hot water, lighting and electrical component meets the specified prescriptive values in addition to mandatory provisions.
2. **Trade-off (Envelope Performance Factor) method** – the envelope may trade a weaker component (e.g. more glazing) against a better one (e.g. better roof insulation), provided the proposed EPF does not exceed that of the standard envelope.
3. **Whole building performance method** – annual energy use of the proposed design, found by simulation, must not exceed that of a standard design meeting the prescriptive requirements. Mandatory provisions apply in all three methods.

(b) Energy efficiency measures (0.5 Mark each, any five)

1. Roof and wall insulation to achieve low U-values; cool (high-reflectance) roof.
2. High-performance glazing with low SHGC and U-value, shading devices and a moderate window-to-wall ratio.
3. High-efficiency chillers/unitary units meeting ECBC efficiency, with VFDs on pumps, AHU fans and cooling tower fans.
4. Energy/heat recovery wheels on fresh air and economiser controls where climate allows.
5. LED lighting within ECBC LPD limits with daylight sensors, occupancy sensors and time switches.
6. BMS with scheduling, temperature resets and sub-metering of major loads.
7. Efficient UPS, transformers and motors; PF correction; solar water heating.

(c) Applicability (Building A 0.25, B 0.25, C 0.5)

Building A: **Not covered** – connected load 90 kW < 100 kW and contract demand 110 kVA < 120 kVA.

Building B: **Covered** – connected load 140 kW ≥ 100 kW (either criterion is enough).

Building C: **Not covered** – the guidebook definition covers buildings used for commercial purposes; private residential apartments are outside it despite the high load.

S-7 A 1,010 kVA DG set was tested for one hour at a steady load of 620 kW. Diesel consumption measured with a calibrated tank was 168 litres. Diesel density is 0.835 kg/litre, GCV 10,800 kcal/kg and price ₹ 92/litre. Exhaust gas temperature after the turbocharger is 450 °C.

(a) Specific energy generation (kWh/litre). (1 Mark)

(b) Overall thermal efficiency of the set. (2 Marks)

(c) Fuel cost per kWh generated. (1 Mark)

(d) Waste heat recovery potential using the guidebook relation. (1 Mark)

S-7 – Model answer (5 marks)

Given: output = 620 kW for 1 h = 620 kWh; fuel = 168 L/h; $\rho = 0.835$ kg/L; GCV = 10,800 kcal/kg ($\approx 45,217$ kJ/kg); ₹ 92/L; $t_g = 450$ °C.

(a) Specific energy generation (1 Mark)

Formula: SEG = kWh generated / litres consumed

Substitution: 620 / 168

Result: **3.69 kWh/litre**

(b) Thermal efficiency (2 Marks)

Fuel heat input = $168 \times 0.835 \times 10,800 = 15,14,952$ kcal/h (= 6,343 MJ/h)

Electrical output = $620 \times 860 = 5,33,200$ kcal/h (≈ 620 kW)

Formula: $\eta = \text{output} / \text{input} \times 100$

Result: **$\eta = 5,33,200 / 15,14,952 \times 100 \approx 35.2\%$**

(c) Fuel cost per kWh (1 Mark)

Cost = $(168 \times 92) / 620 = 15,456 / 620 = \text{₹ } 24.93$ per kWh (about three times the grid tariff, so the DG should be limited to emergencies)

(d) Waste heat recovery potential (1 Mark)

Formula: WHR = kWh/h $\times 8$ kg gas/kWh $\times 0.25$ kcal/kg °C $\times (t_g - 180)$

Substitution: $620 \times 8 \times 0.25 \times (450 - 180) = 1,240 \times 270$

Result: **3,34,800 kcal/h (≈ 389 kW thermal)**, usable for hot water or a VAM.

Marking: (a) 1; (b) 1 input + 1 efficiency; (c) 1; (d) 1.

