

PRACTICE PAPER – SET 2
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 drawing office is 20 m long and 10 m wide, with luminaires mounted 2.5 m above the working plane. Its room index is about:

[2P3CEM001 | Chapter 8: Lighting System | 8.4 Lighting design – room index]

- a) 0.38
- b) 1.33
- c) 2.67**
- d) 4.00

Answer & explanation

Correct answer: (c) ≈ 2.67 .

Given: $L = 20$ m; $W = 10$ m; H_m (mounting height above working plane) = 2.5 m.

Formula: room index $RI = (L \times W) / [H_m \times (L + W)]$.

Substitution: $RI = (20 \times 10) / [2.5 \times (20 + 10)] = 200 / 75$.

Result: **$RI \approx 2.67$** .

Why the others are wrong: (a) inverts the ratio ($75 / 200$); (b) doubles the mounting height in the denominator; (d) uses only the length (20 m) in place of $(L + W)$ in the denominator. Room index, with surface reflectances, selects the utilisation factor from the luminaire's photometric table, which then fixes the number of luminaires by the lumen method; large, low rooms (high RI) use light more effectively.

Ref: BEE Guidebook Paper 3, Ch. 8 (8.4 Lighting design – room index and utilisation factor).

2 In an auditorium whose occupancy varies widely, fresh-air dampers are modulated using return-air CO₂ sensors. The main energy benefit is:

[2P3CEM002 | Chapter 4: HVAC and Refrigeration System | 4.8 Demand-controlled ventilation]

- a) Higher chiller COP from a lower chilled water supply temperature
- b) Less outdoor air to cool and dehumidify during low occupancy**
- c) Elimination of all fresh air to keep conditioned air recirculating
- d) Greater fan power to maintain a constant supply air pressure

Answer & explanation

Correct answer: (b).

Outdoor (fresh) air in hot or humid climates carries a large sensible and latent load. Fixed dampers sized for full occupancy over-ventilate the hall most of the time. CO₂ concentration rises with the number of occupants, so a CO₂ sensor (typical set point around 700–1,000 ppm, or about 700 ppm above outdoor) lets the controller admit only the air needed. This cuts the fresh-air cooling load and associated chiller and fan energy while keeping indoor air quality acceptable.

Why the others are wrong: (a) DCV does not change chilled water temperature; a lower supply temperature would reduce COP; (c) eliminating fresh air would violate ventilation norms and lead to stuffiness and high CO₂; (d) DCV reduces, rather than increases, fan and coil energy; supply pressure control is a separate VAV function.

Ref: BEE Guidebook Paper 3, Ch. 4 (4.8 Energy-saving opportunities – ventilation control).

3 A 6-pole, 50 Hz induction motor driving a conveyor runs at 970 rpm. The frequency of the currents induced in its rotor is:

[2P3CEM003 | Chapter 2: Electrical Motors | 2.3 Motor characteristics – slip and rotor frequency]

- a) 1.5 Hz**
- b) 0.03 Hz
- c) 15 Hz
- d) 48.5 Hz

Answer & explanation

Correct answer: (a) 1.5 Hz.

Given: P = 6 poles; f = 50 Hz; N = 970 rpm.

Formula: $N_s = 120 f / P$; slip $s = (N_s - N) / N_s$; rotor frequency $f_r = s \times f$.

Substitution: $N_s = 120 \times 50 / 6 = 1,000$ rpm; $s = (1,000 - 970) / 1,000 = 0.03$ (3 %); $f_r = 0.03 \times 50$.

Result: **$f_r = 1.5$ Hz.**

Why the others are wrong: (b) is the slip expressed as a fraction, not a frequency; (c) multiplies slip in percent (3) by 5 or misplaces the decimal; (d) subtracts rotor frequency from supply frequency, which has no meaning here. Low rotor frequency at normal load is why rotor iron loss is small; rotor copper loss = slip $\times$ air-gap power, so higher slip means higher rotor loss.

Ref: BEE Guidebook Paper 3, Ch. 2 (2.3 Motor characteristics – speed and slip).

4 In a two-stage air compressor, the air temperature leaving the intercooler is found to be 18 °C above the cooling water inlet temperature, against about 4 °C at commissioning. The most likely cause and effect is:

[2P3CEM004 | Chapter 3: Compressed Air System | 3.6 Intercooler performance]

- a) Fouled intercooler raising second-stage work and power draw**

- b) Leaking first-stage valves reducing the motor current drawn
- c) Overcooled air causing condensation and lower energy demand
- d) Undersized receiver causing the compressor to cycle rapidly

Answer & explanation

Correct answer: (a).

An intercooler should cool the first-stage air close to the cooling-water inlet temperature (within about 3–5 °C), so that the second stage compresses denser, cooler air and the compression approaches the isothermal ideal. An approach rising to 18 °C points to scaling on the water side or fouling on the air side, or to inadequate water flow. Warmer air at the second-stage inlet increases specific power; the guidebook notes that every 4 °C rise in inlet air temperature raises power by about 1 %, and fouled intercoolers also raise second-stage discharge temperature and wear.

Why the others are wrong: (b) leaking valves cut delivery but do not explain an intercooler temperature rise and do not save power per unit of air; (c) the air is undercooled, not overcooled; (d) receiver size affects cycling frequency, not intercooler approach.

Ref: BEE Guidebook Paper 3, Ch. 3 (3.6 Compressed air system components – intercoolers).

5 An office complex wants to shift 1,200 TR-h of daytime cooling to an ice-storage tank charged at night. Considering only the latent heat of fusion of ice (80 kcal/kg, water already at 0 °C), the mass of ice to be produced is about:

[2P3CEM005 | Chapter 4: HVAC and Refrigeration System | 4.8 Thermal energy storage – ice bank sizing]

- a) 6.7 tonnes
- b) 12.9 tonnes
- c) 36.3 tonnes
- d) 45.4 tonnes**

Answer & explanation

Correct answer: (d) ≈ 45.4 tonnes.

Given: stored cooling = 1,200 TRh; 1 TR = 3,024 kcal/h (≈ 3.52 kW); latent heat of fusion = 80 kcal/kg (≈ 335 kJ/kg).

Formula: mass of ice = (TR-h × 3,024) / latent heat.

Substitution: cooling = 1,200 × 3,024 = 36,28,800 kcal; mass = 36,28,800 / 80 = 45,360 kg.

Result: ≈ **45.4 tonnes of ice**.

Why the others are wrong: (a) uses the latent heat of vaporisation (540 kcal/kg) instead of fusion; (b) uses 860 kcal per unit (the kWh conversion) instead of 3,024 kcal per TR-h; (c) rounds the latent heat to 100 kcal/kg. Thermal storage shifts chiller load to off-peak hours, cutting peak demand and TOD energy cost; ice chillers run at lower evaporator temperature and higher kW/TR, which must be set against the tariff benefit.

Ref: BEE Guidebook Paper 3, Ch. 4 (4.8 Energy-saving opportunities – thermal storage).

6 An audit finds a 75 kW motor driving a 20 kW blower load. Which combination best describes its operating condition?

[2P3CEM006 | Chapter 2: Electrical Motors | 2.4 Oversized motors – part-load behaviour]

- a) Higher efficiency and an improved power factor
- b) Lower efficiency and a markedly poor power factor**
- c) Unchanged efficiency but a much higher motor speed

d) Lower efficiency but a power factor close to unity

Answer & explanation

Correct answer: (b).

The motor is loaded at about 27 % (20 / 75). Below about 50 % load, efficiency falls because fixed losses (core, friction and windage) become a large share of the small output, and power factor falls sharply because magnetising current, which is nearly constant, dominates the input current. Both effects increase kWh and kVA demand, so right-sizing (a 22 or 30 kW motor) or star operation is advised.

Why the others are wrong: (a) both efficiency and PF worsen at light load, not improve; (c) speed rises only slightly (slip reduces) and efficiency does change; (d) PF falls at light load; it approaches its best value near full load. The guidebook's motor load survey uses input kW and PF to identify such oversized motors.

Ref: BEE Guidebook Paper 3, Ch. 2 (2.4 Motor efficiency and part-load performance).

7 A dairy transfers 180 m³/h of process water through a 150 mm internal-diameter pipe. The mean flow velocity in the pipe is about:

[2P3CEM007 | Chapter 6: Pumps and Pumping System | 6.3 System characteristics – pipe velocity]

- a) 0.71 m/s
- b) 2.22 m/s
- c) 2.83 m/s**
- d) 11.3 m/s

Answer & explanation

Correct answer: (c) ≈ 2.83 m/s.

Given: $Q = 180 \text{ m}^3/\text{h}$; $D = 150 \text{ mm} = 0.15 \text{ m}$.

Formula: $v = Q / A$, with $A = (\pi/4) \times D^2$ and Q in m³/s.

Substitution: $Q = 180 / 3,600 = 0.05 \text{ m}^3/\text{s}$; $A = 0.7854 \times 0.15^2 = 0.01767 \text{ m}^2$; $v = 0.05 / 0.01767$.

Result: **$v \approx 2.83 \text{ m/s}$** .

Why the others are wrong: (a) uses $\pi \times D^2$ (four times the true area); (b) uses D^2 without $\pi/4$; (d) puts the 75 mm radius in place of the diameter in $(\pi/4)D^2$. Typical economic velocities in pumped water lines are about 1–2 m/s on the delivery side; at 2.83 m/s the friction head, which rises with the square of velocity, is high, and a larger pipe could cut pumping power.

Ref: BEE Guidebook Paper 3, Ch. 6 (6.3 System characteristics – friction head).

8 A 45 kW shaft load is driven through V-belts of 93 % efficiency by a motor of 92 % efficiency. Replacing them with synchronous (cogged) belts of 98 % efficiency, for 6,000 h/year operation, saves about:

[2P3CEM008 | Chapter 2: Electrical Motors | 2.5 Transmission losses – belt drive upgrade]

- a) 16,100 kWh/year**
- b) 13,500 kWh/year
- c) 14,800 kWh/year
- d) 15,800 kWh/year

Answer & explanation

Correct answer: (a) $\approx 16,100$ kWh/year.

Given: driven load = 45 kW; η_{belt} : 93 % $\rightarrow$ 98 %; η_{motor} = 92 %; 6,000 h/year.

Formula: motor input = load / ($\eta_{\text{belt}} \times \eta_{\text{motor}}$); saving = (input₁ – input₂) $\times$ hours.

Substitution: $\text{input}_1 = 45 / (0.93 \times 0.92) = 52.59 \text{ kW}$; $\text{input}_2 = 45 / (0.98 \times 0.92) = 49.91 \text{ kW}$; difference = 2.68 kW; $\times 6,000 \text{ h}$.

Result: **saving $\approx 16,100 \text{ kWh/year}$** ($\approx 58 \text{ GJ}$).

Why the others are wrong: (b) takes 5 % of 45 kW (2.25 kW) directly, ignoring that the load is referred back through both efficiencies; (c) ignores the motor efficiency (computes at motor shaft); (d) applies the 5-point gain to the present motor input (5 % of 52.59 kW), ignoring the ratio of efficiencies. Transmission losses add directly to motor input, so efficient belts or direct coupling are low-cost measures recommended in the guidebook.

Ref: BEE Guidebook Paper 3, Ch. 2 (2.5 Energy-saving opportunities in motors – transmission).

9 A cooling tower installed in a congested courtyard shows cold-water temperatures 2–3 °C higher than expected although fans and fill are in good condition. Warm, moist exhaust is seen drifting back to the air inlets. The effect is that:

[2P3CEM009 | Chapter 7: Cooling Towers | 7.3 Siting – plume recirculation]

a) The inlet air wet bulb rises above ambient, so cold water warms

b) The inlet air wet bulb falls below ambient, so cold water cools

c) Evaporation stops completely and the tower acts as a dry cooler

d) Range increases because the process heat load has been reduced

Answer & explanation

Correct answer: (a).

Recirculation occurs when part of the warm, nearly saturated exhaust plume re-enters the tower inlets, typically because of walls, adjacent buildings, close spacing of cells or adverse wind. The air entering the fill then has a wet-bulb temperature higher than the true ambient wet bulb. Since the cold-water temperature can only approach the inlet wet bulb, the cold water becomes warmer and the measured approach (against ambient) worsens, raising chiller or process energy use. Remedies include raising discharge stacks (velocity recovery stacks), adequate spacing from walls, orienting the tower to prevailing wind and avoiding interference from other heat sources.

Why the others are wrong: (b) recirculated air is warmer and wetter, so wet bulb rises, not falls; (c) evaporation continues, only at a reduced driving force; (d) range is fixed by heat load and flow and is not reduced by recirculation.

Ref: BEE Guidebook Paper 3, Ch. 7 (7.3 Factors affecting cooling tower performance).

10 A fan delivers much less flow than its catalogue curve. Inspection shows a sharp 90° elbow bolted directly to the fan inlet. This loss is best described as:

[2P3CEM010 | Chapter 5: Fans and Blowers | 5.7 System effect at fan inlet]

a) Surge caused by operating the fan to the right of its curve

b) Leakage loss from the fan shaft seal to the outside atmosphere

c) System effect caused by non-uniform, swirling flow entering the fan impeller

d) Motor slip loss arising from a rise in supply voltage at the fan

Answer & explanation

Correct answer: (c).

Fan curves are tested with uniform inlet and outlet flow. A sharp elbow, abrupt transition or swirl at the inlet makes the air enter the impeller unevenly and pre-rotated, so the fan cannot develop its rated pressure; this deficiency is called system effect. It appears as extra system resistance not accounted for in duct calculations,

and the usual remedies are straight inlet duct of a few diameters, turning vanes or an inlet box designed for the fan.

Why the others are wrong: (a) surge (unstable operation) occurs on the left of the peak pressure point at low flow, not to the right; (b) shaft seal leakage is small and does not depend on inlet elbows; (d) a voltage rise reduces slip slightly and does not reduce flow. Correcting system effect often recovers 10–25 % of lost pressure without changing the fan.

Ref: BEE Guidebook Paper 3, Ch. 5 (5.7 Fan design and selection – system effect).

11 A 750 kVA DG set delivers a steady 600 kW load and consumes 152 litres of diesel per hour. With diesel density 0.83 kg/litre, its specific fuel consumption is about:

[2P3CEM011 | Chapter 9: Diesel / Natural Gas Power Generating System | 9.5 DG performance – specific fuel consumption]

- a) 168 g/kWh
- b) 253 g/kWh
- c) 210 g/kWh**
- d) 305 g/kWh

Answer & explanation

Correct answer: (c) ≈ 210 g/kWh.

