

PRACTICE PAPER — NATIONAL CERTIFICATION EXAMINATION FOR ENERGY MANAGERS & ENERGY AUDITORS

PAPER – 1: GENERAL ASPECTS OF ENERGY MANAGEMENT & ENERGY AUDIT

Question code: 2P1CEM001 – 2P1CEM064 | SOLUTIONS & MODEL ANSWERS

Duration: 3 HRS Max. Marks: 150 Pass: 50% marks in the paper

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; show formula, substitution with units and result for every numerical

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Section – I: OBJECTIVE TYPE

Marks: 50 × 1 = 50

- (i) Answer all 50 questions
(ii) Each question carries one mark

1. In a year a nation produced 32 Mt of crude oil domestically and imported 240 Mt, while 12 Mt went into building strategic stocks. Taking import dependence as imports divided by crude actually consumed, what is the import dependence?

[2P1CEM001 | Chapter 1: Energy Scenario | Import dependence of crude oil]

- a) 12.3%
- b) 92.3%
- c) 88.2%
- d) 87.7%

Correct answer: (b) 92.3%.

Given: domestic production = 32 Mt; imports = 240 Mt; addition to stocks = 12 Mt.

Formula: Crude consumed = production + imports – stock build-up; Import dependence = imports ÷ crude consumed × 100.

Substitution: consumed = 32 + 240 – 12 = 260 Mt; dependence = 240 ÷ 260 × 100 = 92.3%.

Result: **92.3%**. The guidebook defines energy security as continuous availability of energy in varied forms, in sufficient quantity, at reasonable prices; a figure this high is why diversification of supply and strategic reserves are stressed.

Why the other options are wrong: (a) 12.3% – is the share met by domestic production (self-sufficiency), the complement of dependence. (c) 88.2% – ignores the stock build-up and divides by total supply instead of crude consumed. (d) 87.7% – deducts the stock build-up from imports as well as from consumption, counting it twice.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 1 – Energy Scenario.

2. Which group consists ENTIRELY of secondary energy, i.e. carriers obtained by converting a primary source?

[2P1CEM002 | Chapter 1: Energy Scenario | Primary and secondary energy]

- a) Electricity, process steam, petrol and coke
- b) Electricity, crude oil, coke and firewood
- c) Coal, crude oil, natural gas and uranium
- d) Process steam, natural gas, petrol and coal

Correct answer: (a) Electricity, process steam, petrol and coke.

Primary energy is found in nature or stored in it: coal, crude oil, natural gas, biomass, uranium, hydro, wind and solar.

Secondary energy is produced by converting primary energy in plants such as refineries, coke ovens, power stations and boilers: petrol and diesel from crude, coke from coal, electricity from fuels or hydro, and steam from boilers.

An energy auditor must count each unit of energy only once, so the distinction matters when energy is aggregated into toe.

Why the other options are wrong: (b) Includes crude oil and firewood, which are primary energy. (c) Lists only primary sources found in nature and used without conversion. (d) Includes natural gas and coal, which are primary energy.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 1 – Energy Scenario.

3. Under the Availability Based Tariff introduced in 2003 for inter-state sale of power, a generator or beneficiary may vary from its day-ahead committed schedule only if the change is notified how far in advance?

[2P1CEM003 | Chapter 1: Energy Scenario | Availability Based Tariff (ABT)]

- a) One and a half hours ahead
- b) Six full hours ahead of time
- c) Fifteen minutes ahead of time
- d) Twenty-four hours ahead of time

Correct answer: (a) One and a half hours ahead.

As per the guidebook, ABT is (i) a performance-based tariff for supply by centrally owned generators; (ii) a system of scheduling and dispatch in which generators and beneficiaries commit to day-ahead schedules; and (iii) a system of rewards and penalties (unscheduled interchange charges) to enforce those schedules, with variations permitted if notified one and a half hours in advance. It also stresses prompt payment of dues. ABT has reduced voltage and frequency fluctuations in the grid.