S-8 A package air conditioner serving a control room was tested by the air-side method. Measured data:

Parameter	Value
Supply air flow (measured at return)	4,800 m ³ /h
Enthalpy of return air at coil inlet	14.6 kcal/kg
Enthalpy of supply air at coil outlet	9.8 kcal/kg
Air density	1.2 kg/m ³
Power input to unit (compressor + fans)	10.2 kW

(a) Cooling capacity in TR. (2 Marks)

(b) Specific power consumption (kW/TR) and EER (W/W). (2 Marks)

(c) Suggest two measures to improve the performance of the unit. (1 Mark)

S-8 – Model answer (5 marks)

Given: $Q = 4,800$ m³/h; $h_{in} = 14.6$ kcal/kg (61.1 kJ/kg); $h_{out} = 9.8$ kcal/kg (41.0 kJ/kg); $\rho = 1.2$ kg/m³; $P = 10.2$ kW.

(a) Cooling capacity (2 Marks)

Formula: $TR = Q \times \rho \times (h_{in} - h_{out}) / 3,024$

Substitution: $4,800 \times 1.2 \times (14.6 - 9.8) / 3,024 = 27,648 / 3,024$

Result: **9.14 TR** (27,648 kcal/h = 32.15 kW of cooling)

(b) kW/TR and EER (2 Marks)

$$\text{kW/TR} = 10.2 / 9.14 = \mathbf{1.12 \text{ kW/TR}}$$

$$\text{EER} = \text{cooling output (kW)} / \text{input (kW)} = 32.15 / 10.2 = \mathbf{3.15 \text{ W/W}}$$

(c) Improvement measures (0.5 Mark each, any two)

1. Clean condenser and evaporator coils and filters; ensure condenser air is not recirculated (shade the outdoor unit).
2. Check refrigerant charge and correct leaks.
3. Seal duct leaks and insulate supply ducts; reduce heat ingress into the room.
4. Raise room set point where permissible (each 1 °C rise saves roughly 3–5 % of compressor energy).
5. Replace with a higher star-rated inverter unit at end of life.

Marking: (a) 1 formula + 1 result; (b) 1 + 1; (c) 0.5 × 2.

..... End of Section II

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

6. Answer all Six questions
7. Each question carries Ten marks

L-1 (a) A three-cell induced-draft cooling tower in a fertiliser plant was assessed. Data:

Parameter	Value
Circulating water flow	4,200 m ³ /h
Hot water temperature	42.5 °C
Cold water temperature	34.0 °C
Ambient wet bulb temperature	28.5 °C
Cycles of concentration (COC)	3.5
Drift loss	0.02 % of circulation
Fan power (measured, 3 fans)	33 kW each

Calculate:

- i) Range, approach and effectiveness. (2 Marks)
- ii) Heat rejected in kcal/h and in TR (1 TR = 3,024 kcal/h). (1 Mark)
- iii) Evaporation loss (guidebook formula), blowdown and make-up water per day. (3 Marks)
- iv) In winter the required cold water temperature is achieved with all fans at 70 % speed. If VFDs (efficiency 97 %) are fitted, estimate the saving for 3,000 h/year of such operation at ₹ 8/kWh, using the fan laws. (2 Marks)

(b) State True or False: (2 Marks)

- i) For the same heat load, a tower designed for a lower approach needs to be larger.
- ii) Drift loss is mainly controlled by the type of fill media used.
- iii) Increasing the COC reduces evaporation loss from the tower.
- iv) Aerodynamic FRP fan blades can reduce cooling tower fan power compared with metallic blades.

L-1 – Model answer (10 marks)

Given: $Q = 4,200 \text{ m}^3/\text{h}$; $T_{\text{hot}} = 42.5 \text{ }^\circ\text{C}$; $T_{\text{cold}} = 34.0 \text{ }^\circ\text{C}$; $\text{WBT} = 28.5 \text{ }^\circ\text{C}$; $\text{COC} = 3.5$; $\text{drift} = 0.02 \%$; $\text{fan power} = 3 \times 33 \text{ kW}$.