Given: load = 600 kW; fuel = 152 L/h; density = 0.83 kg/L; rating = 750 kVA (not needed for SFC).

Formula: SFC = fuel mass flow / electrical output = (L/h $\times$ density) / kW.

Substitution: fuel mass = 152 $\times$ 0.83 = 126.2 kg/h; SFC = 126.2 / 600 = 0.2103 kg/kWh.

Result: **SFC ≈ 210 g/kWh** (equivalently 600 / 152 = 3.95 kWh per litre).

Why the others are wrong: (a) divides by the 750 kVA rating instead of actual kW output; (b) ignores density and treats litres as kilograms (152 / 600); (d) divides by density instead of multiplying. Logging SFC or kWh per litre daily, at known load, is the simplest way to detect injector, turbocharger or filter problems and to compare sets.

Ref: BEE Guidebook Paper 3, Ch. 9 (9.5 Performance assessment of DG sets).

12 A screw conveyor (constant-torque load) presently runs at full speed. If a VFD reduces its speed to 75 % with the same torque, the shaft power required becomes about:

[2P3CEM012 | Chapter 2: Electrical Motors | 2.6 Speed control – constant-torque load]

- a) 42 % of the full-speed power
- b) 56 % of the full-speed power
- c) 100 % of the full-speed power
- d) 75 % of the full-speed power**

Answer & explanation

Correct answer: (d) ≈ 75 %.

Given: constant-torque load; $N_2 / N_1 = 0.75$; $T_2 = T_1$.

Formula: shaft power $P = 2\pi N T / 60$, so with constant torque $P \propto N$.

Substitution: $P_2 / P_1 = (T_2 \times N_2) / (T_1 \times N_1) = 1 \times 0.75$.

Result: **$P_2 \approx 75$ % of full-speed power.**

Why the others are wrong: (a) applies the cube law ($0.75^3 = 0.42$), which is valid only for centrifugal (variable-torque) fans and pumps; (b) applies a square law ($0.75^2 = 0.56$), which describes torque, not power, of centrifugal loads; (c) assumes power stays unchanged. For conveyors, extruders and positive-displacement machines, VFD

savings come mainly from matching throughput, not from the cube law, so audit claims must use the correct load type.

Ref: BEE Guidebook Paper 3, Ch. 2 (2.6 Speed control of AC induction motors – load types).

13 A plant consumed 4,38,000 kWh in a 30-day month. The trivector meter recorded a maximum demand of 1,000 kVA at an average PF of 0.90 during the demand interval. The monthly load factor (kW basis) is about:

[2P3CEM013 | Chapter 1: Electrical Systems | 1.3 Load management – load factor]

- a) 60.8 %
- b) 65.4 %
- c) 75.1 %
- d) 67.6 %**

Answer & explanation

Correct answer: (d) 67.6 %.

Given: energy = 4,38,000 kWh; period = 30 days = 720 h; MD = 1,000 kVA at PF 0.90.

Formula: load factor = energy consumed / (maximum demand in kW × hours in the period) × 100; MD (kW) = MD (kVA) × PF.

Substitution: MD = 1,000 × 0.90 = 900 kW; LF = 4,38,000 / (900 × 720) × 100 = 4,38,000 / 6,48,000 × 100.

Result: **load factor ≈ 67.6 %**; average load = 4,38,000 / 720 = 608 kW.

Why the others are wrong: (a) uses 1,000 kVA as if it were kW; (b) takes 31 days (744 h) for a 30-day month; (c) applies the PF twice (810 kW). A higher load factor means the demand (kVA) charge is spread over more kWh, lowering average cost; it is raised by load shifting and MD control.

Ref: BEE Guidebook Paper 3, Ch. 1 (1.3 Electrical load management and MD control).

14 Test data for a motor at its operating load: input 33.2 kW; stator copper loss 0.90 kW; rotor copper loss 0.85 kW; core loss 0.70 kW; friction and windage 0.30 kW; stray load loss 0.25 kW. The motor efficiency is about:

[2P3CEM014 | Chapter 2: Electrical Motors | 2.4 Motor efficiency – loss summation]

- a) 91.0 %**
- b) 83.4 %
- c) 91.7 %
- d) 94.0 %

Answer & explanation

Correct answer: (a) ≈ 91.0 %.

Given: input = 33.2 kW; losses: stator copper 0.90, rotor copper 0.85, core 0.70, friction and windage 0.30, stray 0.25 kW.

Formula: output = input – total losses; η = output / input × 100.

Substitution: total losses = 0.90 + 0.85 + 0.70 + 0.30 + 0.25 = 3.00 kW; output = 33.2 – 3.0 = 30.2 kW; η = 30.2 / 33.2 × 100.

Result: **η ≈ 91.0 %**.

Why the others are wrong: (b) adds the losses to the input (30.2 / 36.2) instead of subtracting; (c) omits the stray load loss; (d) counts only copper and stray losses and ignores the fixed core and friction losses. The guidebook groups losses as fixed (core, friction and windage) and variable (stator and rotor copper, stray), and energy-efficient designs reduce each group.

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

15 A plant's air demand swings between 35 % and 90 % of one compressor's capacity through the day. Which capacity-control arrangement normally gives the lowest specific power over this range?

[2P3CEM015 | Chapter 3: Compressed Air System | 3.5 Capacity control – variable demand]

- a) A fixed-speed screw compressor in modulation (inlet throttling)
- b) A fixed-speed screw compressor in load and unload operation
- c) A variable speed drive screw compressor matching speed to demand**
- d) Opening a manual blow-off valve to keep the compressor loaded

Answer & explanation

Correct answer: (c).

A VSD screw compressor reduces motor speed in proportion to air demand, so its input power falls almost in line with delivery over a wide band (typically 20–100 % of capacity), and it holds a steady, lower discharge pressure. This gives the lowest kW per m³/min when demand varies widely.

Why the others are wrong: (a) inlet modulation reduces flow, but power falls only slightly (about 70 % power at 40 % flow), so specific power rises sharply at part load; (b) load-unload control is better than modulation, but an unloaded screw still draws about 25–35 % of full-load power and needs a wide pressure band; (d) blowing off air wastes all the energy used to compress it. In multi-compressor plants, a common practice is to base-load fixed-speed machines and trim with one VSD unit.

Ref: BEE Guidebook Paper 3, Ch. 3 (3.5 Compressor capacity control).

16 A hospital ward is being re-lamped. Which statement about correlated colour temperature (CCT) is correct?

[2P3CEM016 | Chapter 8: Lighting System | 8.2 Colour temperature]

- a) Lamps around 6,500 K look warm; around 2,700 K look cool and bluish
- b) CCT expresses the efficacy of a lamp in lumens per watt of input
- c) CCT measures how faithfully colours of objects appear under a lamp
- d) Lamps around 2,700–3,000 K look warm; around 6,500 K look cool**

Answer & explanation

Correct answer: (d).

Correlated colour temperature, in kelvin, is the temperature of a black-body radiator whose colour appearance matches the lamp. Low CCT (about 2,700–3,000 K) gives a yellowish, warm appearance similar to incandescent lamps; around 4,000 K is neutral white; about 5,000–6,500 K appears cool, bluish daylight. Selection depends on the activity and ambience, for example warm light for wards and lounges and neutral to cool light for operation theatres and offices.

Why the others are wrong: (a) reverses the warm and cool descriptions; (b) lumens per watt is luminous efficacy, a separate parameter; (c) colour fidelity is the colour rendering index (CRI, Ra), not CCT. Energy-efficient re-lamping should specify efficacy, CRI and CCT together so that savings do not compromise visual quality.

Ref: BEE Guidebook Paper 3, Ch. 8 (8.2 Basic terms – colour temperature and colour rendering).

17 A municipal water works stops its overhead-tank filling pumps during the evening peak and runs them from 23:00 to 05:00 under a TOD tariff, with no change in daily energy use. In DSM terms this is:

[2P3CEM017 | Chapter 1: Electrical Systems | 1.9 Demand side management – load shifting]

- a) Strategic conservation that reduces annual energy use
- b) Load shifting from peak hours to off-peak hours**

- c) Valley filling by adding new loads in off-peak hours
- d) Peak clipping by permanently disconnecting the pumps

Answer & explanation

Correct answer: (b).

The guidebook classifies DSM load-shape objectives as peak clipping, valley filling, load shifting, strategic conservation, strategic load growth and flexible load shape. Moving an existing load (the same pumps, the same kWh) from peak to off-peak hours is load shifting. It lowers the utility's peak demand and the consumer's bill under TOD tariffs, and storage (overhead tanks) is what makes it possible.

Why the others are wrong: (a) strategic conservation reduces total energy use, e.g. by efficient pumps; here daily kWh is unchanged; (c) valley filling builds new off-peak load (e.g. thermal storage or new night loads) rather than moving an existing one; (d) peak clipping reduces peak load, usually by direct load control, without the energy being supplied at another time.

Ref: BEE Guidebook Paper 3, Ch. 1 (1.9 Demand side management).

18 A DG set is to be installed at a hill site at about 1,500 m altitude where summer ambient reaches 45 °C. Its continuous rating at site will normally be:

[2P3CEM018 | Chapter 9: Diesel / Natural Gas Power Generating System | 9.4 DG selection – site derating]

- a) Higher than nameplate, as cooler hill air improves the combustion
- b) Lower than nameplate, as thin hot air reduces combustion air mass**
- c) Equal to nameplate, as altitude and ambient have no effect at all
- d) Higher than nameplate, as lower air pressure eases the exhaust flow

Answer & explanation

Correct answer: (b).

DG ratings are specified at standard reference conditions (for example 27 °C, 100 kPa and 60 % relative humidity per ISO 3046 / IS 10002). At higher altitude the air is thinner and at high ambient temperature it is less dense, so the engine receives less oxygen per stroke. To avoid incomplete combustion, high exhaust temperature and smoke, the output must be derated using the manufacturer's factors, commonly a few percent per 300 m above about 150 m and per few degrees above the reference temperature. Correct derating prevents overloading and poor SFC.

Why the others are wrong: (a) cooler air helps, but this site has high ambient and low pressure; (c) site conditions clearly affect output; (d) lower ambient pressure does not compensate for reduced air mass. Proper sizing should also consider motor starting kVA and non-linear loads.

Ref: BEE Guidebook Paper 3, Ch. 9 (9.4 Selection and installation factors – derating).

19 A large IT office installs a building management system (BMS). Its main contribution to energy saving is:

[2P3CEM019 | Chapter 10: Energy Conservation in Buildings and ECBC | 10.4 Building management system]

- a) Scheduling and optimising HVAC, lighting and pumps from sensor data**
- b) Raising the contract demand so that the building never pays penalties
- c) Replacing all chillers with absorption machines driven by waste heat
- d) Keeping every AHU at full speed to guarantee comfort in all zones

Answer & explanation

Correct answer: (a).

A BMS is a computer-based control system that monitors and controls building services through sensors, controllers and actuators. Energy is saved by time scheduling of AHUs, chillers, pumps and lighting to occupancy; optimum start and stop; temperature and chilled-water reset; VFD control of fans and pumps on actual demand; sequencing of chillers; and alarms and trend logs that reveal faults such as simultaneous heating and cooling or valves left open. Typical savings reported are 10–20 % of HVAC and lighting energy in large commercial buildings. Why the others are wrong: (b) raising contract demand increases fixed demand charges and saves no energy; (c) a BMS controls existing equipment and does not itself change chiller technology; (d) running every AHU at full speed is exactly what a BMS avoids by matching supply to load. A BMS is effective only if set points and schedules are maintained after commissioning.

Ref: BEE Guidebook Paper 3, Ch. 10 (10.4 Energy conservation in buildings – controls and BMS).

20 A 500 TR chiller is measured at 0.62 kW/TR. At the same time the chilled water pump draws 45 kW, the condenser water pump 55 kW and the cooling tower fans 22 kW. The overall chiller-plant specific power is about:

[2P3CEM020 | Chapter 4: HVAC and Refrigeration System | 4.6 Assessment – overall plant kW/TR]

- a) 0.244 kW/TR
- b) 0.730 kW/TR
- c) 0.820 kW/TR
- d) 0.864 kW/TR**

Answer & explanation

Correct answer: (d) ≈ 0.864 kW/TR.

Given: cooling load = 500 TR ($\approx 1,758$ kW); chiller = 0.62 kW/TR; auxiliaries: CHW pump 45 kW, CW pump 55 kW, CT fans 22 kW.

Formula: plant kW/TR = (chiller kW + auxiliary kW) / TR.

Substitution: chiller kW = $0.62 \times 500 = 310$ kW; auxiliaries = $45 + 55 + 22 = 122$ kW; plant kW/TR = $(310 + 122) / 500$.

Result: ≈ 0.864 kW/TR (auxiliaries add 0.244 kW/TR, about 28 %).

Why the others are wrong: (a) is the auxiliary share alone; (b) adds only the condenser water pump; (c) omits the cooling tower fans. Benchmarking on plant kW/TR, not compressor kW/TR alone, shows the scope in pumps and fans, for example VFDs on CHW pumps and better tower fans.

Ref: BEE Guidebook Paper 3, Ch. 4 (4.6 Assessment of refrigeration and air-conditioning).

21 In a commercial building, 50 m² of west-facing glass receives a peak incident solar radiation of 500 W/m². If clear glass with SHGC 0.60 is replaced by solar-control glass with SHGC 0.25, the reduction in peak solar heat gain is about:

[2P3CEM021 | Chapter 10: Energy Conservation in Buildings and ECBC | 10.3 Building envelope – glazing SHGC]

- a) 6.25 kW
- b) 8.75 kW**
- c) 15.0 kW
- d) 21.3 kW

Answer & explanation

Correct answer: (b) ≈ 8.75 kW.

Given: glass area $A = 50$ m²; incident solar radiation = 500 W/m²; SHGC₁ = 0.60; SHGC₂ = 0.25.

Formula: solar heat gain = $A \times \text{incident radiation} \times \text{SHGC}$; reduction = $A \times I \times (\text{SHGC}_1 - \text{SHGC}_2)$.

Substitution: before = $50 \times 500 \times 0.60 = 15,000$ W; after = $50 \times 500 \times 0.25 = 6,250$ W; reduction = $50 \times 500 \times 0.35$.