Why the other options are wrong: (b) This option is not the notice period stated for schedule revisions. (c) This option is the length of a scheduling time block, not the notice period. (d) This option confuses the day-ahead scheduling itself with the notice period for revisions.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 1 – Energy Scenario.

4. Farm pump-sets in many States receive unmetered power at a flat charge based on declared horsepower. Why does this encourage wasteful pumping?

[2P1CEM004 | Chapter 1: Energy Scenario | Electricity pricing - flat-rate farm supply]

- a) Pump-sets are rated in horsepower rather than in kilowatts
- b) Each extra kWh pumped costs the farmer nothing at the margin
- c) Farm tariffs are fixed by the Central Electricity Authority
- d) Industrial consumers pay the fixed charge on behalf of farmers

Correct answer: (b) Each extra kWh pumped costs the farmer nothing at the margin.

The guidebook notes that agricultural supply is largely unmetered and farmers pay a subsidised lump sum based on the declared horsepower of their pumps. This leads to a zero marginal cost of power: running the pump longer does not raise the bill, so there is no price signal to save energy. This promotes inefficient use and over-exploitation of ground water. The burden of the resulting cross-subsidy falls on paying industrial, commercial and large domestic consumers, which is why metering and cost-reflective tariffs are part of power-sector reform.

Why the other options are wrong: (a) The unit of rating has no effect on how much water is pumped. (c) Tariffs are set by State Electricity Regulatory Commissions, and who sets them is not the cause. (d) Cross-subsidy loads cost on industry, but it is the zero marginal price that drives waste.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 1 – Energy Scenario.

5. A designated consumer fails to furnish information required under a clause of Section 14 that attracts Section 26(1), and the failure continues for 45 days after the first contravention. What is the maximum penalty it is liable to?

[2P1CEM005 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | EC Act Section 26(1) - penalty for continuing failure]

- a) ₹ 10.45 lakh
- b) ₹ 4.50 lakh
- c) ₹ 55.00 lakh
- d) ₹ 14.50 lakh

Correct answer: (d) ₹ 14.50 lakh.

Given: continuing failure = 45 days; Section 26(1) as amended in 2010.

Formula: Maximum penalty = ₹10 lakh for the failure + up to ₹10,000 for every day the failure continues.

Substitution: ₹10,00,000 + 45 × ₹10,000 = ₹10,00,000 + ₹4,50,000 = ₹14,50,000.

Result: **₹ 14.50 lakh.** Any amount not paid can be recovered as arrears of land revenue (Section 26(2)).

Why the other options are wrong: (a) ₹ 10.45 lakh – takes the daily penalty as ₹1,000 instead of ₹10,000 per day. (b) ₹ 4.50 lakh – counts only the daily penalty and omits the ₹10 lakh for the failure itself. (c) ₹ 55.00 lakh – treats the daily penalty as ₹1 lakh per day.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 2 – Energy Conservation Act, 2001 and Related Policies.

6. A PAT designated consumer had a baseline SEC of 0.320 toe/t and a target SEC of 0.300 toe/t. In the assessment year it produced 5,00,000 t at an SEC of 0.312 toe/t and bought no ESCerts. If the notified price of 1 toe is ₹10,154, what is the minimum penalty linked to energy consumed in excess of the norm?

[2P1CEM006 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | PAT scheme - Section 26(1A) penalty on shortfall]

- a) ₹ 4.06 crore
- b) ₹ 158.40 crore
- c) ₹ 6.09 crore
- d) ₹ 10.15 crore

Correct answer: (c) ₹ 6.09 crore.

Given: target SEC = 0.300 toe/t (≈ 12.6 GJ/t); achieved SEC = 0.312 toe/t (≈ 13.1 GJ/t); production = 5,00,000 t; price = ₹10,154/toe.