(a) i) Range, approach, effectiveness (2 Marks)

Result: $\text{Range} = 42.5 - 34.0 = \mathbf{8.5 \text{ }^\circ\text{C}}$

Result: $\text{Approach} = 34.0 - 28.5 = \mathbf{5.5 \text{ }^\circ\text{C}}$

Result: $\text{Effectiveness} = \text{Range} / (\text{Range} + \text{Approach}) \times 100 = 8.5 / 14.0 \times 100 = \mathbf{60.7 \%}$

ii) Heat rejected (1 Mark)

Formula: $\text{Heat load} = m \times C_p \times \text{Range}$

Substitution: $42,00,000 \text{ kg/h} \times 1 \times 8.5 = 3,57,00,000 \text{ kcal/h}$ ($\approx 1,49,470 \text{ MJ/h}$; $41,512 \text{ kW}$)

Result: $\text{TR} = 3,57,00,000 / 3,024 = \mathbf{11,806 \text{ TR}} \text{ } (\approx \mathbf{41,513 \text{ kW}})$

iii) Water balance (3 Marks)

Result: $\text{Evaporation loss } E = 0.00085 \times 1.8 \times 4,200 \times 8.5 = \mathbf{54.62 \text{ m}^3/\text{h}}$ (1 Mark)

Result: $\text{Blowdown } B = E / (\text{COC} - 1) = 54.62 / 2.5 = \mathbf{21.85 \text{ m}^3/\text{h}}$ (1 Mark)

$\text{Drift } D = 0.0002 \times 4,200 = 0.84 \text{ m}^3/\text{h}$

Result: $\text{Make-up} = E + B + D = 54.62 + 21.85 + 0.84 = 77.31 \text{ m}^3/\text{h} \rightarrow \mathbf{1,855 \text{ m}^3/\text{day}}$ (1 Mark)

iv) VFD on CT fans (2 Marks)

Present fan power = $3 \times 33 = 99 \text{ kW}$

Fan law: $P_2 = P_1 \times (N_2/N_1)^3 = 99 \times 0.7^3 = 99 \times 0.343 = 33.96 \text{ kW}$; with VFD loss: $33.96 / 0.97 = 35.01 \text{ kW}$

Result: $\text{Saving} = 99 - 35.01 = 63.99 \text{ kW}$; $\text{energy} = 63.99 \times 3,000 = \mathbf{1,91,970 \text{ kWh/year}}$

Result: $\text{Cost saving} = 1,91,970 \times 8 = \mathbf{₹ 15,35,760} \text{ } (\approx \mathbf{₹ 15.4 \text{ lakh}}) \text{ per year}$

(b) True/False (0.5 Mark each)

i) **True** – a lower approach needs more fill volume and air flow, so a bigger tower.

ii) **False** – drift is controlled by drift eliminators, not the fill.

iii) **False** – evaporation depends on heat load ($\text{range} \times \text{flow}$); higher COC reduces blowdown and make-up.

iv) **True** – the guidebook notes that FRP blades with efficient aerodynamic profile save fan energy.

L-2 A pharmaceutical plant operates a 400 TR water-cooled centrifugal chiller (hermetic motor) for about 6,000 h/year. Measured data at steady load:

Parameter	Value
Chilled water flow	$230 \text{ m}^3/\text{h}$
Chilled water return / supply temperature	$12.2 \text{ }^\circ\text{C} / 7.0 \text{ }^\circ\text{C}$
Compressor power input	290 kW
Condenser water flow	$330 \text{ m}^3/\text{h}$
Condenser water inlet temperature	$31.5 \text{ }^\circ\text{C}$
Tariff	$\text{₹ } 8.50/\text{kWh}$

Assume all compressor input appears as heat in the refrigerant (hermetic machine) and C_p of water = $1 \text{ kcal/kg } ^\circ\text{C}$.

a) Calculate the cooling load (TR), specific power (kW/TR) and COP. (3 Marks)

b) Calculate the heat rejected in the condenser and the expected condenser water outlet temperature. (2 Marks)

c) The process permits the chilled water supply to be raised from $7 \text{ }^\circ\text{C}$ to $9 \text{ }^\circ\text{C}$. Using the thumb rule of 3 % compressor power saving per $^\circ\text{C}$ rise in evaporator temperature, estimate the annual energy and cost saving. (2 Marks)

d) Independently of (c), a magnetic-bearing chiller rated at 0.55 kW/TR at this load is offered at ₹ 1.60 crore. Calculate the annual saving and simple payback. (2 Marks)

e) List two other measures to reduce chiller plant energy. (1 Mark)