Result: **reduction ≈ 8.75 kW of peak cooling load (≈ 2.5 TR).**

Why the others are wrong: (a) is the heat gain remaining with the new glass; (c) is the heat gain with the old glass; (d) adds both SHGC values. ECBC prescribes maximum SHGC and U-values for vertical fenestration by climate zone, because glazing is often the largest envelope heat gain in Indian commercial buildings; visible light transmittance should be checked so that daylight is not lost.

Ref: BEE Guidebook Paper 3, Ch. 10 (10.3 Building envelope – fenestration and ECBC).

22 A municipal pumping station lifts water through a total head of 48 m and its metered energy is 230 kWh per million litres (ML) pumped. Taking the ideal energy as 2.725 kWh per ML per metre of head, its overall wire-to-water efficiency is about:

[2P3CEM022 | Chapter 6: Pumps and Pumping System | 6.5 Water pumping – wire-to-water efficiency]

- a) 20.9 %
- b) 43.1 %
- c) 56.9 %**
- d) 175.8 %

Answer & explanation

Correct answer: (c) ≈ 56.9 %.

Given: total head = 48 m; actual specific energy = 230 kWh/ML; ideal = 2.725 kWh/ML/m.

Formula: ideal energy = $2.725 \times \text{head}$ (from $\rho g H / 3.6 \times 10^6$ for 10^6 L); overall efficiency = ideal / actual $\times 100$.

Substitution: ideal = $2.725 \times 48 = 130.8$ kWh/ML; efficiency = $130.8 / 230 \times 100$.

Result: **wire-to-water efficiency ≈ 56.9 %.**

Why the others are wrong: (a) divides head by kWh ($48 / 230$), which is dimensionally meaningless; (b) is the loss fraction ($100 - 56.9$); (d) inverts the ratio and exceeds 100 %. Specific energy in kWh/ML is a practical benchmark for water utilities because it captures motor, pump and drive losses together; values well above the ideal point to pump wear, throttling or poor operating points.

Ref: BEE Guidebook Paper 3, Ch. 6 (6.5 Assessment of pumps – efficiency).

23 A single-acting, single-cylinder reciprocating compressor has a bore of 250 mm and a stroke of 200 mm and runs at 720 rpm. If the measured free air delivery is $5.8 \text{ m}^3/\text{min}$, its volumetric efficiency is about:

[2P3CEM023 | Chapter 3: Compressed Air System | 3.3 Reciprocating compressor – volumetric efficiency]

- a) 20.5 %
- b) 82.1 %**
- c) 41.0 %
- d) 121.9 %

Answer & explanation

Correct answer: (b) ≈ 82.1 %.

Given: $D = 0.25$ m; $L = 0.20$ m; $N = 720$ rpm; single-acting, one cylinder; FAD = $5.8 \text{ m}^3/\text{min}$.

Formula: swept volume = $(\pi/4) \times D^2 \times L \times N \times (\text{number of acting faces})$; $\eta_{\text{vol}} = \text{FAD} / \text{swept volume} \times 100$.

Substitution: $(\pi/4) \times 0.25^2 \times 0.20 \times 720 = 0.04909 \times 0.20 \times 720 = 7.07 \text{ m}^3/\text{min}$; $\eta_{\text{vol}} = 5.8 / 7.07 \times 100$.

Result: **$\eta_{\text{vol}} \approx 82.1$ %.**

Why the others are wrong: (a) uses the full area $D^2 \times L \times N$ without $\pi/4$ and a wrong unit scaling; (c) treats the machine as double-acting ($14.14 \text{ m}^3/\text{min}$); (d) inverts the ratio (swept/FAD), giving an impossible value above 100 %. Falling volumetric efficiency over time indicates worn valves, rings or excess clearance.

Ref: BEE Guidebook Paper 3, Ch. 3 (3.3 Compressor efficiency definitions).

24 An air washer cools outdoor air at 38 °C DBT and 24 °C WBT (dew point 20 °C) to 27 °C DBT leaving. Its saturation (humidifying) efficiency is about:

[2P3CEM024 | Chapter 4: HVAC and Refrigeration System | 4.3 Evaporative cooling – air washer efficiency]

- a) 21.4 %
- b) 78.6 %**
- c) 28.9 %
- d) 61.1 %

Answer & explanation

Correct answer: (b) $\approx$ 78.6 %.

Given: entering DBT = 38 °C; entering WBT = 24 °C; leaving DBT = 27 °C; dew point (not needed) = 20 °C.

Formula: saturation efficiency = $(\text{DBT}_{\text{in}} - \text{DBT}_{\text{out}}) / (\text{DBT}_{\text{in}} - \text{WBT}_{\text{in}}) \times 100$; in adiabatic evaporative cooling the air can at best approach its wet-bulb temperature.

Substitution: $(38 - 27) / (38 - 24) \times 100 = 11 / 14 \times 100$.

Result: $\approx$ **78.6 %**.

Why the others are wrong: (a) is the unachieved fraction (3 / 14); (c) divides the temperature drop by entering DBT (11 / 38); (d) uses dew point instead of wet bulb as the limit (11 / 18). Evaporative cooling uses only fan and pump power, so it suits hot-dry climates; its effectiveness falls in humid weather as the DBT–WBT gap narrows.

Ref: BEE Guidebook Paper 3, Ch. 4 (4.3 Types of air-conditioning – evaporative cooling).

25 An ID fan absorbs 50 kW handling flue gas at 120 °C. During a cold start it handles ambient air at 30 °C at the same speed and volume flow. Assuming density varies inversely with absolute temperature, the shaft power during the cold start is about:

[2P3CEM025 | Chapter 5: Fans and Blowers | 5.3 Fan laws – effect of gas density]

- a) 38.5 kW
- b) 50.0 kW
- c) 56.9 kW
- d) 64.9 kW**

Answer & explanation

Correct answer: (d) $\approx$ 64.9 kW.

Given: $P_1 = 50$ kW at $t_1 = 120$ °C; $t_2 = 30$ °C; same speed and volume flow.

Formula: at constant speed and volume flow, fan pressure and power vary directly with gas density; density $\propto 1 / (273 + t)$, so $P_2 = P_1 \times (273 + t_1) / (273 + t_2)$.

Substitution: $P_2 = 50 \times 393 / 303 = 50 \times 1.297$.

Result: **$P_2 \approx 64.9$ kW** (about 30 % higher).

Why the others are wrong: (a) inverts the temperature ratio; (b) assumes power is independent of density; (c) applies the square root of the density ratio, which relates velocity to pressure in a pitot measurement, not power. This is why ID fan motors can overload during cold starts and why dampers are partly closed until gas temperature rises; fan curves must always state the density at which they apply.

Ref: BEE Guidebook Paper 3, Ch. 5 (5.3 Fan laws and density correction).

26 The conductivity of circulating water in a cooling tower is 2,400 $\mu\text{S}/\text{cm}$ and that of make-up water 480 $\mu\text{S}/\text{cm}$. Neglecting drift, blowdown as a percentage of make-up water is:

[2P3CEM026 | Chapter 7: Cooling Towers | 7.4 Water balance – cycles of concentration]

- a) 16.7 %
- b) 20.0 %**
- c) 25.0 %
- d) 80.0 %

Answer & explanation

Correct answer: (b) 20.0 %.

Given: circulating water conductivity = 2,400 $\mu\text{S}/\text{cm}$; make-up conductivity = 480 $\mu\text{S}/\text{cm}$; drift neglected.

Formula: $\text{COC} = \text{conductivity of circulating water} / \text{conductivity of make-up}$; dissolved-solids balance gives $M \times C_m = B \times C_c$, so $B / M = 1 / \text{COC}$.

Substitution: $\text{COC} = 2,400 / 480 = 5$; $B / M = 1 / 5$.

Result: **blowdown = 20.0 % of make-up** (evaporation 80 %).

Why the others are wrong: (a) uses $1 / (\text{COC} + 1)$; (c) is blowdown as a fraction of evaporation, $1 / (\text{COC} - 1)$; (d) is the evaporation share of make-up. Raising COC through better water treatment reduces blowdown and make-up water, but scaling limits how high COC can go.

Ref: BEE Guidebook Paper 3, Ch. 7 (7.4 Performance assessment – cycles of concentration and blowdown).

27 A farmer irrigates 1 hectare with 50 mm depth of water from a total head of 25 m. If the old pump-set (overall efficiency 35 %) is replaced by a BEE star-rated set of 50 % overall efficiency, the energy saved per irrigation is about:

[2P3CEM027 | Chapter 6: Pumps and Pumping System | 6.6 Agricultural pumping – efficient pump-set]

- a) 5.1 kWh
- b) 29.2 kWh**
- c) 34.1 kWh
- d) 97.3 kWh

Answer & explanation

Correct answer: (b) ≈ 29.2 kWh per irrigation.

Given: area = 10,000 m^2 ; depth = 0.05 m; head $H = 25$ m; $\eta_1 = 0.35$; $\eta_2 = 0.50$.

Formula: volume $V = \text{area} \times \text{depth}$; hydraulic energy (kWh) = $\rho g V H / 3.6 \times 10^6$; input = hydraulic energy / η .

Substitution: $V = 10,000 \times 0.05 = 500 \text{ m}^3$; hydraulic = $1,000 \times 9.81 \times 500 \times 25 / 3.6 \times 10^6 = 34.06$ kWh; input₁ = $34.06 / 0.35 = 97.3$ kWh; input₂ = $34.06 / 0.50 = 68.1$ kWh.

Result: **saving ≈ 29.2 kWh per irrigation (30 %)**.

Why the others are wrong: (a) multiplies the hydraulic energy by the 15-point efficiency gap, which is not how input changes; (c) is the hydraulic energy itself; (d) is the old pump-set's input. Agricultural pumping is a large share of India's electricity use, so efficient pump-sets, proper suction pipes and foot valves offer big national savings.

Ref: BEE Guidebook Paper 3, Ch. 6 (6.6 Energy conservation opportunities in pumping systems).

28 A belt-driven centrifugal fan runs at 960 rpm with a 300 mm fan pulley and absorbs 38 kW. To reduce excess flow, the fan pulley is changed to 340 mm (motor pulley unchanged). The new fan speed and power are about:

[2P3CEM028 | Chapter 5: Fans and Blowers | 5.6 Fan speed change by pulley]

- a) 847 rpm and 29.6 kW
- b) 847 rpm and 33.5 kW
- c) 1,088 rpm and 55.3 kW
- d) 847 rpm and 26.1 kW**

Answer & explanation

Correct answer: (d) $\approx$ 847 rpm and 26.1 kW.

Given: $N_1 = 960$ rpm; fan pulley $d_1 = 300$ mm $\rightarrow d_2 = 340$ mm; $P_1 = 38$ kW.

Formula: $N_2 = N_1 \times d_1 / d_2$ (driven pulley larger $\rightarrow$ slower); fan law $P_2 = P_1 \times (N_2 / N_1)^3$.

Substitution: $N_2 = 960 \times 300 / 340 = 847$ rpm; $P_2 = 38 \times (0.8824)^3 = 38 \times 0.687$.

Result: $\approx$ **847 rpm and 26.1 kW** (saving $\approx$ 11.9 kW).

Why the others are wrong: (a) applies a square law to power; (b) applies a linear law; (c) wrongly assumes a larger fan pulley raises speed and then applies the cube law. Pulley change is a low-cost, permanent way to cut fan speed when flow is consistently in excess, unlike damper throttling.

Ref: BEE Guidebook Paper 3, Ch. 5 (5.6 Flow control strategies – pulley change; fan laws).

29 Over six years a cooling water pump's efficiency has fallen from 78 % to 66 %; at the same head it now delivers less flow while drawing similar power. The most probable cause is:

[2P3CEM029 | Chapter 6: Pumps and Pumping System | 6.5 Pump deterioration – internal wear]

- a) A rise in supply frequency that increases the pump speed
- b) A smaller system resistance due to a newly opened valve
- c) A higher suction head from a raised sump level
- d) Worn impeller and wear rings causing internal recirculation**

Answer & explanation

Correct answer: (d).

As the clearance between the impeller eye and casing wear rings increases through erosion and corrosion, part of the discharged water leaks back to the suction side and is pumped again. This internal recirculation reduces delivered flow at a given head while the shaft power stays nearly the same, so efficiency falls steadily. The guidebook recommends periodic performance testing against the original curve and restoring clearances, coating or replacing impellers when the loss of efficiency justifies the cost; savings of 5–15 % are common after such refurbishment.

Why the others are wrong: (a) higher speed would raise both flow and head along the affinity laws; (b) lower system resistance moves the pump to higher flow, not lower; (c) a higher sump level reduces the total head and improves flow and NPSH margin. Trending flow, head and kW over time reveals such deterioration early.

Ref: BEE Guidebook Paper 3, Ch. 6 (6.5 Assessment of pumps; 6.6 Energy conservation – maintenance).

30 Which one of these statements on transformer core and copper losses is NOT true?

[2P3CEM030 | Chapter 1: Electrical Systems | 1.5 Transformer losses – wrong statement]

- a) Copper (load) loss remains constant at all levels of loading**
- b) Core loss depends mainly on applied voltage and supply frequency
- c) Copper loss varies with the square of the load current carried
- d) Core loss is present whenever the transformer is kept energised

Answer & explanation

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

Copper (load or I^2R) loss depends on current, so it varies with the square of the per-unit load: at 50 % load it is only 25 % of the full-load value. It is the core (no-load) loss that is practically constant.

The other statements are correct: (b) core loss comprises hysteresis and eddy-current loss, which depend on flux density, i.e. on applied voltage and frequency; (c) copper loss = I^2R , hence $\propto (\text{load})^2$; (d) core loss occurs as long as the transformer is energised, even at no load, which is why lightly loaded or standby transformers should be switched off or why low-loss (amorphous) cores are justified for transformers energised round the clock.

Ref: BEE Guidebook Paper 3, Ch. 1 (1.5 Transformers).

31 A foundry uses compressed air hoses for floor cleaning and for cooling operators. The most energy-efficient corrective action recommended is:

[2P3CEM031 | Chapter 3: Compressed Air System | 3.7 Inappropriate use of compressed air]

- a) Raise the receiver capacity so that the hoses run longer
- b) Increase the compressor pressure setting to boost the airflow rate
- c) Replace these uses with a blower or fan of matching duty**
- d) Install larger diameter hoses to cut the pressure drop

Answer & explanation

Correct answer: (c).

Compressed air at 6–7 bar costs about seven to eight times the electricity of the same volume of low-pressure air because only a small fraction of compressor input becomes useful work. Uses such as cleaning, body cooling, agitation or drying need volume rather than pressure and are better met by a low-pressure blower or fan; the guidebook lists them as inappropriate uses to be eliminated. Where a nozzle must remain, engineered low-flow nozzles with automatic shut-off reduce consumption.