Formula: Excess energy = (achieved SEC – target SEC) × production; Section 26(1A) penalty $\geq$ price of every toe in excess (plus up to ₹10 lakh).

Substitution: $(0.312 - 0.300) \times 5,00,000 = 6,000$ toe; $6,000 \times ₹10,154 = ₹6,09,24,000$.

Result: **₹ 6.09 crore.** The unit could avoid this by buying 6,000 ESCerts, each ESCert being equal to 1 toe (≈ 41.9 GJ).

Why the other options are wrong: (a) ₹ 4.06 crore – prices the saving actually achieved, which earns credit rather than penalty. (b) ₹ 158.40 crore – prices the whole energy consumption of the year rather than the excess. (d) ₹ 10.15 crore – prices the entire targeted saving instead of only the shortfall.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 2 – Energy Conservation Act, 2001 and Related Policies.

7. Under the EC Act definition used for the Energy Conservation Building Code, which of these commercial buildings falls within its scope?

[2P1CEM007 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | Energy Conservation Building Code - applicability]

- a) Clinic with 95 kW connected load and 110 kVA contract demand
- b) Shop with 80 kW connected load and 95 kVA contract demand
- c) Hotel with 90 kW connected load and 130 kVA contract demand
- d) School with 60 kW connected load and 75 kVA contract demand

Correct answer: (c) Hotel with 90 kW connected load and 130 kVA contract demand.

The EC Act covers a building or building complex having a connected load of 100 kW or more, or a contract demand of 120 kVA or more, and used for commercial purposes. Either condition is sufficient.

The hotel's connected load (90 kW) is below 100 kW, but its contract demand of 130 kVA exceeds 120 kVA, so it is covered.

The Central Government prescribes the ECBC, and State Governments may amend it to suit regional and local climatic conditions.

Why the other options are wrong: (a) This option is just below both limits, so it is not covered. (b) This option is below both the 100 kW and the 120 kVA limits. (d) This option is well below both limits.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 2 – Energy Conservation Act, 2001 and Related Policies.

8. When BEE made labelling mandatory from 7 January 2010, four products were notified. Which of the following remained under the VOLUNTARY scheme at that time?

[2P1CEM008 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | Standards & Labelling - mandatory products]

- a) Frost-free refrigerators
- b) Tubular fluorescent lamps
- c) Room air conditioners
- d) Ceiling fans

Correct answer: (d) Ceiling fans.

The guidebook lists the four products notified for mandatory labelling from 7 January 2010: frost-free (no-frost) refrigerators, room air conditioners, tubular fluorescent lamps and distribution transformers (up to 200 kVA).

Ceiling fans were listed under the voluntary scheme, together with direct-cool refrigerators, induction motors, agricultural pump-sets, colour TVs, geysers, LPG stoves and others.

Star ratings run from 1 star (least efficient) to 5 stars (most efficient).

Why the other options are wrong: (a) Frost-free refrigerators – was one of the four products under mandatory labelling. (b) Tubular fluorescent lamps – was one of the four products under mandatory labelling. (c) Room air conditioners – was one of the four products under mandatory labelling.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 2 – Energy Conservation Act, 2001 and Related Policies.

9. Under the Bachat Lamp Yojana, households received good-quality CFLs at about ₹15, close to the price of an incandescent bulb. How was the cost difference between the market price and ₹15 recovered?

[2P1CEM009 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | Bachat Lamp Yojana (BLY)]

- a) Through customs duty exemption on imported CFL components
- b) Through a direct capital subsidy paid by BEE to suppliers
- c) Through a surcharge added to all household electricity bills
- d) Through carbon credits earned under the Clean Development Mechanism

Correct answer: (d) Through carbon credits earned under the Clean Development Mechanism.

BLY was a public-private partnership between the Government of India, private CFL suppliers or investors and State DISCOMs. It aimed to replace incandescent lamps in households with CFLs: 60 W lamps were replaced by 11–15 W CFLs and 100 W lamps by 20–25 W CFLs, saving about 80% energy at equal light output.