[1P3CEM060 | Chapter 4: HVAC and Refrigeration System | 4.7 / 4.16 Chiller performance assessment, heat balance and energy saving options]

L-2 – Model answer (10 marks)

Given: $m_{chw} = 230 \text{ m}^3/\text{h} = 2,30,000 \text{ kg/h}$; $\Delta T_{chw} = 12.2 - 7.0 = 5.2 \text{ }^\circ\text{C}$; $P = 290 \text{ kW}$; $m_{cw} = 3,30,000 \text{ kg/h}$; $T_{cw,in} = 31.5 \text{ }^\circ\text{C}$; 6,000 h/year; ₹ 8.50/kWh.

a) Cooling load, kW/TR, COP (3 Marks)

Formula: $Q = m \times C_p \times \Delta T$; $TR = Q / 3,024$

$Q = 2,30,000 \times 1 \times 5.2 = 11,96,000 \text{ kcal/h}$ (= 5,007 MJ/h; 1,390.7 kW)

Result: $TR = 11,96,000 / 3,024 = \mathbf{395.5 \text{ TR}} \text{ } (\approx \mathbf{1,391 \text{ kW}})$ (1 Mark)

Result: $\text{kW/TR} = 290 / 395.5 = \mathbf{0.733 \text{ kW/TR}}$ (1 Mark)

Result: $\text{COP} = 1,390.7 / 290 = \mathbf{4.80}$ (1 Mark)

b) Condenser heat rejection (2 Marks)

Formula: $Q_{cond} = Q_{evap} + \text{compressor input}$

Substitution: $11,96,000 + 290 \times 860 = 11,96,000 + 2,49,400 = \mathbf{14,45,400 \text{ kcal/h}}$ ($\approx 478 \text{ TR}$ of heat rejection; ≈ 1.21 times cooling load)

Condenser $\Delta T = 14,45,400 / (3,30,000 \times 1) = 4.38 \text{ }^\circ\text{C}$

Result: Outlet temperature = $31.5 + 4.38 = \mathbf{35.9 \text{ }^\circ\text{C}}$

c) Raising chilled water set point (2 Marks)

Saving = $3\% \times 2 \text{ }^\circ\text{C} = 6\%$ of compressor power = $0.06 \times 290 = 17.4 \text{ kW}$

Result: Annual energy = $17.4 \times 6,000 = \mathbf{1,04,400 \text{ kWh}}$

Result: Annual cost = $1,04,400 \times 8.50 = \mathbf{₹ 8,87,400}$ ($\approx \mathbf{₹ 8.9 \text{ lakh}}$)

d) Magnetic-bearing chiller (2 Marks)

New power = $395.5 \times 0.55 = 217.5 \text{ kW}$; saving = $290 - 217.5 = 72.5 \text{ kW}$

Result: Annual energy = $72.5 \times 6,000 = \mathbf{4,34,841 \text{ kWh}}$; cost = $4,34,841 \times 8.50 = \mathbf{₹ 36.96 \text{ lakh}}$

Result: Simple payback = $1,60,00,000 / 36,96,151 = \approx \mathbf{4.3 \text{ years}}$

e) Other measures (0.5 Mark each, any two)

Clean condenser tubes (online tube cleaning) to lower condenser approach; optimise cooling tower to give the coldest condenser water; VFDs on secondary chilled water pumps and AHU fans; reduce heat ingress and insulate chilled water lines; sequence chillers for best part-load efficiency; thermal storage to shift load.

L-3 A closed-circuit process cooling water pump (static head negligible) is rated 700 m³/h, 45 m head, 1,480 rpm, 80 % efficiency. It is directly coupled to a 132 kW motor. The delivery valve is kept partly closed. Audit measurements:

Parameter	Value
Flow (ultrasonic flow meter)	520 m ³ /h
Suction pressure	0.5 kg/cm ² (g)
Pump discharge pressure (before valve)	4.9 kg/cm ² (g)
Header pressure (after valve)	3.2 kg/cm ² (g)
Motor input power	112 kW
Motor efficiency	94 %

Operating hours: 8,000 h/year; tariff ₹ 7/kWh. Gauges are at the same elevation; neglect velocity head.