Why the others are wrong: (a) a larger receiver only smooths demand; it does not reduce the air wasted; (b) raising pressure increases both compressor power (about 6–10 % per bar) and the volume blown out, worsening waste; (d) larger hoses cut pressure drop but increase flow through open ends, so consumption rises.

Ref: BEE Guidebook Paper 3, Ch. 3 (3.7 Energy-efficiency practices – inappropriate uses).

32 In a cooling tower, hot water at 40 °C is cooled to 33.5 °C. The enthalpy of air rises from 18.5 kcal/kg at inlet to 26.0 kcal/kg at outlet. Taking the specific heat of water as 1 kcal/kg °C, the L/G ratio is about:

[2P3CEM032 | Chapter 7: Cooling Towers | 7.4 Liquid to gas ratio]

- a) 0.87
- b) 2.85
- c) 1.15**
- d) 4.00

Answer & explanation

Correct answer: (c) ≈ 1.15 .

Given: $T_1 = 40\text{ °C}$; $T_2 = 33.5\text{ °C}$; $h_1 = 18.5\text{ kcal/kg}$ ($\approx 77.5\text{ kJ/kg}$); $h_2 = 26.0\text{ kcal/kg}$ ($\approx 109\text{ kJ/kg}$); $c_p = 1\text{ kcal/kg °C}$ ($\approx 4.19\text{ kJ/kg·K}$).

Formula: heat lost by water = heat gained by air: $L \times c_p \times (T_1 - T_2) = G \times (h_2 - h_1)$, so $L/G = (h_2 - h_1) / (T_1 - T_2)$.

Substitution: $L/G = (26.0 - 18.5) / (40 - 33.5) = 7.5 / 6.5$.

Result: **$L/G \approx 1.15$** .

Why the others are wrong: (a) inverts the ratio (G/L); (b) uses the inlet air enthalpy instead of the enthalpy rise; (d) uses the outlet air enthalpy alone. Tower design fixes an L/G; if water flow is increased beyond design without more air, approach worsens, and if air is short (fan blades at low pitch), cooling suffers.

Ref: BEE Guidebook Paper 3, Ch. 7 (7.4 Performance – L/G ratio).

33 A screw compressor draws 132 kW while delivering 22.5 m³/min of free air. With electricity at ₹ 8/kWh, the cost of generating 1,000 m³ of free air is about:

[2P3CEM033 | Chapter 3: Compressed Air System | 3.4 Specific power and cost of compressed air]

- a) ₹ 782
- b) ₹ 7.8
- c) ₹ 46.9
- d) ₹ 869

Answer & explanation

Correct answer: (a) ≈ ₹ 782 per 1,000 m³.

Given: input power = 132 kW; FAD = 22.5 m³/min; tariff ₹ 8/kWh.

Formula: specific energy (kWh/m³) = kW / (m³/min × 60); cost = specific energy × 1,000 × tariff.

Substitution: hourly delivery = 22.5 × 60 = 1,350 m³/h; specific energy = 132 / 1,350 = 0.0978 kWh/m³; cost = 0.0978 × 1,000 × 8.

Result: ≈ **₹ 782 per 1,000 m³** (specific power 5.87 kW per m³/min).

Why the others are wrong: (b) is the cost of only 10 m³ (a factor-of-100 slip); (c) multiplies the specific power in kW per m³/min (5.87) by ₹ 8 without converting minutes to hours; (d) uses 1,215 m³/h (a 10 % lower FAD) by mistake. Knowing the cost per 1,000 m³ helps convince users that compressed air is one of the costliest utilities.

Ref: BEE Guidebook Paper 3, Ch. 3 (3.4 Compressor performance – specific power).

34 For prescribing envelope requirements, ECBC divides India into how many climate zones, and which group is correct?

[2P3CEM034 | Chapter 10: Energy Conservation in Buildings and ECBC | 10.2 ECBC – climate zones]

- a) Four: hot-dry, warm-humid, temperate and cold only
- b) Five: hot-dry, warm-humid, composite, temperate and cold**
- c) Six: hot-dry, warm-humid, composite, temperate, cold, alpine
- d) Five: tropical, arid, coastal, upland and polar zones

Answer & explanation

Correct answer: (b).

ECBC uses the National Building Code climate classification of five zones: hot-dry (e.g. Ahmedabad, Jodhpur), warm-humid (e.g. Mumbai, Chennai, Kolkata), composite (e.g. Delhi, Nagpur), temperate (e.g. Bengaluru, Pune) and cold (e.g. Shimla, Srinagar). Envelope requirements, such as maximum roof and wall U-factors and fenestration SHGC, differ by zone, because cooling and heating needs differ. For example, warm-humid zones focus on solar gain and dehumidification, while cold zones emphasise insulation and solar heat gain in winter.

Why the others are wrong: (a) omits the composite zone; (c) adds a non-existent alpine zone (cold covers high-altitude areas); (d) uses names that are not part of the Indian classification. Knowing the zone is the first step in applying ECBC prescriptive tables during design or audit.

Ref: BEE Guidebook Paper 3, Ch. 10 (10.2 ECBC – climate zones).

35 Under IS 12615 (based on IEC 60034-30), which IE efficiency class represents a higher efficiency than IE2 but lower than IE4?

[2P3CEM035 | Chapter 2: Electrical Motors | 2.7 Energy-efficient motors – IE classes]

- a) IE1 (standard efficiency)
- b) IE0 (basic efficiency)
- c) IE3 (premium efficiency)**
- d) IE5 (ultra-premium efficiency)

Answer & explanation

Correct answer: (c).

IS 12615 aligns with the IEC 60034-30 classification of low-voltage induction motor efficiency: IE1 standard, IE2 high, IE3 premium and IE4 super-premium efficiency (IE5 ultra-premium is defined in later editions for future motor technologies). So the class between IE2 and IE4 is IE3. Higher classes achieve lower losses by using more and better active material (copper, low-loss lamination steel), optimised air gaps and improved fan design, typically 2–4 percentage points better than standard motors in medium ratings.

Why the others are wrong: (a) IE1 is the lowest commercial class, below IE2; (b) there is no IE0 class in the standard; (d) IE5 lies above IE4, not between IE2 and IE4. When replacing motors, an auditor compares life-cycle cost because energy forms over 90 % of a motor's lifetime cost.

Ref: BEE Guidebook Paper 3, Ch. 2 (2.7 Energy-efficient motors).

36 A unit billed on kVAh at ₹ 7.50/kVAh consumes 1,20,000 kWh a month at an average PF of 0.86. If APFC panels raise the average PF to 0.98, the monthly saving in energy charges is about:

[2P3CEM036 | Chapter 1: Electrical Systems | 1.2 Electricity billing – kVAh tariff]

- a) ₹ 1,08,000
- b) ₹ 1,46,512
- c) ₹ 9,18,367
- d) ₹ 1,28,144**

Answer & explanation

Correct answer: (d) ≈ ₹ 1,28,144 per month.

Given: 1,20,000 kWh/month; $PF_1 = 0.86$; $PF_2 = 0.98$; tariff ₹ 7.50/kVAh.

Formula: $kVAh = kWh / PF$; saving = $(kVAh_1 - kVAh_2) \times \text{tariff}$.

Substitution: $kVAh_1 = 1,20,000 / 0.86 = 1,39,535$; $kVAh_2 = 1,20,000 / 0.98 = 1,22,449$; difference = 17,086 kVAh; saving = $17,086 \times 7.50$.

Result: ≈ **₹ 1,28,144 per month (≈ ₹ 15.4 lakh per year)**.

Why the others are wrong: (a) multiplies kWh by the PF difference (0.12), which is not how kVAh is computed; (b) is the extra cost at 0.86 relative to unity PF, not the gain from 0.86 to 0.98; (c) is the new monthly bill at 0.98, not the saving. Under kVAh billing every lagging kVAh is effectively paid for, so PF improvement saves energy charges directly.

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

37 A 30 kW motor on a press runs most of the shift at about 25 % load. Operating it permanently in star connection is recommended because:

[2P3CEM037 | Chapter 2: Electrical Motors | 2.5 Star-delta operation at light load]

- a) Star connection raises the motor's rated output by about 73 %
- b) Reduced voltage lowers core and magnetising losses at light load**
- c) Star connection eliminates friction and windage losses entirely
- d) Phase current in star is always three times the delta value

Answer & explanation

Correct answer: (b).

In star connection each winding receives $1/\sqrt{3}$ of line voltage, so flux falls to about 58 %. Core (iron) loss, roughly proportional to the square of voltage, drops to about one-third, and magnetising current falls, improving power factor. At light loads (typically below 30–40 %), this reduction outweighs the small rise in load current, so efficiency and PF improve. The motor's maximum torque in star is only one-third of that in delta, so this is applied only where the load stays light, often with an automatic star-delta-star controller.

Why the others are wrong: (a) star connection reduces available output; it never raises rating; (c) friction and windage depend on speed, which barely changes; (d) line current in star is one-third of delta line current for the same voltage; the relationship is reversed and not a benefit.

Ref: BEE Guidebook Paper 3, Ch. 2 (2.5 Energy-saving opportunities – operating in star mode).

38 An office has 80 luminaires of 40 W each, used 3,000 h/year. Occupancy sensors cut burning hours by 30 %; then daylight sensors dim 40 % of the luminaires to half power for all their remaining hours. The total annual saving is about:

[2P3CEM038 | Chapter 8: Lighting System | 8.6 Lighting controls – occupancy and daylight]

- a) 4,224 kWh**
- b) 3,840 kWh
- c) 4,800 kWh
- d) 5,376 kWh

Answer & explanation

Correct answer: (a) $\approx 4,224$ kWh/year.

Given: 80×40 W = 3.2 kW; 3,000 h/year; occupancy saving 30 % of hours; daylight dimming of 40 % of luminaires to 50 % power.

Formula: savings applied in sequence: $E_1 = \text{base} \times (1 - 0.30)$; daylight saving = $E_1 \times 0.40 \times 0.50$.

Substitution: base = $3.2 \times 3,000 = 9,600$ kWh; $E_1 = 6,720$ kWh (saving 2,880 kWh); daylight saving = $6,720 \times 0.20 = 1,344$ kWh; total = $2,880 + 1,344$.

Result: **saving $\approx 4,224$ kWh/year (44 %)**; new use 5,376 kWh.

Why the others are wrong: (b) takes 40 % of base use, treating daylight fittings as switched off; (c) adds 30 % and 20 % of the base, ignoring that the second measure acts on the reduced hours; (d) is the remaining consumption, not the saving. Combined control savings must always be applied sequentially to avoid double counting.

Ref: BEE Guidebook Paper 3, Ch. 8 (8.6 Energy-saving opportunities – lighting controls).

39 While replacing an old R-22 chiller, an auditor compares refrigerants. Which statement about R-22 is correct?

[2P3CEM039 | Chapter 4: HVAC and Refrigeration System | 4.4 Refrigerants – environmental properties]

- a) It is an HFC with zero ozone depletion and very low global warming
- b) It is a natural refrigerant with zero ozone and zero warming impact
- c) It is a CFC with the highest ozone depletion of all refrigerants
- d) It is an HCFC with some ozone depletion potential, being phased out**

Answer & explanation

Correct answer: (d).

R-22 (chlorodifluoromethane) is a hydrochlorofluorocarbon (HCFC). Its chlorine gives it a small but non-zero ozone depletion potential (about 0.05, against 1.0 for R-11), and it also has a significant global warming potential (about 1,800). Under the Montreal Protocol, HCFCs are being phased out in India, so replacements such as R-134a, R-410A, R-32, HFOs or natural refrigerants are selected considering efficiency, GWP and safety.

Why the others are wrong: (a) describes an HFC; HFCs have zero ODP but generally high, not very low, GWP; (b) natural refrigerants are ammonia, CO₂ and hydrocarbons, not R-22; (c) CFCs such as R-11 and R-12 have the highest ODP; R-22 is an HCFC with much lower ODP. Replacement projects should also compare kW/TR, because energy use usually dominates life-cycle emissions.

Ref: BEE Guidebook Paper 3, Ch. 4 (4.4 Types of refrigerants).

40 Two identical centrifugal pumps, each giving 30 m head at 100 m³/h, are connected in series in a system with negligible friction change. Their combined characteristic at 100 m³/h gives:

[2P3CEM040 | Chapter 6: Pumps and Pumping System | 6.4 Pumps in series]

- a) About 30 m head at double the flow of 200 m³/h
- b) About 60 m head at the same flow of 100 m³/h**
- c) About 60 m head at double the flow of 200 m³/h
- d) About 15 m head at half the flow of 50 m³/h

Answer & explanation

Correct answer: (b).

In series, the same flow passes through both pumps one after the other, so the combined curve is obtained by adding heads at each flow. At 100 m³/h each pump adds 30 m, giving about 60 m. Series operation is used where a high head is needed, for example multi-stage boiler feed pumps or booster pumps in long pipelines; the actual operating point is the intersection of this combined curve with the system curve.

Why the others are wrong: (a) describes parallel operation, where flows add at the same head (and the real gain is less than double because system resistance rises with flow); (c) wrongly adds both head and flow; (d) has no basis in pump combination laws. Pumps in series must handle higher casing pressure in the second unit, and the guidebook advises checking the second pump's pressure rating.

Ref: BEE Guidebook Paper 3, Ch. 6 (6.4 Pump curves – series and parallel operation).

41 A spot luminaire of luminous intensity 1,500 cd in the relevant direction is 3 m from a point on a display surface. The light strikes the surface at 30° from its normal. The illuminance at the point is about:

[2P3CEM041 | Chapter 8: Lighting System | 8.2 Illuminance – inverse square and cosine law]

- a) 144 lux**
- b) 83.3 lux
- c) 167 lux
- d) 433 lux

Answer & explanation

Correct answer: (a) ≈ 144 lux.

Given: $I = 1,500$ cd; distance $d = 3$ m; angle of incidence $\theta = 30^\circ$ from the normal.

Formula: $E = I \times \cos \theta / d^2$ (inverse square law combined with Lambert's cosine law).

Substitution: $E = 1,500 \times \cos 30^\circ / 3^2 = 1,500 \times 0.866 / 9$.

Result: **$E \approx 144 \text{ lux}$** .

Why the others are wrong: (b) uses $\sin 30^\circ$ (0.5) instead of $\cos 30^\circ$; (c) ignores the angle of incidence (normal-incidence value $1,500 / 9$); (d) divides by distance instead of distance squared. These laws explain why doubling mounting height cuts illuminance to one-quarter and why task lighting close to the work plane can save energy compared with raising general lighting levels.