The CFLs were sold at ₹15 each, and the investor recovered the cost difference by selling carbon credits from the verified energy saving under the Clean Development Mechanism.

Why the other options are wrong: (a) Duty relief was not the recovery mechanism of the scheme. (b) BEE empanelled suppliers and set up the umbrella framework, but did not pay the difference. (c) The scheme was designed so that households did not pay extra on their bills.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 2 – Energy Conservation Act, 2001 and Related Policies.

10. In BEE's agricultural DSM programme for replacing inefficient farm pump-sets with star-rated pump-sets on segregated rural feeders, who is expected to invest in the replacement?

[2P1CEM010 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | Agricultural Demand Side Management]

- a) The State agriculture department alone
- b) The pump manufacturer under warranty
- c) An ESCO or the distribution utility
- d) Each farmer from his own funds

Correct answer: (c) An ESCO or the distribution utility.

The guidebook states that a BEE pilot study showed an energy saving potential of about 40% from replacing inefficient pumps with star-rated pump-sets.

Under Ag-DSM, the replacement is carried out by an Energy Service Company (ESCO) or the distribution company, which invests in the efficiency measures. The work is done on rural pump-set feeders where supply-quality improvements such as feeder segregation and HVDS are already in place, and the investment is recovered from the verified savings.

DSM savings are treated like new supply-side capacity.

Why the other options are wrong: (a) The programme design places the investment with the ESCO or utility. (b) Warranty does not cover replacement of old, inefficient pumps. (d) Farmers with near-zero marginal tariff have no incentive to invest.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 2 – Energy Conservation Act, 2001 and Related Policies.

11. A feeder cable supplies a constant 300 kW load. If the power factor at the load is raised from 0.75 to 0.95 by capacitors at the load end, by what percentage do the I^2R losses in the cable fall?

[2P1CEM011 | Chapter 3: Basics of Energy and its Various Forms | Power factor and cable losses]

- a) 21.1%
- b) 37.7%
- c) 60.4%
- d) 20.0%

Correct answer: (b) 37.7%.

Given: P constant = 300 kW; $PF_1 = 0.75$; $PF_2 = 0.95$.

Formula: $I = P \div (\sqrt{3} V \times PF)$, so $I \propto 1/PF$; cable loss = $I^2R \propto 1/PF^2$; reduction = $1 - (PF_1/PF_2)^2$.

Substitution: $1 - (0.75/0.95)^2 = 1 - 0.6233 = 0.3767$.

Result: **37.7% reduction in cable I^2R losses** (current falls by 21.1%).

Why the other options are wrong: (a) 21.1% – is the fall in current; losses vary with the square of current. (c) 60.4% – divides the wrong way round and gives the increase in losses from the new to the old condition. (d) 20.0% – simply subtracts the two power factors, which is not how losses change.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 3 – Basics of Energy and its Various Forms.

12. A coal-fired unit has a gross heat rate of 2,450 kcal/kWh, and its auxiliary consumption is 8% of gross generation. What is its net efficiency?

[2P1CEM012 | Chapter 3: Basics of Energy and its Various Forms | Heat rate and net efficiency]

- a) 37.6%
- b) 32.3%
- c) 38.2%
- d) 35.1%

Correct answer: (b) 32.3%.

Given: gross heat rate = 2,450 kcal/kWh ($\approx 10,258$ kJ/kWh); auxiliary consumption = 8%; 1 kWh = 860 kcal ($\approx 3,601$ kJ).

Formula: Gross efficiency = $860 \div \text{heat rate}$; Net efficiency = gross efficiency $\times (1 - \text{auxiliary fraction})$.

Substitution: $860 \div 2,450 = 0.3510$ (35.1%); $35.10\% \times (1 - 0.08) = 32.29\%$.

Result: **32.3% net efficiency** (net heat rate = 2,663 kcal/kWh ($\approx 11,149$ kJ/kWh)).