- a) Calculate the total head, hydraulic power and present pump efficiency. (3 Marks)
- b) Calculate the hydraulic power wasted across the throttle valve. (1 Mark)
- c) If the valve is fully opened and a VFD fitted, estimate the required pump speed for the same flow, using the affinity laws. (1 Mark)
- d) Assuming pump efficiency of 78 % at the new speed and combined motor + VFD efficiency of 92 %, calculate the new input power and the annual energy and cost savings. (3 Marks)
- e) If the VFD costs ₹ 12 lakh installed, calculate the simple payback. (1 Mark)
- f) Give one reason why a VFD may be preferred to impeller trimming here. (1 Mark)

[1P3CEM061 | Chapter 6: Pumps and Pumping System | 6.4 / 6.6 Throttled pump – efficiency, throttling loss and VFD retrofit]

L-3 – Model answer (10 marks)

Given: $Q = 520 \text{ m}^3/\text{h} = 0.1444 \text{ m}^3/\text{s}$; $P_s = 0.5 \text{ kg/cm}^2 (\approx 0.490 \text{ bar} = 49.0 \text{ kPa})$ (5 m); $P_d = 4.9 \text{ kg/cm}^2 (\approx 4.81 \text{ bar})$ (49 m); header = $3.2 \text{ kg/cm}^2 (\approx 3.14 \text{ bar})$ (32 m); motor input = 112 kW; $\eta_m = 0.94$; 8,000 h/year; ₹ 7/kWh.

Formula: $H = (P_d - P_s) \times 10 \text{ m}$ ($1 \text{ kg/cm}^2 \approx 10 \text{ m}$ of water); hydraulic power = $Q \times H \times \rho \times g / 1,000 \text{ kW}$; $\eta_{\text{pump}} = \text{hydraulic power} / \text{shaft power}$; affinity laws: $H \propto N^2$, $P \propto N^3$, so $N_2 = N_1 \times \sqrt{(H_2/H_1)}$; SPP = investment / annual saving.

a) Head, hydraulic power, efficiency (3 Marks)

Result: Total head $H = 49 - 5 = \mathbf{44 \text{ m}}$ (1 Mark)

Result: Hydraulic power = $Q \times H \times \rho \times g / 1,000 = 0.1444 \times 44 \times 1,000 \times 9.81 / 1,000 = \mathbf{62.35 \text{ kW}}$ (1 Mark)

Shaft power = $112 \times 0.94 = 105.28 \text{ kW}$

Result: Pump efficiency = $62.35 / 105.28 \times 100 = \mathbf{59.2 \%}$ (against 80 % rated – the pump is far from its BEP) (1 Mark)

b) Throttling loss (1 Mark)

Pressure drop across valve = $4.9 - 3.2 = 1.7 \text{ kg/cm}^2 (\approx 1.67 \text{ bar}) = 17 \text{ m}$

Result: Hydraulic power wasted = $0.1444 \times 17 \times 9.81 = \mathbf{24.1 \text{ kW}}$

c) Required speed (1 Mark)

Head needed with valve open = $32 - 5 = 27 \text{ m}$

Result (Affinity law): $H \propto N^2 \rightarrow N_2 = 1,480 \times \sqrt{(27 / 44)} = 1,480 \times 0.7833 = \mathbf{1,159 \text{ rpm}}$

d) New power and savings (3 Marks)

New hydraulic power = $0.1444 \times 27 \times 9.81 = 38.26 \text{ kW}$

Shaft power = $38.26 / 0.78 = 49.05 \text{ kW}$

Result: Input power = $49.05 / 0.92 = \mathbf{53.3 \text{ kW}}$ (1 Mark)

Result: Saving = $112 - 53.3 = 58.7 \text{ kW}$; energy = $58.7 \times 8,000 = \mathbf{4,69,478 \text{ kWh/year}}$ (1 Mark)

Result: Cost saving = $4,69,478 \times 7 = \mathbf{₹ 32,86,348 (\approx ₹ 32.9 \text{ lakh}) per year}$ (1 Mark)

e) Payback (1 Mark)

Result: SPP = $12,00,000 / 32,86,348 = \mathbf{0.365 \text{ year} (\approx 4.4 \text{ months})}$

f) Reason (1 Mark)

A VFD can follow seasonal and process variations in cooling demand and allows soft starting; trimming is permanent and suits only a fixed, steady over-capacity, and future higher flow would need a new impeller.