Ref: BEE Guidebook Paper 3, Ch. 8 (8.2 Basic terms in lighting – laws of illumination).

42 An evaporative condenser on an ammonia cold store is preferred over an air-cooled condenser mainly because:

[2P3CEM042 | Chapter 4: HVAC and Refrigeration System | 4.2 Condensers – evaporative condensers]

- a) Condensing temperature tracks dry bulb, raising compressor power
- b) It needs no make-up water or any water treatment
- c) Condensing temperature tracks wet bulb, cutting compressor power**
- d) Refrigerant can condense below the ambient wet bulb

Answer & explanation

Correct answer: (c).

In an evaporative condenser, water sprayed over the refrigerant coil evaporates into the air stream, so heat rejection is limited by the ambient wet-bulb temperature, which in India is often 8–12 °C below the dry bulb. The condensing temperature, and hence head pressure, is therefore lower than with an air-cooled condenser, which depends on dry bulb. The guidebook notes that each 1 °C reduction in condensing temperature saves roughly 2–3 % of compressor power.

Why the others are wrong: (a) describes air-cooled condensers; (b) evaporative condensers need make-up water and treatment to control scaling and bacteria; (d) condensation can approach but never fall below the wet-bulb temperature, because a temperature difference is needed for heat transfer. Keeping coils clean and water treated preserves the advantage.

Ref: BEE Guidebook Paper 3, Ch. 4 (4.2 Vapour compression refrigeration – condensers).

43 A dairy's 500 kVA unit has core losses of 1.2 kW and rated-load copper losses of 6.0 kW. Daily duty at 0.9 PF: 8 h at 80 % loading, 10 h at 40 % loading and 6 h energised on no load. What is its energy (all-day) efficiency?

[2P3CEM043 | Chapter 1: Electrical Systems | 1.5 Transformers – all-day (energy) efficiency]

- a) 98.54 %**
- b) 98.09 %
- c) 98.69 %
- d) 99.39 %

Answer & explanation

Correct answer: (a) 98.54 %.

Given: 500 kVA; core loss 1.2 kW (all 24 h); full-load copper loss 6.0 kW; PF 0.9; 80 % × 8 h, 40 % × 10 h, 0 % × 6 h.

Formula: all-day efficiency = output kWh / (output kWh + core loss kWh + copper loss kWh); copper loss at fraction $x = x^2 \times$ full-load copper loss.

Substitution: output = $500 \times 0.8 \times 0.9 \times 8 + 500 \times 0.4 \times 0.9 \times 10 = 2,880 + 1,800 = 4,680 \text{ kWh}$; core = $1.2 \times 24 = 28.8 \text{ kWh}$; copper = $6.0 \times 0.64 \times 8 + 6.0 \times 0.16 \times 10 = 30.72 + 9.60 = 40.32 \text{ kWh}$; $\eta = 4,680 / (4,680 + 69.12)$.

Result: **all-day efficiency $\approx 98.54 \%$** (daily loss 69.1 kWh).

Why the others are wrong: (b) takes copper loss proportional to load, not load squared; (c) counts core loss for only the 18 loaded hours; (d) ignores copper loss.

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

44 A ventilation duct system has a resistance of 120 mmWC at 40,000 m³/h. If the flow is reduced to 32,000 m³/h with no change in the system, the system resistance becomes about:

[2P3CEM044 | Chapter 5: Fans and Blowers | 5.4 System characteristic – resistance at reduced flow]

- a) 43.2 mmWC
- b) 61.4 mmWC
- c) 96.0 mmWC
- d) 76.8 mmWC**

Answer & explanation

Correct answer: (d) $\approx$ 76.8 mmWC.

Given: $\Delta P_1 = 120$ mmWC (≈ 1.18 kPa) at $Q_1 = 40,000$ m³/h; $Q_2 = 32,000$ m³/h.

Formula: system resistance varies with the square of flow: $\Delta P_2 = \Delta P_1 \times (Q_2 / Q_1)^2$.

Substitution: $\Delta P_2 = 120 \times (32,000 / 40,000)^2 = 120 \times 0.64$.

Result: **$\Delta P_2 \approx 76.8$ mmWC (≈ 753 Pa).**

Why the others are wrong: (a) is the reduction in resistance (120 – 76.8), not the new value; (b) applies the cube law (0.512), which governs power, not pressure; (c) assumes resistance falls in proportion to flow. The system curve, plotted with the fan curve, fixes the operating point; when flow falls by speed reduction, fan pressure falls along the same square law, which is why VFDs save so much on such systems.

Ref: BEE Guidebook Paper 3, Ch. 5 (5.4 Fan performance and system characteristics).

45 A plant with several large VFDs plans a PF correction panel. Why does the guidebook practice favour capacitors with series (detuning) reactors rather than plain capacitors?

[2P3CEM045 | Chapter 1: Electrical Systems | 1.10 Harmonics – detuned capacitor banks]

- a) To raise the kVAr output above the capacitor nameplate value
- b) To remove the need for any automatic switching of capacitor steps
- c) To avoid resonance and harmonic overload of the capacitors**
- d) To convert harmonic currents into useful active power at the load

Answer & explanation

Correct answer: (c).

Plain capacitors form a parallel resonant circuit with the supply (transformer) inductance. If the resonant frequency is near a harmonic produced by drives (typically the 5th or 7th), harmonic currents are amplified, capacitors overheat, fuses blow and voltage distortion rises. A series reactor (typically 7 % detuning) shifts the resonance of each step below the 5th harmonic, so the bank behaves inductively at harmonic frequencies, protecting the capacitors while still correcting the fundamental PF.

Why the others are wrong: (a) a series reactor slightly raises the voltage across the capacitor but the purpose is not extra kVAr; capacitors of higher voltage rating are used for this reason; (b) APFC switching of steps is still required to follow load; (d) harmonics cannot be converted into active power; filters only divert or absorb them.

Ref: BEE Guidebook Paper 3, Ch. 1 (1.10 Harmonics; 1.4 PF improvement).

46 Which measure saves energy in lifts and escalators of a commercial building as described for building services?

- a) Running all escalators at full speed through the night
- b) Regenerative VVVF drives with sleep mode when idle**
- c) Replacing VVVF drives with two-speed AC motor control
- d) Keeping car lights and fans on in idle parked lifts

Answer & explanation

Correct answer: (b).

Variable-voltage variable-frequency (VVVF) drives give smooth acceleration with lower starting current than older two-speed or AC resistance drives. With regenerative units, energy released when a loaded car descends or an empty car rises (counterweight heavier) is fed back to the building network instead of being burnt in braking resistors, typically saving 20–35 % of lift energy. For escalators, slow-speed or stop mode when no passenger is sensed, and for lifts, automatic switching off of car lights and fans when idle, give further savings. Group control logic also reduces unnecessary trips.

Why the others are wrong: (a) running escalators empty at night wastes energy; (c) two-speed control is less efficient than VVVF; (d) idle car lighting and fans waste energy continuously. These measures are simple to specify in new buildings and retrofits.

Ref: BEE Guidebook Paper 3, Ch. 10 (10.4 Energy conservation in building services).

47 During winter nights the cold-water temperature from a multi-cell cooling tower falls well below what the chillers need. The most energy-efficient response is to:

- a) Reduce fan speed or switch fans off based on cold-water temperature**
- b) Run all fans at full speed and bypass water around the fill
- c) Increase circulating water flow so the fans run at full load
- d) Close the make-up valve so the basin level drops lower

Answer & explanation

Correct answer: (a).

Cooling-tower fan power is needed only to achieve the required cold-water temperature. When ambient wet bulb falls, the same duty is met with less air, so fans can be cycled off cell by cell, run on two-speed motors or controlled by VFDs from a cold-water temperature sensor. Fan power falls roughly with the cube of speed, so even modest speed reductions save substantially, and automatic control (thermostat or controller) avoids operator neglect. The chiller's minimum condenser water temperature limit must still be respected.

Why the others are wrong: (b) running fans flat out while bypassing water wastes fan energy; (c) extra water flow raises pump energy with no benefit; (d) low basin level risks pump cavitation and does not control temperature. The guidebook lists automatic fan control as a key cooling tower energy measure.

Ref: BEE Guidebook Paper 3, Ch. 7 (7.5 Energy-saving opportunities in cooling towers).

48 A natural gas engine generator in a hospital supplies power and, through heat recovery, also hot water and chilled water. Its overall fuel utilisation can reach 70–80 % mainly because:

- a) Gas engines convert nearly 80 % of fuel energy into electricity
- b) Natural gas has a far higher calorific value than any liquid fuel
- c) Jacket water and exhaust heat drive heating and absorption cooling**

d) Absorption chillers produce electricity from the exhaust gas flow

Answer & explanation

Correct answer: (c).

A reciprocating gas engine converts only about 35–42 % of fuel energy into electricity; the rest leaves as heat in jacket cooling water (about 80–90 °C), lube oil coolers and exhaust gas (about 400–500 °C). In tri-generation, jacket water heats service water and the exhaust drives a vapour absorption chiller or a heat recovery steam generator, so useful power plus recovered heat and cooling reach 70–80 % of fuel input. This avoids separate boiler fuel and electric chiller power and reduces grid demand.

Why the others are wrong: (a) electrical efficiency of engines is far lower than 80 %; (b) on a mass basis natural gas has a somewhat higher calorific value than diesel, but this does not explain high overall utilisation; (d) absorption chillers produce chilled water using heat, not electricity. Tri-generation pays best where heating and cooling demands are steady and coincide with power demand.

Ref: BEE Guidebook Paper 3, Ch. 9 (9.2 Gas-based power generation and cogeneration).

49 A 50 kVAr capacitor bank rated at 440 V is connected to a 415 V bus. Its effective reactive output at 415 V is about:

[2P3CEM049 | Chapter 1: Electrical Systems | 1.4 Capacitor output at reduced voltage]

a) 47.2 kVAr

b) 50.0 kVAr

c) 56.2 kVAr

d) 44.5 kVAr

Answer & explanation

Correct answer: (d) ≈ 44.5 kVAr.

Given: rated output $Q_r = 50$ kVAr at $V_r = 440$ V; operating voltage $V = 415$ V.

Formula: capacitor kVAr $= V^2 / X_c$ (X_c fixed at constant frequency), so $Q = Q_r \times (V / V_r)^2$.

Substitution: $Q = 50 \times (415 / 440)^2 = 50 \times 0.8896$.

Result: ≈ 44.5 kVAr, about 11 % below nameplate.

Why the others are wrong: (a) scales output linearly with voltage; (b) assumes nameplate output regardless of voltage; (c) inverts the ratio. Higher-voltage-rated capacitors are often chosen for longer life where harmonics or overvoltage exist, but the bank must then be oversized to deliver the required kVAr at the actual bus voltage.

Ref: BEE Guidebook Paper 3, Ch. 1 (1.4 Power factor improvement – capacitor selection).

50 A hotel with boiler steam available at 9 kg/cm²g is choosing between LiBr absorption chiller designs. Opting for the double-effect type means the machine:

[2P3CEM050 | Chapter 4: HVAC and Refrigeration System | 4.5 Vapour absorption – double-effect machines]

a) Needs higher-pressure steam but gives a much higher COP

b) Runs on low-grade hot water with a lower COP

c) Uses ammonia as refrigerant and water as the absorbent

d) Needs a mechanical compressor in addition to the generator

Answer & explanation

Correct answer: (a).

A double-effect LiBr–water absorption chiller has two generators. Vapour from the high-temperature generator, heated by steam at about 8–10 kg/cm²g (or by direct firing or hot exhaust), is used to heat the low-temperature generator, so the input heat is used twice. Its COP is about 1.1–1.3, against about 0.6–0.7 for single-effect machines driven by low-pressure steam or hot water. Hence double-effect units suit sites with medium-pressure steam or high-temperature waste heat.

Why the others are wrong: (b) describes a single-effect machine, which can run on hot water at about 85–95 °C; (c) ammonia–water systems exist for sub-zero temperatures, but LiBr machines use water as refrigerant and LiBr as absorbent; (d) absorption machines replace the compressor with the absorber–generator pair and need only small pumps.

Ref: BEE Guidebook Paper 3, Ch. 4 (4.5 Vapour absorption refrigeration).

..... 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 An engineering works has an HT contract demand (CD) of 2,000 kVA. Its recorded monthly maximum demands (kVA) over the last year were:

Month	Apr	May	Jun	Jul	Aug	Sep
MD (kVA)	1,480	1,520	1,610	1,690	1,720	1,650
Month	Oct	Nov	Dec	Jan	Feb	Mar
MD (kVA)	1,580	1,540	1,600	1,660	1,700	1,560

Tariff: billing demand is the higher of the recorded MD or 85 % of CD, charged at ₹ 420 per kVA per month. Any demand above CD is charged an additional ₹ 420 per kVA for the excess (i.e. at double rate). Assume the load pattern will repeat.

- (a) Annual demand charges at the present CD of 2,000 kVA. (2 Marks)
- (b) Annual demand charges if CD is reduced to 1,750 kVA. (1.5 Marks)
- (c) Annual demand charges if CD is reduced to 1,650 kVA. (1 Mark)
- (d) Recommend the CD with justification. (0.5 Mark)

[2P3CEM051 | Chapter 1: Electrical Systems | 1.3 Contract demand optimisation from a 12-month MD record]

S-1 – Model answer (5 marks)

Given: 12 monthly MD values (kVA) as tabulated; sum of MD = 19,310 kVA-months; highest MD = 1,720 kVA; demand rate ₹ 420/kVA/month; minimum billing = 85 % of CD; excess over CD billed at an additional ₹ 420/kVA.

(a) Present CD = 2,000 kVA (2 Marks)

Formula: Billing demand (each month) = max (MD, 0.85 × CD) + excess penalty where MD > CD

Substitution: 0.85 × 2,000 = 1,700 kVA. Only August (1,720 kVA) exceeds 1,700; every other month is billed at 1,700 kVA. No month exceeds 2,000 kVA, so no penalty.