Why the other options are wrong: (a) 37.6% – takes 1 kWh as 1,000 kcal instead of 860 kcal. (c) 38.2% – divides by $(1 - \text{auxiliary fraction})$ instead of multiplying by it. (d) 35.1% – is the gross efficiency, which ignores the auxiliary consumption.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 3 – Basics of Energy and its Various Forms.

13. The surface temperature of a furnace wall rises from 327 °C to 527 °C with emissivity unchanged. By roughly what factor does the radiant energy emitted per square metre increase?

[2P1CEM013 | Chapter 3: Basics of Energy and its Various Forms | Radiation heat transfer - temperature effect]

- a) 1.61 times

- b) 1.33 times
- c) 6.75 times
- d) 3.16 times

Correct answer: (d) 3.16 times.

Given: $T_1 = 327^\circ\text{C} = 600\text{ K}$; $T_2 = 527^\circ\text{C} = 800\text{ K}$; emissivity constant.

Formula: Stefan–Boltzmann law, $E = \epsilon\sigma T^4$ with T in kelvin, so $E_2/E_1 = (T_2/T_1)^4$.

Substitution: $(800/600)^4 = (1.3333)^4 = 3.160$.

Result: **about 3.16 times** more radiant emission. This is why hot surfaces at high temperature lose heat fast and insulation or radiation shields pay back quickly.

Why the other options are wrong: (a) 1.61 times – uses a linear ratio of Celsius temperatures. (b) 1.33 times – uses absolute temperatures but omits the fourth power. (c) 6.75 times – applies the fourth power to Celsius instead of absolute temperatures.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 3 – Basics of Energy and its Various Forms.

14. A fuel oil has a gross calorific value of 10,500 kcal/kg and contains 11.5% hydrogen by mass (no free moisture). Taking the latent heat of water vapour as 587 kcal/kg, what is its net calorific value?

[2P1CEM014 | Chapter 3: Basics of Energy and its Various Forms | Gross and net calorific value]

- a) 9,892 kcal/kg
- b) 10,432 kcal/kg
- c) 11,108 kcal/kg
- d) 9,960 kcal/kg

Correct answer: (a) 9,892 kcal/kg.

Given: GCV = 10,500 kcal/kg ($\approx 43,961\text{ kJ/kg}$); H = 0.115 kg/kg fuel; latent heat = 587 kcal/kg ($\approx 2,458\text{ kJ/kg}$).

Formula: NCV = GCV – 9H × latent heat ($2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$, so 1 kg H_2 forms 9 kg water whose latent heat leaves in the flue gas).

Substitution: water formed = $9 \times 0.115 = 1.035\text{ kg/kg}$; $9\text{H} \times 587 = 607.5\text{ kcal/kg}$; NCV = $10,500 - 607.5 = 9892.5\text{ kcal/kg}$.

Result: **9,892 kcal/kg ($\approx 41,416\text{ kJ/kg}$)**.

Why the other options are wrong: (b) 10,432 kcal/kg – omits the factor 9; each kg of hydrogen forms 9 kg of water. (c) 11,108 kcal/kg – adds the latent heat instead of subtracting it. (d) 9,960 kcal/kg – uses 8 kg water per kg hydrogen (the oxygen mass ratio) instead of 9.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 3 – Basics of Energy and its Various Forms.

15. An ice plant converts 8,000 kg/day of water at 0°C into ice at 0°C . The latent heat of fusion is 80 kcal/kg and the plant works 16 h/day. What average refrigeration capacity is needed for this duty?

[2P1CEM015 | Chapter 3: Basics of Energy and its Various Forms | Latent heat of fusion and refrigeration load]

- a) 13.2 TR
- b) 46.5 TR
- c) 8.8 TR
- d) 3.3 TR

Correct answer: (a) 13.2 TR.