L-4 A plant receives power at 11 kV through two identical 1,600 kVA, 11/0.433 kV transformers, each with no-load loss 2.4 kW and full-load copper loss 16.0 kW. The plant load is 1,150 kW at 0.82 PF and runs round the clock (8,760 h/year). The demand charge is ₹ 410/kVA/month and MD may be taken equal to the plant kVA.

- Calculate the plant kVA and the loading of each transformer when both share the load equally. (1 Mark)
- Compare total transformer losses with (i) both transformers in parallel and (ii) one transformer carrying the whole load. Which mode should be adopted? (3 Marks)
- Calculate the capacitor kVAr required to raise the PF to 0.97. (2 Marks)
- Calculate the transformer losses after PF correction (both in parallel) and the annual energy saved in the transformers. (2 Marks)
- Calculate the monthly and annual saving in demand charges after PF correction. (2 Marks)

[1P3CEM062 | Chapter 1: Electrical Systems | 1.5 / 1.4 Transformer loading, parallel operation and PF correction economics]

L-4 – Model answer (10 marks)

Given: $2 \times 1,600$ kVA; $P_o = 2.4$ kW; $P_{cu,FL} = 16.0$ kW each; load = 1,150 kW at PF 0.82; target PF 0.97; 8,760 h/year; ₹ 410/kVA/month.

a) kVA and loading (1 Mark)

kVA = $1,150 / 0.82 = 1,402.4$ kVA; each transformer carries 701.2 kVA $\rightarrow$ loading = $701.2 / 1,600 = 43.8\%$

b) Loss comparison (3 Marks)

Formula: total loss = $P_o + (kVA \text{ load} / kVA \text{ rated})^2 \times P_{cu,FL}$

(i) Both in parallel: $2 \times [2.4 + 16.0 \times (0.4383)^2] = 2 \times [2.4 + 3.07] = 10.95$ kW (1 Mark)

(ii) One transformer: $2.4 + 16.0 \times (1,402.4 / 1,600)^2 = 2.4 + 16.0 \times 0.7683 = 14.69$ kW (1 Mark)

Result: parallel operation saves 3.75 kW ($\approx 32,800$ kWh/year), so **run both transformers in parallel** at this load. (1 Mark)

c) Capacitor rating (2 Marks)

Formula: kVAr = kW $\times (\tan \phi_1 - \tan \phi_2)$

$\tan \phi_1 (0.82) = 0.6979$; $\tan \phi_2 (0.97) = 0.2506$

kVAr = $1,150 \times (0.6979 - 0.2506) = 1,150 \times 0.4473 = 514.5$ kVAr (install ≈ 525 kVAr APFC panel)

d) Losses after correction (2 Marks)

New kVA = $1,150 / 0.97 = 1,185.6$ kVA; each transformer 592.8 kVA (37.0 %)

Loss = $2 \times [2.4 + 16.0 \times (592.8 / 1,600)^2] = 2 \times [2.4 + 2.196] = 9.19$ kW

Reduction = $10.95 - 9.19 = 1.75$ kW $\rightarrow 1.75 \times 8,760 = 15,365$ kWh/year

e) Demand charge saving (2 Marks)

kVA reduction = $1,402.4 - 1,185.6 = 216.9$ kVA

Monthly saving = $216.9 \times 410 = ₹ 88,918$; annual = ₹ 10,67,010 ($\approx ₹ 10.7$ lakh)

(plus any PF incentive under the state tariff; capacitors at load end would also cut LT cable losses).

L-5 An engineering plant has three identical screw compressors, each with FAD $15 \text{ m}^3/\text{min}$ at $7.5 \text{ kg/cm}^2(\text{g})$, loaded power 92 kW and unloaded power 28 kW. Average plant demand is $34 \text{ m}^3/\text{min}$, so two compressors run fully loaded and the third runs loaded 60 % of the time and unloaded 40 %. A leak test showed leakage of $6.8 \text{ m}^3/\text{min}$ (20 % of demand). The farthest user needs only 6.0 kg/cm^2 and the distribution pressure drop is 0.5 kg/cm^2 . The plant runs 8,000 h/year; tariff ₹ 8/kWh. Manufacturer's data: power falls by 6 % for each 1 kg/cm^2 reduction in generation pressure.