Annual billed kVA = 11 × 1,700 + 1,720 = 20,420 kVA-months (1 Mark)

Result: **Annual demand charges = 20,420 × 420 = ₹ 85,76,400** (1 Mark)

(b) CD = 1,750 kVA (1.5 Marks)

Minimum billing = $0.85 \times 1,750 = 1,487.5$ kVA; only April (1,480) is below it and is billed at 1,487.5 kVA. Highest MD $1,720 < 1,750$, so no excess penalty. (0.5 Mark)

Annual billed kVA = $19,310 - 1,480 + 1,487.5 = 19,317.5$ kVA-months (0.5 Mark)

Result: **Annual demand charges = $19,317.5 \times 420 = ₹ 81,13,350$** (0.5 Mark)

(c) CD = 1,650 kVA (1 Mark)

Minimum billing = $0.85 \times 1,650 = 1,402.5$ kVA (all months exceed it), so billed kVA = 19,310 kVA-months.

Excess over 1,650 kVA: Jul 40 + Aug 70 + Jan 10 + Feb 50 = 170 kVA-months, charged an additional ₹ 420/kVA.

Result: **Annual demand charges = $(19,310 + 170) \times 420 = ₹ 81,81,600$** (1 Mark)

(d) Recommendation (0.5 Mark)

Result: **Recommend CD = 1,750 kVA: saving ₹ 85,76,400 – ₹ 81,13,350 = ₹ 4,63,050 per year.** Going down to 1,650 kVA costs ₹ 68,250 more than 1,750 kVA because of excess-demand penalties, and leaves no margin for load growth. MD control (load scheduling, demand controller) should be used to keep the monthly peak below 1,750 kVA.

Marking: (a) 1 for billed kVA + 1 for amount; (b) 0.5×3 ; (c) 1; (d) 0.5.

S-2 A 45 kW, 415 V, 4-pole, delta-connected induction motor driving a blower was tested. Stator resistance (per phase, as measured for the delta winding at operating temperature) is 0.12Ω .

Test	Input power	Phase current	Other data
No-load test	1,900 W	18 A	Friction and windage loss estimated at 400 W
Load test	41.5 kW	70 A	Slip 2.0 %

Assume stray load loss = 0.5 % of input. Determine:

- (a) Core loss from the no-load test. (1 Mark)
- (b) Stator copper loss, air-gap power and rotor copper loss at the load point. (2 Marks)
- (c) Output power and efficiency at the load point. (1.5 Marks)
- (d) Percentage loading of the motor. (0.5 Mark)

[2P3CEM052 | Chapter 2: Electrical Motors | 2.4 Motor loss segregation from no-load and load tests]

S-2 – Model answer (5 marks)

Given: $R = 0.12 \Omega$ per phase; no-load input 1,900 W at 18 A; friction and windage (F&W) = 400 W; load input 41,500 W at 70 A; slip $s = 0.02$; stray = 0.5 % of input; rating 45 kW.

(a) Core loss (1 Mark)

Formula: core loss = no-load input – no-load stator copper loss – F&W; stator copper loss = $3 I^2 R$

Substitution: no-load stator copper loss = $3 \times 18^2 \times 0.12 = 116.6$ W; core loss = $1,900 - 116.6 - 400$

Result: **Core loss $\approx 1,383$ W (1.38 kW)**

(b) Load-point losses (2 Marks)

Stator copper loss = $3 \times 70^2 \times 0.12 = 1,764$ W (0.5 Mark)

Air-gap power = input – stator copper loss – core loss = $41,500 - 1,764 - 1,383.4 = 38,352.6$ W (0.75 Mark)

Rotor copper loss = $s \times$ air-gap power = $0.02 \times 38,352.6 = 767.1$ W (0.75 Mark)

(c) Output and efficiency (1.5 Marks)

Stray load loss = $0.005 \times 41,500 = 207.5$ W

Total losses = 1,764 + 1,383.4 + 767.1 + 400 + 207.5 = 4,522 W

Formula: output = input – total losses; η = output / input $\times$ 100

Substitution: output = 41,500 – 4,522 = 36,978 W; η = 36,978 / 41,500 $\times$ 100

Result: **Output $\approx$ 36.98 kW; efficiency $\approx$ 89.1 %**

(d) Loading (0.5 Mark)

Result: **Loading = 36.98 / 45 $\times$ 100 $\approx$ 82.2 %**

Comment: the segregation shows fixed losses (core + F&W $\approx$ 1.78 kW) and variable losses ($\approx$ 2.74 kW); the efficiency of 89.1 % is below the IE3 level for 45 kW, so replacement can be evaluated.

Marking: (a) 1; (b) 0.5 + 0.75 + 0.75; (c) 0.5 losses + 0.5 output + 0.5 η ; (d) 0.5.

S-3 In a textile spinning mill, four open compressed-air hoses are used for continuous machine cleaning, each consuming 0.75 m³/min of free air at 6 kg/cm²g. The compressor plant's specific power is 6.4 kW per m³/min. A centrifugal blower system (5.5 kW input) with ducted nozzles can do the same cleaning duty. The mill runs 6,000 h/year; electricity costs ₹ 8/kWh; the blower system costs ₹ 1,50,000 installed.

(a) Power and annual energy cost of the present practice. (2 Marks)

(b) Annual energy and cost savings with the blower. (2 Marks)

(c) Simple payback period. (1 Mark)

[2P3CEM053 | Chapter 3: Compressed Air System | 3.7 Replacing compressed air cleaning with a blower]

S-3 – Model answer (5 marks)

Given: 4 hoses $\times$ 0.75 m³/min; specific power 6.4 kW per m³/min; blower 5.5 kW; 6,000 h/year; ₹ 8/kWh; investment ₹ 1,50,000.

(a) Present practice (2 Marks)

Formula: compressor power attributable = air flow $\times$ specific power

Substitution: air flow = 4 $\times$ 0.75 = 3.0 m³/min; power = 3.0 $\times$ 6.4 = 19.2 kW (1 Mark)

Annual energy = 19.2 $\times$ 6,000 = 1,15,200 kWh

Result: **Annual cost = 1,15,200 $\times$ 8 = ₹ 9,21,600** (1 Mark)

(b) Savings with blower (2 Marks)

Blower energy = 5.5 $\times$ 6,000 = 33,000 kWh/year (0.5 Mark)

Energy saving = 1,15,200 – 33,000 = 82,200 kWh/year (0.75 Mark)

Result: **Cost saving = 82,200 $\times$ 8 = ₹ 6,57,600 per year** (0.75 Mark)

(c) Payback (1 Mark)

Formula: SPP = investment / annual saving

Substitution: 1,50,000 / 6,57,600 = 0.23 year

Result: **Payback $\approx$ 0.23 year (about 2.7 months)**

Note: compressed air delivers only a small fraction of compressor input as useful work; cleaning, cooling and agitation needing volume rather than pressure should use blowers. With the hoses removed, the compressor load falls and one machine may be stopped or kept as standby.

Marking: (a) 1 + 1; (b) 0.5 + 0.75 + 0.75; (c) 1.

S-4 A cement mill bag-house fan handles 30 m³/s. Because of choked filter bags the total system resistance has risen to 420 mmWC. After installing an improved pulse-jet cleaning system, the resistance is brought down to 350 mmWC at the same flow; the fan speed is reduced by its VFD to deliver the same flow at this lower pressure. Fan efficiency

70 % and motor efficiency 93 % may be taken as unchanged. Operating hours are 7,000 per year and the tariff is ₹ 8.50/kWh. (Take 1 mmWC = 9.81 Pa.)

(a) Fan input power before and after. (3 Marks)

(b) Annual energy and cost saving. (2 Marks)

[2P3CEM054 | Chapter 5: Fans and Blowers | 5.5 Fan energy saving from reduced system resistance (bag filter)]

S-4 – Model answer (5 marks)

Given: $Q = 30 \text{ m}^3/\text{s}$; $\Delta P_1 = 420 \text{ mmWC}$ ($\approx 4.12 \text{ kPa}$); $\Delta P_2 = 350 \text{ mmWC}$ ($\approx 3.43 \text{ kPa}$); $\eta_{\text{fan}} = 0.70$; $\eta_{\text{motor}} = 0.93$; 7,000 h/year; ₹ 8.50/kWh.

(a) Input power (3 Marks)

Formula: motor input (kW) = $Q \times \Delta P \text{ (Pa)} / (1,000 \times \eta_{\text{fan}} \times \eta_{\text{motor}})$

Before: $\Delta P_1 = 420 \times 9.81 = 4,120 \text{ Pa}$; air power = $30 \times 4,120 / 1,000 = 123.6 \text{ kW}$ (0.75 Mark)

Substitution: $\text{input}_1 = 123.6 / (0.70 \times 0.93)$ (0.75 Mark)

Result: **Input before $\approx 189.9 \text{ kW}$**

After: $\Delta P_2 = 350 \times 9.81 = 3,433.5 \text{ Pa}$; air power = $30 \times 3,433.5 / 1,000 = 103.0 \text{ kW}$ (0.75 Mark)

Result: **Input after $\approx 158.2 \text{ kW}$** (0.75 Mark)

(b) Savings (2 Marks)

Power saving = $189.9 - 158.2 = 31.6 \text{ kW}$ (0.5 Mark)

Annual energy saving = $31.6 \times 7,000 \approx 2,21,516 \text{ kWh}$ (0.75 Mark)

Result: **Annual cost saving $\approx 2,21,516 \times 8.50 = ₹ 18,82,887$** (0.75 Mark)

Note: the 70 mmWC (686.7 Pa) reduction is 16.7 % of system resistance and, at constant flow, saves the same 16.7 % of fan power because power is proportional to pressure. Monitoring filter ΔP and cleaning on condition sustains the saving.

Marking: as indicated against each step.

S-5 A municipal corporation operates 1,200 street lights, each a 150 W HPSV lamp with a 20 W ballast loss, burning 12 hours every night (365 nights). It proposes 70 W LED luminaires with a timer-based dimming scheme: full power for the first 6 hours and 50 % power for the remaining 6 hours. Each LED luminaire costs ₹ 9,500 installed. Tariff: ₹ 7.50/kWh. Grid emission factor: 0.82 t CO₂/MWh.

(a) Annual energy use before and after. (2 Marks)

(b) Annual energy and cost savings. (1 Mark)

(c) Simple payback period. (1 Mark)

(d) Annual CO₂ reduction. (1 Mark)

[2P3CEM055 | Chapter 8: Lighting System | 8.6 Street lighting retrofit with LED and dimming]

S-5 – Model answer (5 marks)

Given: 1,200 lights; HPSV 150 W + 20 W ballast = 170 W; 12 h $\times$ 365 = 4,380 h/year; LED 70 W, 6 h at 100 % + 6 h at 50 %; ₹ 9,500 each; ₹ 7.50/kWh; 0.82 t CO₂/MWh.

(a) Annual energy (2 Marks)

Formula: energy = number $\times$ watts $\times$ hours / 1,000

Before: $1,200 \times 170 \times 4,380 / 1,000 = 8,93,520 \text{ kWh/year}$ (1 Mark)

After: equivalent full-power hours = $6 + 6 \times 0.5 = 9 \text{ h/night}$; $1,200 \times 70 \times 9 \times 365 / 1,000 = 2,75,940 \text{ kWh/year}$ (1 Mark)

(b) Savings (1 Mark)

Energy saving = $8,93,520 - 2,75,940 = 6,17,580 \text{ kWh/year}$ (69 %)

Result: **Cost saving = $6,17,580 \times 7.50 = ₹ 46,31,850 \text{ per year}$**

(c) Payback (1 Mark)

Investment = $1,200 \times 9,500 = ₹ 1,14,00,000$ (₹ 1.14 crore)

Result: **Payback = $1,14,00,000 / 46,31,850 \approx 2.46 \text{ years}$**

(d) CO₂ reduction (1 Mark)

Substitution: $6,17,580 \text{ kWh} = 617.58 \text{ MWh}$; 617.58×0.82

Result: **$\approx 506 \text{ t CO}_2 \text{ per year}$**

Note: maintenance savings (longer LED life, no lamp replacement) further improve the payback; ensure luminaires meet the required road lux levels and uniformity.

Marking: (a) 1 + 1; (b) 0.5 + 0.5; (c) 1; (d) 1.

S-6 A single-storey air-conditioned retail building has a flat RCC roof of $2,000 \text{ m}^2$ with a U-value of $2.0 \text{ W/m}^2\text{K}$. Adding insulation (cost ₹ 900 per m^2 laid) will bring the U-value to $0.4 \text{ W/m}^2\text{K}$. Take the average roof-to-indoor temperature difference during cooling hours as 18 K , cooling hours as $2,600$ per year, plant specific power as 1.0 kW/TR and tariff ₹ 9/kWh.

(a) Roof heat gain before and after insulation, and reduction in TR. (2 Marks)

(b) Annual electricity and cost savings. (2 Marks)

(c) Simple payback period. (1 Mark)

[2P3CEM056 | Chapter 10: Energy Conservation in Buildings and ECBC | 10.3 Roof insulation – heat gain, cooling energy and payback]

S-6 – Model answer (5 marks)

Given: $A = 2,000 \text{ m}^2$; $U_1 = 2.0 \text{ W/m}^2\text{K}$; $U_2 = 0.4 \text{ W/m}^2\text{K}$; $\Delta T = 18 \text{ K}$; $2,600 \text{ h/year}$; 1.0 kW/TR ; ₹ 9/kWh; insulation ₹ 900/ m^2 .

(a) Heat gain (2 Marks)

Formula: $Q = U \times A \times \Delta T$

Substitution: $Q_1 = 2.0 \times 2,000 \times 18 = 72,000 \text{ W}$; $Q_2 = 0.4 \times 2,000 \times 18 = 14,400 \text{ W}$ (1 Mark)

Reduction = 57.6 kW ; $\text{TR} = 57.6 / 3.516$

Result: **Heat gain falls from 72 kW to 14.4 kW ; reduction $\approx 16.38 \text{ TR}$ ($\approx 57.6 \text{ kW}$)** (1 Mark)

(b) Savings (2 Marks)

Formula: electricity saving = $\text{TR reduction} \times \text{kW/TR} \times \text{hours}$

Substitution: $16.38 \times 1.0 \times 2,600$ (1 Mark)

Result: **$\approx 42,594 \text{ kWh/year}$; cost saving $\approx 42,594 \times 9 = ₹ 3,83,345 \text{ per year}$** (1 Mark)

(c) Payback (1 Mark)

Investment = $2,000 \times 900 = ₹ 18,00,000$

Result: **Payback = $18,00,000 / 3,83,345 \approx 4.7 \text{ years}$**

Note: ECBC prescribes maximum roof U-factors by climate zone; reflective (cool roof) coatings reduce the roof surface temperature and add to the savings. The chiller capacity reduction of about 16 TR can also be credited in new designs.