Given: water frozen = 8,000 kg/day at 0°C ; latent heat of fusion = 80 kcal/kg ($\approx 335\text{ kJ/kg}$); operation = 16 h/day; 1 TR = 3,024 kcal/h ($\approx 3.52\text{ kW}$).

Formula: $Q = m \times L$; capacity (TR) = $Q \div (\text{hours} \times 3,024)$.

Substitution: $Q = 8,000 \times 80 = 640,000\text{ kcal/day}$; $640,000 \div (16 \times 3,024) = 13.23\text{ TR}$.

Result: **13.2 TR ($\approx 46.4\text{ kW}$)** average refrigeration. Only latent heat is involved because the temperature stays at 0°C during the phase change.

Why the other options are wrong: (b) 46.5 TR – gives the duty in kW of refrigeration but labels it as TR. (c) 8.8 TR – spreads the load over 24 hours instead of the 16 operating hours. (d) 3.3 TR – divides by 12,000, the BTU/h value of 1 TR, while the heat is in kcal.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 3 – Basics of Energy and its Various Forms.

16. Which statement is a direct consequence of the second law of thermodynamics?

[2P1CEM016 | Chapter 3: Basics of Energy and its Various Forms | Laws of thermodynamics]

- a) Energy can be neither created nor destroyed in any process, only converted
- b) No heat engine can convert all the heat it receives into work
- c) Two bodies each in thermal equilibrium with a third are equal in temperature
- d) The entropy of a perfect crystal at absolute zero is taken as zero

Correct answer: (b) No heat engine can convert all the heat it receives into work.

The first law states that energy is conserved, so it can only change form. The second law states that the quality of energy degrades: heat flows naturally from hot to cold, and a heat engine must reject part of the heat supplied to a cold sink.

Hence no engine can convert all the heat it receives into work. This is why power-plant efficiency is limited, and why recovering low-grade waste heat for heating, not for power, is usually the practical choice in energy audits.

Why the other options are wrong: (a) This option is the first law (conservation of energy). (c) This option is the zeroth law, the basis of temperature measurement. (d) This option is the third law of thermodynamics.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 3 – Basics of Energy and its Various Forms.

17. A hospital used 21,60,000 kWh/yr from the grid and 1,40,000 kWh/yr from its DG sets. Its built-up area is 16,000 m², of which 4,000 m² is basement parking excluded from the benchmark area. What is its EPI?

[2P1CEM017 | Chapter 4: Energy Management and Audit | Building energy performance index (EPI)]

- a) 135.0 kWh/m²·yr
- b) 191.7 kWh/m²·yr
- c) 180.0 kWh/m²·yr
- d) 143.8 kWh/m²·yr

Correct answer: (b) 191.7 kWh/m²·yr.

Given: grid energy = 21,60,000 kWh/yr; DG energy = 1,40,000 kWh/yr; benchmark area = 16,000 – 4,000 = 12,000 m².

Formula: EPI = Total annual electricity used (all sources) ÷ benchmark built-up area.

Substitution: (21,60,000 + 1,40,000) ÷ 12,000 = 23,00,000 ÷ 12,000 = 191.67.

Result: **191.7 kWh/m²·yr**. Benchmarking needs consistent boundaries: all energy sources in, and the same area definition as the reference building.

Why the other options are wrong: (a) 135.0 kWh/m²·yr – leaves out DG energy and also includes the parking area. (c) 180.0 kWh/m²·yr – leaves out the DG-generated electricity. (d) 143.8 kWh/m²·yr – divides by the total area including the excluded parking.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 4 – Energy Management and Audit.

18. An ice-cream factory can shift 1,800 kWh/day of cold-store pull-down load from the peak period (₹9.60/kWh) to the night off-peak period (₹6.40/kWh) on 300 working days a year. Total kWh is unchanged. What is the annual saving?