- a) Calculate the present average power and specific power (kW per m³/min of delivered air). (2 Marks)
- b) Calculate the present annual energy and cost. (1 Mark)
- c) Leaks are reduced to 2.7 m³/min. Two compressors can then meet the demand fully loaded with the third kept on standby. Calculate the power and annual savings. (3 Marks)
- d) After (c), generation pressure is reduced from 7.5 to 6.5 kg/cm². Calculate the additional annual saving. (2 Marks)
- e) State True or False: (2 Marks)
 - i) An unloaded screw compressor consumes negligible power.
 - ii) Pressure drop in a well-designed distribution system should be well below 10 % of compressor discharge pressure.
 - iii) Compressed air is one of the cheapest utilities in a plant.
 - iv) Multi-stage compression with inter-cooling needs less power than single-stage for the same pressure ratio.

[1P3CEM063 | Chapter 3: Compressed Air System | 3.5 Compressed air system optimisation – leakage, compressor scheduling and pressure]

L-5 – Model answer (10 marks)

Given: 3 × (15 m³/min, 92 kW loaded, 28 kW unloaded); demand = 34 m³/min; leakage 6.8 → 2.7 m³/min; 8,000 h/year; ₹ 8/kWh; 6 % saving per kg/cm².

Formula: power = $\Sigma(\text{loaded kW} \times \text{load fraction} + \text{unloaded kW} \times \text{unload fraction})$; specific power = kW / (m³/min); annual energy = kW × hours; pressure-reduction saving ≈ 6 % of power per 1 kg/cm² lower generation pressure.

a) Present power and specific power (2 Marks)

Result: Power = 2 × 92 + (0.6 × 92 + 0.4 × 28) = 184 + 55.2 + 11.2 = **250.4 kW** (1 Mark)

Result: Specific power = 250.4 / 34 = **7.36 kW per m³/min** (against 92/15 = 6.13 for a fully loaded machine – unload losses) (1 Mark)

b) Annual energy and cost (1 Mark)

Result: Energy = 250.4 × 8,000 = **20,03,200 kWh**; cost = 20,03,200 × 8 = ₹ **1,60,25,600** (≈ ₹ **1.60 crore**)

c) Leak reduction and scheduling (3 Marks)

Result: New demand = 34 – (6.8 – 2.7) = **29.9 m³/min** ≤ 2 × 15 = 30 m³/min (1 Mark)

Result: New power = 2 × 92 = 184 kW; saving = 250.4 – 184 = **66.4 kW** (1 Mark)

Result: Annual saving = 66.4 × 8,000 = 5,31,200 kWh → ₹ **42,49,600** (≈ ₹ **42.5 lakh**) (1 Mark)

d) Pressure reduction (2 Marks)

Required generation pressure = 6.0 + 0.5 = 6.5 kg/cm² (≈ 6.37 bar) → reduction of 1 kg/cm² (≈ 0.981 bar = 98.1 kPa) → 6 %

Result: Saving = 0.06 × 184 = 11.04 kW; energy = 11.04 × 8,000 = **88,320 kWh**; cost = ₹ **7,06,560** (≈ ₹ **7.1 lakh**)

Total saving (c + d) ≈ ₹ 49.6 lakh/year (≈ 31 % of the present bill).

e) True/False (0.5 Mark each)

i) **False** – unloaded power is typically 25–35 % of loaded power (here 28/92 = 30 %).

ii) **True** – excessive pressure drop forces a higher generation pressure.

iii) **False** – compressed air is one of the most expensive utilities; only a small fraction of input energy reaches the point of use as useful work.

iv) **True** – inter-cooling brings compression closer to isothermal and reduces work.