Marking: as indicated.

S-7 A process plant runs three identical 1,000 kVA DG sets. One month's log shows:

DG set	Energy generated (kWh)	Diesel consumed (litres)
DG-1	62,400	17,330
DG-2	58,100	14,250
DG-3	40,800	12,380

Diesel costs ₹ 92 per litre; density 0.83 kg/litre. All three sets operate at similar average loads.

(a) Specific energy generation (kWh/litre) and specific fuel consumption (g/kWh) of each set, and rank the sets. (2 Marks)

(b) Excess diesel consumed this month by DG-1 and DG-3 compared with the performance of DG-2, and its annual cost. (2 Marks)

(c) List four checks the auditor should make on DG-3. (1 Mark)

[2P3CEM057 | Chapter 9: Diesel / Natural Gas Power Generating System | 9.5 DG fleet log – fuel performance comparison]

S-7 – Model answer (5 marks)

Given: DG-1 62,400 kWh / 17,330 L; DG-2 58,100 kWh / 14,250 L; DG-3 40,800 kWh / 12,380 L; ₹ 92/L; 0.83 kg/L.

(a) Performance indicators (2 Marks)

Formula: kWh/L = energy / fuel; SFC (g/kWh) = fuel × density × 1,000 / energy

DG-1: 62,400 / 17,330 = **3.60 kWh/L**; 17,330 × 0.83 × 1,000 / 62,400 = **231 g/kWh**

DG-2: 58,100 / 14,250 = **4.08 kWh/L**; 14,250 × 0.83 × 1,000 / 58,100 = **204 g/kWh**

DG-3: 40,800 / 12,380 = **3.30 kWh/L**; 12,380 × 0.83 × 1,000 / 40,800 = **252 g/kWh**

Ranking: **DG-2 (best) > DG-1 > DG-3 (worst)**

(b) Excess fuel versus DG-2 (2 Marks)

Formula: excess fuel = actual fuel – energy / (kWh/L of DG-2)

Substitution: DG-1: 17,330 – 62,400 / 4.077 = 17,330 – 15,305 = 2,025 L; DG-3: 12,380 – 40,800 / 4.077 = 12,380 – 10,007 = 2,373 L (1 Mark)

Total excess = 4,398 L/month; × ₹ 92 = ₹ 4,04,659 per month (0.5 Mark)

Result: **Annual avoidable fuel cost ≈ ₹ 4,04,659 × 12 ≈ ₹ 48.6 lakh** (0.5 Mark)

(c) Checks on DG-3 (1 Mark; 0.25 each)

- Fuel injector spray and timing; injection pump calibration
- Air intake filter pressure drop and turbocharger condition
- Exhaust gas temperature and smoke per cylinder (balance)
- Fuel leakage, meter calibration and lube oil / cooling water temperatures

Marking: (a) 6 values × 0.25 + 0.5 ranking; (b) as shown; (c) 4 × 0.25.

S-8 A potato cold store is loaded with 400 tonnes of potatoes at 30 °C, which must be cooled to 4 °C in 40 hours. Specific heat of potatoes is 0.82 kcal/kg °C. Respiration heat, infiltration, lights and fan loads together add 25 % to the product cooling load. The ammonia refrigeration plant operates at 1.4 kW/TR, and electricity costs ₹ 8/kWh.

(a) Product cooling load in kcal/h and TR. (2 Marks)

(b) Total refrigeration load in TR. (1 Mark)

(c) Compressor power required. (1 Mark)

(d) Electricity consumption and cost for the 40-hour pull-down. (1 Mark)

[2P3CEM058 | Chapter 4: HVAC and Refrigeration System | 4.6 Cold storage – product pull-down load and compressor power]

S-8 – Model answer (5 marks)

Given: $m = 4,00,000$ kg; $c_p = 0.82$ kcal/kg °C (≈ 3.43 kJ/kg·K); $\Delta T = 30 - 4 = 26$ °C; time = 40 h; other loads = 25 % of product load; 1.4 kW/TR; ₹ 8/kWh; 1 TR = 3,024 kcal/h (≈ 3.52 kW).

(a) Product load (2 Marks)

Formula: $Q = m \times c_p \times \Delta T / \text{time}$

Substitution: total heat = $4,00,000 \times 0.82 \times 26 = 85,28,000$ kcal; $Q = 85,28,000 / 40 = 2,13,200$ kcal/h (1 Mark)

Result: **Product load = 2,13,200 kcal/h (≈ 248 kW) $\div 3,024 \approx 70.5$ TR (≈ 248 kW)** (1 Mark)

(b) Total load (1 Mark)

Result: **Total = 70.5 $\times$ 1.25 $\approx$ 88.1 TR (≈ 310 kW)**

(c) Compressor power (1 Mark)

Result: **Power = 88.1 $\times$ 1.4 $\approx$ 123.4 kW**

(d) Energy and cost (1 Mark)

Energy = $123.4 \times 40 \approx 4,935$ kWh

Result: **Cost $\approx 4,935 \times 8 = ₹ 39,481$ for the pull-down**

Note: loading the store in batches matched to plant capacity, keeping doors closed with strip curtains and maintaining evaporator defrost reduce the kW/TR and total energy.

Marking: as indicated.

..... 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 forging plant's typical working-day load profile is:

Time block	Duration (h)	Load (kW)	TOD period
00:00–06:00	6	900	Off-peak
06:00–09:00	3	1,600	Peak
09:00–18:00	9	1,900	Normal
18:00–22:00	4	2,000	Peak
22:00–24:00	2	1,000	Off-peak

Tariff: base energy rate ₹ 7.40/kWh; peak-hour surcharge ₹ 1.50/kWh; off-peak rebate ₹ 1.20/kWh; demand charge ₹ 450 per kVA per month on the maximum demand; average PF 0.95. The plant works 300 days a year.

A 350 kW batch heat-treatment furnace now runs from 18:00 to 22:00; it can be rescheduled to 22:00–02:00 with no change in its energy use.

(a) Daily energy consumption, maximum demand and daily load factor at present. (3 Marks)

(b) Daily energy cost at present under the TOD tariff. (2 Marks)

(c) Maximum demand, load factor and daily energy cost after rescheduling. (2 Marks)

(d) Annual savings in energy and demand charges. (2 Marks)

(e) State True or False with reason: (i) Load shifting always reduces kWh consumption. (ii) Improving load factor reduces the average cost per kWh under a two-part tariff. (1 Mark)

[2P3CEM059 | Chapter 1: Electrical Systems | 1.3 Daily load profile, load factor and TOD load shifting]

L-1 – Model answer (10 marks)

Given: load blocks as tabulated; base ₹ 7.40/kWh, peak ₹ 8.90/kWh (7.40 + 1.50), off-peak ₹ 6.20/kWh (7.40 – 1.20); demand ₹ 450/kVA/month; PF 0.95; 300 days/year; furnace 350 kW × 4 h moved from 18–22 to 22–02.

(a) Present energy, MD and load factor (3 Marks)

Daily energy = $900 \times 6 + 1,600 \times 3 + 1,900 \times 9 + 2,000 \times 4 + 1,000 \times 2$
= 5,400 + 4,800 + 17,100 + 8,000 + 2,000 = **37,300 kWh/day** (1 Mark)

MD = **2,000 kW** (18:00–22:00 block), i.e. $2,000 / 0.95 = 2,105$ kVA (1 Mark)

Formula: load factor = energy / (MD × 24)

Substitution: $37,300 / (2,000 \times 24) \times 100$

Result: **Load factor ≈ 77.7 %** (1 Mark)

(b) Present daily energy cost (2 Marks)

Off-peak: $(5,400 + 2,000) = 7,400$ kWh × 6.20 = ₹ 45,880

Peak: $(4,800 + 8,000) = 12,800$ kWh × 8.90 = ₹ 1,13,920

Normal: $17,100$ kWh × 7.40 = ₹ 1,26,540

Result: **Daily energy cost = ₹ 2,86,340** (0.5 Mark per slab + 0.5 for total)

(c) After rescheduling (2 Marks)

New loads: 18–22 = 1,650 kW; 22–24 = 1,350 kW; 00–02 = 1,250 kW; other blocks unchanged.

New MD = **1,900 kW** (09:00–18:00 block) = 2,000 kVA; load factor = $37,300 / (1,900 \times 24) = 81.8 \%$ (1 Mark)

Peak energy = $12,800 - 1,400 = 11,400$ kWh × 8.90 = ₹ 1,01,460; off-peak = $7,400 + 1,400 = 8,800$ kWh × 6.20 = ₹ 54,560; normal unchanged ₹ 1,26,540

Result: **New daily energy cost = ₹ 2,82,560** (1 Mark)

(d) Annual savings (2 Marks)

Energy charge saving = $(2,86,340 - 2,82,560) \times 300 = 3,780 \times 300 = ₹ 11,34,000$ per year (1 Mark)

Demand reduction = $(2,000 - 1,900) / 0.95 = 105.3$ kVA; saving = $105.3 \times 450 \times 12 = ₹ 5,68,421$ per year (0.75 Mark)

Result: **Total saving ≈ ₹ 17,02,421 per year (≈ ₹ 17.0 lakh)**, with no capital cost and no change in kWh. (0.25 Mark)

(e) True / False with reason (1 Mark)

(i) **False** – load shifting moves consumption to another time; kWh stays the same (as in this case), only the cost and the peak demand fall. (0.5 Mark)

(ii) **True** – under a two-part tariff, demand charges are fixed by MD; a higher load factor spreads them over more kWh, so the average cost per kWh falls. (0.5 Mark)

L-2 A hospital's central plant has three 300 TR water-cooled screw chillers, each with a design evaporator ΔT of 5.5 °C and a maximum permitted evaporator flow of 175 m³/h. Each chiller has a dedicated primary chilled water pump (30 kW) and condenser water pump (37 kW). Two secondary chilled water pumps (45 kW input each) run at full speed with three-way valves at the AHUs.

Measured at peak: total chilled water flow 520 m³/h, supply 7.0 °C and return 10.2 °C. Because of the high flow, all three chillers must run.

The audit proposes converting AHU valves to two-way, fixing coil fouling, and putting the secondary pumps on VFD with differential pressure control so that the system returns to a 5.5 °C ΔT at the same cooling load. Assume the secondary pump power varies with the cube of flow and VFD efficiency is 97 %. Operating hours 6,500 per year; tariff ₹ 9/kWh.

- (a) Actual cooling load in kcal/h and TR. (1.5 Marks)
- (b) Chilled water flow required at 5.5 °C ΔT for the same load. (1 Mark)
- (c) Number of chillers required after correction, with justification. (1.5 Marks)
- (d) Secondary pump power after correction. (2 Marks)
- (e) Annual energy and cost saving from pumps (secondary VFD plus one set of primary and condenser pumps switched off). (2 Marks)
- (f) List four causes of low ΔT in chilled water systems. (2 Marks)

[2P3CEM060 | Chapter 4: HVAC and Refrigeration System | 4.7 Low delta-T syndrome in a chilled water system]

L-2 – Model answer (10 marks)

Given: Q = 520 m³/h; ΔT = 10.2 – 7.0 = 3.2 °C; design ΔT 5.5 °C; chiller 300 TR (≈ 1,055 kW) each, max flow 175 m³/h; primary pump 30 kW and condenser pump 37 kW per chiller; secondary pumps 2 × 45 kW; cube law; VFD 97 %; 6,500 h/year; ₹ 9/kWh.

(a) Cooling load (1.5 Marks)

Formula: load (kcal/h) = flow (kg/h) × cp × ΔT, with 1 m³ water = 1,000 kg, cp = 1 kcal/kg °C

Substitution: 520 × 1,000 × 1 × 3.2 = 16,64,000 kcal/h (1 Mark)

Result: **Load = 16,64,000 / 3,024 ≈ 550.3 TR (≈ 1,935 kW)** (0.5 Mark)

(b) Flow at design ΔT (1 Mark)

Substitution: flow = 16,64,000 / (1,000 × 5.5)

Result: **≈ 302.5 m³/h** (58.2 % of present flow)

(c) Chillers required (1.5 Marks)

Present: 520 m³/h exceeds 2 × 175 = 350 m³/h, so three chillers run although the load (550 TR (≈ 1,934 kW)) is within two chillers' 600 TR (≈ 2,110 kW) capacity.

After correction: 302.5 m³/h < 350 m³/h and 550.3 TR (≈ 1,935 kW) < 600 TR (≈ 2,110 kW).

Result: **Two chillers suffice (each about 92 % loaded); one chiller with its primary and condenser pumps can be stopped.**

(d) Secondary pump power (2 Marks)

Formula: $P_2 = P_1 \times (Q_2 / Q_1)^3 / \eta_{VFD}$

Substitution: flow ratio = 302.5 / 520 = 0.582; $P_2 = 90 \times 0.582^3 / 0.97 = 90 \times 0.197 / 0.97$

Result: **P₂ ≈ 18.3 kW** (saving ≈ 71.7 kW)

(e) Annual savings (2 Marks)

Pump power saving = 71.7 (secondary) + 30 + 37 (one primary and one condenser pump) = 138.7 kW (0.5 Mark)

Annual energy = 138.7 × 6,500 ≈ 9,01,719 kWh (0.75 Mark)

Result: **Annual cost saving = 9,01,719 × 9 = ₹ 81,15,473 (≈ ₹ 81.2 lakh)** (0.75 Mark)

(Compressor kW is nearly unchanged because the load is the same; two better-loaded chillers usually run at equal or better kW/TR, which is an added benefit not counted here.)

(f) Causes of low ΔT (2 Marks; 0.5 each)

- Three-way valves or open bypasses sending chilled water back unused
- Fouled or undersized AHU coils, or air-side filters choked, reducing heat transfer
- Low chilled water supply set point or over-pumping with valves wide open
- Faulty or manual control valves, and decoupler (common pipe) flow reversal in primary–secondary systems

L-3 A town water-supply pumping main carries $900 \text{ m}^3/\text{h}$ from a sump to an elevated reservoir. Static head is 32 m. The existing 300 mm cast-iron main (old and encrusted) has a friction head (including fittings) of 18 m at this flow. The corporation plans to lay a new 350 mm main. Assume friction head varies inversely as the fifth power of diameter at the same flow, and that the pump is modified (impeller trimmed) so that it delivers the same flow at the new head with an unchanged pump efficiency of 72 % and motor efficiency of 92 %. The pumps run 20 h/day, 365 days a year; tariff ₹ 6.50/kWh; new main costs ₹ 1.2 crore.