[2P1CEM018 | Chapter 4: Energy Management and Audit | Time-of-day tariff - load shifting]

- a) ₹ 34.56 lakh
- b) ₹ 51.84 lakh
- c) ₹ 17.28 lakh
- d) ₹ 21.02 lakh

Correct answer: (c) ₹ 17.28 lakh.

Given: energy shifted = 1,800 kWh/day; peak rate = ₹9.60/kWh; off-peak rate = ₹6.40/kWh; 300 days/yr.

Formula: Saving = kWh shifted × (peak rate – off-peak rate) × days.

Substitution: $1,800 \times (9.60 - 6.40) \times 300 = 1,800 \times 3.20 \times 300 = ₹17,28,000$.

Result: **₹ 17.28 lakh/yr**. This is a cost saving, not an energy saving, which is why the guidebook asks the auditor to understand the tariff structure.

Why the other options are wrong: (a) ₹ 34.56 lakh – multiplies the shifted energy by the off-peak rate instead of the rate difference. (b) ₹ 51.84 lakh – treats the whole peak-rate cost as saved, as if the load disappeared. (d) ₹ 21.02 lakh – uses 365 days instead of the stated 300 working days.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 4 – Energy Management and Audit.

19. A portable flue gas analyser shows 4.5% O₂ (dry basis) at a boiler outlet. Using the usual approximation, what is the excess air?

[2P1CEM019 | Chapter 4: Energy Management and Audit | Combustion analyser - excess air from O₂]

- a) 366.7%
- b) 27.3%
- c) 78.6%
- d) 21.4%

Correct answer: (b) 27.3%.

Given: O₂ in flue gas = 4.5% (dry).

Formula: Excess air (%) = $O_2 \div (21 - O_2) \times 100$.

Substitution: $4.5 \div (21 - 4.5) \times 100 = 4.5 \div 16.5 \times 100 = 27.27\%$.

Result: **27.3% excess air**. The combustion analyser (O₂, CO, flue temperature) is a basic audit instrument. Excess air well above the optimum raises stack loss, while too little gives CO and unburnt fuel.

Why the other options are wrong: (a) 366.7% – inverts the ratio. (c) 78.6% – is the fraction of oxygen used up in combustion, not excess air. (d) 21.4% – divides by 21 instead of by (21 – O₂).

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 4 – Energy Management and Audit.

20. An audit of a warehouse finds 120 high-bay HPMV fittings of 400 W, each with a ballast loss of 40 W, burning 4,000 h/yr. They are to be replaced with 150 W LED fittings of equal lumen output. What is the annual energy saving?

[2P1CEM020 | Chapter 4: Energy Management and Audit | Lighting retrofit saving]

- a) 1,39,200 kWh
- b) 72,000 kWh
- c) 2,11,200 kWh
- d) 1,20,000 kWh

Correct answer: (a) 1,39,200 kWh.

Given: 120 fittings; existing input = 400 + 40 = 440 W each; LED = 150 W; 4,000 h/yr.

Formula: Saving = (old input – new input) × number × hours ÷ 1,000.

Substitution: $(440 - 150) \times 120 \times 4,000 \div 1,000 = 290 \times 120 \times 4,000 \div 1,000 = 1,39,200$ kWh.

Result: **1,39,200 kWh/yr** saved (66% of lighting energy). Always include control-gear losses in the baseline.

Why the other options are wrong: (b) 72,000 kWh – is the consumption after retrofit, not the saving. (c) 2,11,200 kWh – is the present consumption, not the saving. (d) 1,20,000 kWh – ignores the ballast loss of the existing fittings.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 4 – Energy Management and Audit.

21. In the three-phase methodology of a detailed energy audit, which activity belongs to Phase III (post-audit)?

[2P1CEM021 | Chapter 4: Energy Management and Audit | Detailed energy audit - phases]

- a) Walk-through visit to collect plant layout and energy bills
- b) Implementing agreed measures and monitoring the savings achieved
- c) Analysing energy use and drafting the audit report

d) Conducting trials and measurements on major energy users

Correct answer: (b) Implementing agreed measures and monitoring the savings achieved.