L-6 An ID fan driven by a 160 kW motor (efficiency 93 %) is controlled by an outlet damper. Logged data over a year:

Flow (% of design)	Hours/year	Motor input with damper (kW)
100 %	2,000	148
80 %	3,000	132
60 %	2,500	118

A VFD (efficiency 97 %) is proposed with the damper fully open. Assume fan power follows the cube law from the 100 % point (negligible fixed pressure) and motor efficiency remains constant. Tariff ₹ 7.80/kWh; VFD installed cost ₹ 18 lakh.

- Calculate the motor loading at 100 % flow. (1 Mark)
- Calculate the present annual energy consumption. (1 Mark)
- Calculate the annual energy consumption with the VFD. (3 Marks)
- Calculate the annual savings and simple payback. (2 Marks)
- State True or False: (3 Marks)
 - Motor efficiency falls sharply when loading drops below about 50 %.
 - Reducing supply frequency without reducing voltage keeps the motor flux constant.
 - Every 10 °C rise in winding temperature above rated roughly halves insulation life.
 - Oversized, lightly loaded motors operate at a higher power factor.
 - Stray load losses increase with motor load.
 - A VFD can inject harmonic currents into the plant supply.

[1P3CEM064 | Chapter 2: Electrical Motors | 2.9 Speed control of induction motors – VFD retrofit on damper-controlled fan]

L-6 – Model answer (10 marks)

Given: rated output 160 kW; $\eta_m = 0.93$; damper inputs 148/132/118 kW for 2,000/3,000/2,500 h; $\eta_{VFD} = 0.97$; ₹ 7.80/kWh; cost ₹ 18 lakh.

a) Motor loading (1 Mark)

Result: Output at 100 % flow = $148 \times 0.93 = 137.6$ kW $\rightarrow$ loading = $137.6 / 160 = 86 \%$

b) Present energy (1 Mark)

Result: $148 \times 2,000 + 132 \times 3,000 + 118 \times 2,500 = 2,96,000 + 3,96,000 + 2,95,000 = 9,87,000$ kWh/year

c) Energy with VFD (3 Marks)

Formula: $P_2 = P_1 \times (Q_2/Q_1)^3$; input with VFD = $P_2 / 0.97$ ($P_1 = 148$ kW motor input at 100 %)

100 %: $148 \times 1.000 / 0.97 = 152.58$ kW $\times 2,000$ h = 3,05,155 kWh

80 %: $148 \times 0.512 / 0.97 = 78.12$ kW $\times 3,000$ h = 2,34,359 kWh

60 %: $148 \times 0.216 / 0.97 = 32.96$ kW $\times 2,500$ h = 82,392 kWh

Result: Total = **6,21,905 kWh/year** (1 Mark per correct line)

Note: at 100 % flow the VFD adds its own loss ($152.6 > 148$ kW); savings come from part-load hours. A bypass contactor is recommended for full-load running.

d) Savings and payback (2 Marks)

Result: Saving = 9,87,000 – 6,21,905 = **3,65,095 kWh/year** ($\approx 1,314$ GJ)

Result: Cost saving = $3,65,095 \times 7.80 = \text{₹ } 28,47,740$ ($\approx \text{₹ } 28.5$ lakh)

Result: SPP = $18,00,000 / 28,47,740 = 0.63$ year (≈ 7.6 months)

e) True/False (0.5 Mark each)

i) **True** ii) **False** – V/f must be held constant, otherwise the core saturates. iii) **True** iv) **False** – lightly loaded motors run at low PF. v) **True** – stray losses rise roughly with the square of load current. vi) **True** – the rectifier front-end draws non-sinusoidal current; use line reactors/filters.

..... End of Section III

Section I – Answer key

Q	Ans	Q	Ans	Q	Ans	Q	Ans	Q	Ans
1	a	11	b	21	c	31	c	41	d
2	d	12	d	22	a	32	b	42	d
3	c	13	c	23	d	33	c	43	c
4	c	14	b	24	d	34	d	44	b
5	a	15	a	25	b	35	a	45	c
6	a	16	c	26	b	36	a	46	d
7	b	17	d	27	a	37	b	47	b
8	a	18	d	28	d	38	a	48	b
9	c	19	b	29	d	39	a	49	a
10	c	20	b	30	b	40	c	50	a