(a) Present motor input power and specific energy in kWh per million litres (ML). (3 Marks)

(b) Friction head and total head with the new main. (2 Marks)

(c) New motor input power, specific energy and annual savings. (3 Marks)

(d) Simple payback and two comments on implementation. (2 Marks)

[2P3CEM061 | Chapter 6: Pumps and Pumping System | 6.3 Pipeline replacement – friction head, pump power and kWh per ML]

L-3 – Model answer (10 marks)

Given: $Q = 900 \text{ m}^3/\text{h} = 0.25 \text{ m}^3/\text{s}$; $H_{\text{static}} = 32 \text{ m}$; $h_f(300 \text{ mm}) = 18 \text{ m}$; $D_1 = 300 \text{ mm}$; $D_2 = 350 \text{ mm}$; $\eta_{\text{pump}} = 0.72$; $\eta_{\text{motor}} = 0.92$; 7,300 h/year (20×365); ₹ 6.50/kWh; cost ₹ 1,20,00,000.

(a) Present power and kWh/ML (3 Marks)

Total head $H_1 = 32 + 18 = 50 \text{ m}$ (0.5 Mark)

Formula: motor input (kW) = $Q \times H \times \rho \times g / (1,000 \times \eta_{\text{pump}} \times \eta_{\text{motor}})$

Substitution: $0.25 \times 50 \times 1,000 \times 9.81 / (1,000 \times 0.72 \times 0.92) = 122.6 / 0.6624$ (1 Mark)

Result: **Present input $\approx 185.1 \text{ kW}$** (0.5 Mark)

Flow = $900 \text{ m}^3/\text{h} = 0.9 \text{ ML/h}$; specific energy = $185.1 / 0.9$

Result: **$\approx 205.7 \text{ kWh/ML}$** (1 Mark)

(b) New friction and total head (2 Marks)

Formula: $h_{f2} = h_{f1} \times (D_1 / D_2)^5$

Substitution: $18 \times (300 / 350)^5 = 18 \times 0.4627$ (1 Mark)

Result: **$h_{f2} \approx 8.33 \text{ m}$; total head $H_2 = 32 + 8.33 = 40.33 \text{ m}$** (1 Mark)

(c) New power and savings (3 Marks)

Input₂ = $0.25 \times 40.33 \times 9.81 / (0.72 \times 0.92) = 149.3 \text{ kW}$ (1 Mark)

Specific energy = $149.3 / 0.9 = 165.9 \text{ kWh/ML}$ (0.5 Mark)

Power saving = $185.1 - 149.3 = 35.8 \text{ kW}$; annual energy = $35.8 \times 7,300 \approx 2,61,415 \text{ kWh}$ (0.75 Mark)

Result: **Annual cost saving $\approx 2,61,415 \times 6.50 = ₹ 16,99,194$ ($\approx ₹ 17.0 \text{ lakh}$)** (0.75 Mark)

(d) Payback and comments (2 Marks)

Result: **Payback = $1,20,00,000 / 16,99,194 \approx 7.1 \text{ years}$** (1 Mark)

Comments (0.5 each):

- Without trimming the impeller (or adding a VFD), the existing pump would move to the right on its curve, giving more flow at lower efficiency and possibly overloading the motor; matching the pump to the new system curve is essential to realise the savings.
- Since the old main is encrusted and nearing end of life, the pipe cost is partly a renewal cost; the energy benefit alone gives about 7 years payback, and lower leakage and higher reliability add to the justification.

L-4 A 600 TR chiller plant runs at 0.68 kW/TR with its cooling tower delivering cold water at 34 °C against a design value of 31 °C; the ambient wet-bulb temperature is 28 °C and the hot water temperature is 39 °C. The tower has two cells, each with a 30 kW fan having aluminium blades. Refurbishment proposed: new film fill, uniform water distribution nozzles and energy-efficient FRP fan blades. After refurbishment the tower is expected to deliver cold water at 31 °C (same range) and each fan input falls to 21 kW. From the chiller manufacturer's data, chiller power falls by 2.5 % for every 1 °C reduction in condenser water inlet temperature. The plant runs 6,000 h/year; tariff ₹ 8.50/kWh; refurbishment cost ₹ 45 lakh.

- Approach before and after refurbishment, and the reduction in condenser water inlet temperature. (1.5 Marks)
- Chiller power saving. (2 Marks)
- Fan power saving. (1 Mark)
- Annual cost saving and simple payback. (2 Marks)
- List three likely causes of the poor approach found before refurbishment. (1.5 Marks)
- State True or False with reason: (i) Increasing the circulating water flow well beyond design, at the same air flow, lowers the cold-water temperature. (ii) Lowering condenser water temperature below the chiller manufacturer's minimum limit is always beneficial. (2 Marks)

[2P3CEM062 | Chapter 7: Cooling Towers | 7.5 Cooling tower refurbishment and its effect on chiller power]

L-4 – Model answer (10 marks)

Given: chiller 600 TR ($\approx 2,110$ kW) at 0.68 kW/TR; WBT = 28 °C; before: hot 39 °C, cold 34 °C; after: hot 36 °C, cold 31 °C (same range); fans 2×30 kW $\rightarrow 2 \times 21$ kW; 2.5 % chiller power per °C; 6,000 h/year; ₹ 8.50/kWh; investment ₹ 45,00,000.

- Approach and condenser water temperature (1.5 Marks)

Formula: approach = cold water temperature – ambient WBT

Substitution: before = $34 - 28 = 6$ °C (0.5 Mark); after = $31 - 28 = 3$ °C (0.5 Mark)

Result: **Approach improves from 6 °C to 3 °C (design value); condenser water inlet falls by $34 - 31 = 3$ °C** (0.5 Mark)

- Chiller power saving (2 Marks)

Chiller power = $600 \times 0.68 = 408$ kW (0.5 Mark)

Reduction in condenser water temperature = $34 - 31 = 3$ °C $\rightarrow 3 \times 2.5 = 7.5$ % (0.5 Mark)

Result: **Chiller saving = $408 \times 0.075 = 30.6$ kW** (1 Mark)

- Fan saving (1 Mark)

Result: **Fan saving = $2 \times (30 - 21) = 18$ kW**

- Annual saving and payback (2 Marks)

Total saving = $30.6 + 18 = 48.6$ kW; annual energy = $48.6 \times 6,000 = 2,91,600$ kWh (0.5 Mark)

Annual cost saving = $2,91,600 \times 8.50 = ₹ 24,78,600$ (0.75 Mark)

Result: **Payback = 45,00,000 / 24,78,600 ≈ 1.8 years** (0.75 Mark)

(e) Likely causes of poor approach (1.5 Marks; 0.5 each)

- Scaled, clogged or broken fill reducing the air–water contact area
- Choked or missing distribution nozzles giving uneven water loading and dry patches in the fill
- Low air flow from worn or wrongly pitched fan blades, slipping belts or obstructed louvres (and plume recirculation where siting is poor)

(f) True / False with reason (2 Marks)

(i) **False** – with air flow unchanged, more water raises the L/G ratio; each kg of air must absorb more heat, so the range falls and the cold-water temperature (approach) rises; pump power also increases. (1 Mark)

(ii) **False** – too low a condenser water temperature can reduce refrigerant pressure difference below what the expansion device and oil return need, causing unstable operation or trips; the chiller limit must be respected, typically by tower fan control or bypass. (1 Mark)

L-5 In an automobile component plant, three screw compressors (total 320 kW input) generate air at 7.6 kg/cm²g so that the farthest assembly line receives the required 6.0 kg/cm²g. The 1.6 kg/cm² drop is due to an undersized, long, dead-end header. A properly sized ring main with additional receivers would limit the drop to 0.3 kg/cm², allowing generation at 6.3 kg/cm²g. Measured leakage is 4.0 m³/min (free air) at 7.6 kg/cm²g. After lowering pressure, the plant specific power is 6.2 kW per m³/min.

Assume: (1) compressor power is proportional to $\ln(P_{\text{discharge abs}} / P_{\text{suction abs}})$, with suction at 1.033 kg/cm² abs; (2) leakage flow is proportional to absolute line pressure. The plant runs 7,200 h/year; tariff ₹ 8/kWh; ring main cost ₹ 18 lakh.

(a) Percentage and kW reduction in compressor power from lowering the generation pressure. (3 Marks)

(b) Additional saving from reduced leakage. (2 Marks)

(c) Annual energy and cost savings and payback. (3 Marks)

(d) List four good practices for compressed air distribution. (2 Marks)

[2P3CEM063 | Chapter 3: Compressed Air System | 3.8 Distribution pressure drop – ring main and lower generation pressure]

L-5 – Model answer (10 marks)

Given: generation pressure 7.6 kg/cm²g (≈ 7.45 bar(g)) reduced to 6.3 kg/cm²g (≈ 6.18 bar(g)); suction 1.033 kg/cm² (≈ 1.01 bar) abs; power 320 kW; leakage 4.0 m³/min at 7.6 kg/cm²g (≈ 7.45 bar(g)); specific power 6.2 kW per m³/min; 7,200 h/year; ₹ 8/kWh; cost ₹ 18,00,000.

(a) Power reduction from lower pressure (3 Marks)

Formula: $P_2 / P_1 = \ln(r_2) / \ln(r_1)$, with $r = (\text{gauge} + 1.033) / 1.033$

Substitution: $r_1 = 8.633 / 1.033 = 8.357$, $\ln r_1 = 2.123$; $r_2 = 7.333 / 1.033 = 7.099$, $\ln r_2 = 1.960$ (1.5 Marks)

Reduction = $1 - 1.960 / 2.123 = 0.0769$ (0.75 Mark)

Result: **≈ 7.7 % reduction = 320 × 0.0769 ≈ 24.6 kW** (0.75 Mark)

(b) Leakage reduction (2 Marks)

Formula: $\text{leak}_2 = \text{leak}_1 \times (P_2 \text{ abs} / P_1 \text{ abs})$

Substitution: $4.0 \times 7.333 / 8.633 = 3.40 \text{ m}^3/\text{min}$; reduction = $0.60 \text{ m}^3/\text{min}$ (1 Mark)

Result: **Leakage power saving = 0.60 × 6.2 ≈ 3.7 kW** (1 Mark)

(c) Annual savings and payback (3 Marks)

Total = $24.6 + 3.7 = 28.3 \text{ kW}$ (0.5 Mark)

Annual energy = $28.3 \times 7,200 \approx 2,04,000$ kWh (1 Mark)

Annual cost saving = $2,04,000 \times 8 \approx \text{₹ } 16,32,000$ (0.75 Mark)

Result: **Payback = $18,00,000 / 16,32,000 \approx 1.1$ years** (0.75 Mark)

(d) Good distribution practices (2 Marks; 0.5 each)

- Size headers for low velocity (about 6–10 m/s) and limit total drop from compressor to farthest point to about 0.3 kg/cm^2 ($\approx 0.294 \text{ bar} = 29.4 \text{ kPa}$)
- Use ring mains with take-offs from the top of the header and slopes with auto drain traps at low points
- Isolate idle sections with valves and survey and repair leaks regularly (ultrasonic detection)
- Use local receivers or pressure regulators for high-pressure or intermittent users instead of raising plant pressure

L-6 A textile mill without reliable grid supply has three identical 800 kW (1,000 kVA) DG sets. The plant load is a steady 1,440 kW for 3,000 hours a year. The manufacturer's part-load performance is:

Load (% of rating)	40	60	80	90	100
kWh per litre	3.00	3.45	3.80	3.75	3.60

Diesel costs ₹ 92 per litre. The present practice is to run all three sets with equal load sharing.

(a) Load on each set and fuel consumption (L/h) with three sets and with two sets in operation. (3 Marks)

(b) Annual fuel and cost saving with two-set operation. (2 Marks)

(c) Fuel cost per kWh in each case and comparison with a grid tariff of ₹ 9/kWh. (2 Marks)

(d) One precaution while running two sets at high load. (1 Mark)

(e) State True or False with reason: (i) A DG set gives its best kWh per litre at full load. (ii) Monthly kWh-per-litre figures of different DG sets can be compared fairly only when their loading is also known. (2 Marks)

[2P3CEM064 | Chapter 9: Diesel / Natural Gas Power Generating System | 9.6 DG load sharing – choosing the number of sets]

L-6 – Model answer (10 marks)

Given: 3×800 kW; load 1,440 kW; 3,000 h/year; kWh/L: 60 % $\rightarrow$ 3.45, 90 % $\rightarrow$ 3.75; ₹ 92/L.

(a) Loading and fuel use (3 Marks)

Three sets: $1,440 / 3 = 480$ kW each = 60 % $\rightarrow$ 3.45 kWh/L

Formula: fuel (L/h) = load (kW) / (kWh per litre)

Substitution: $1,440 / 3.45$

Result: **Three sets: ≈ 417.4 L/h** (1.5 Marks)

Two sets: $1,440 / 2 = 720$ kW each = 90 % $\rightarrow$ 3.75 kWh/L; $1,440 / 3.75$

Result: **Two sets: 384.0 L/h** (1.5 Marks)

(b) Annual saving (2 Marks)

Fuel saving = $417.4 - 384.0 = 33.4$ L/h; $\times 3,000$ h = 1,00,174 litres/year (1 Mark)

Result: **Annual cost saving $\approx 1,00,174 \times 92 = \text{₹ } 92,16,000$ ($\approx \text{₹ } 92.2$ lakh)** (1 Mark)

(c) Fuel cost per kWh (2 Marks)

Three sets: $92 / 3.45 = \text{₹ } 26.67/\text{kWh}$; two sets: $92 / 3.75 = \text{₹ } 24.53/\text{kWh}$ (1 Mark)

Result: **Even at best loading, DG power costs about 2.7 times the grid tariff of ₹ 9/kWh; securing a reliable grid connection should be pursued, with DG retained as backup.** (1 Mark)

(d) Precaution (1 Mark)

Keep the third set as hot standby or provide load-shedding so that a trip of one set, or a large motor start, does not overload the remaining set beyond its rating; check exhaust temperature and cooling margin at 90 % load in summer.

(e) True / False with reason (2 Marks)

(i) **False** – as per the given curve, kWh per litre peaks around 80 % load (3.80) and falls slightly at 100 % (3.60); best efficiency is typically at 75–90 % load. (1 Mark)

(ii) **True** – kWh per litre varies with load, as the table shows (3.00 at 40 % against 3.80 at 80 %); a set running at light load will look worse even when mechanically healthy, so load must be logged alongside fuel and energy. (1 Mark)

..... End of Section III

Section I – Answer key

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