The guidebook divides a detailed energy audit into three phases.

Phase I (pre-audit): plan and organise, walk-through audit, informal meeting with management and collection of macro data.

Phase II (audit): primary data gathering, measurements and trials, analysis of energy use, identification of options, cost-benefit analysis, and reporting and presentation to management.

Phase III (post-audit): implementation of the agreed measures and monitoring of their performance, which also feeds the next audit cycle.

Why the other options are wrong: (a) This option is part of Phase I, the pre-audit phase. (c) This option is part of Phase II, the audit phase. (d) This option is part of Phase II, the audit phase.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 4 – Energy Management and Audit.

22. Which audit recommendation is an example of the strategy 'matching energy usage to the requirement'?

[2P1CEM022 | Chapter 4: Energy Management and Audit | Energy audit strategy - matching use to requirement]

a) Recovering flash steam from high-pressure condensate for use in process heating

b) Trimming an oversized pump impeller to deliver only the needed flow

c) Switching the boiler fuel from furnace oil to imported coal

d) Replacing a standard motor with a premium-efficiency IE3 motor

Correct answer: (b) Trimming an oversized pump impeller to deliver only the needed flow.

The guidebook groups energy audit strategies as (i) matching energy usage to the requirement, (ii) maximising system efficiency, and (iii) optimising the input energy requirement.

An oversized pump throttled at the valve wastes energy because supply exceeds need. Trimming the impeller, or using a VFD, matches the delivered flow and head to the actual requirement.

Motor upgrades and heat recovery fall under maximising efficiency, while fuel switching optimises the input energy.

Why the other options are wrong: (a) This option is waste heat recovery, which maximises system efficiency. (c) This option is fuel substitution, i.e. optimising the input energy. (d) Maximises system efficiency rather than matching use to need.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 4 – Energy Management and Audit.

23. A surface condenser receives 2,000 kg/h of dry saturated steam (enthalpy 640 kcal/kg, latent heat 540 kcal/kg). The condensate leaves sub-cooled at 60 °C. Cooling water at 54,000 kg/h enters at 30 °C. Neglecting losses, what is the cooling water outlet temperature?

[2P1CEM023 | Chapter 5: Material and Energy Balance | Energy balance of a surface condenser]

a) 53.7 °C

b) 21.5 °C

c) 51.5 °C

d) 50.0 °C

Correct answer: (c) 51.5 °C.

Given: steam = 2,000 kg/h at 640 kcal/kg ($\approx 2,680$ kJ/kg); condensate at 60 °C (≈ 60 kcal/kg); water = 54,000 kg/h, $C_p = 1$ kcal/kg °C (≈ 4.19 kJ/kg·K), inlet 30 °C.

Formula: Heat given by steam = $m_s(h_g - h_c)$ = heat gained by water = $m_w \times C_p \times \Delta T$.

Substitution: $2,000 \times (640 - 60) = 11,60,000$ kcal/h; $\Delta T = 11,60,000 \div 54,000 = 21.48$ °C; outlet = $30 + 21.48$.

Result: **51.5 °C.**

Why the other options are wrong: (a) 53.7 °C – ignores the heat still held by the condensate leaving the condenser. (b) 21.5 °C – is the temperature rise of the water, not its outlet temperature. (d) 50.0 °C – uses latent heat only and ignores the sub-cooling of the condensate.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 5 – Material and Energy Balance.

24. A furnace burns 600 kg/h of fuel oil whose theoretical air requirement is 13.9 kg/kg fuel. It is operated with 20% excess air. Treating the oil as ash-free, what is the mass flow of flue gas?

[2P1CEM024 | Chapter 5: Material and Energy Balance | Combustion air and flue gas quantity]

- a) 8,340 kg/h
- b) 10,008 kg/h
- c) 8,940 kg/h
- d) 10,608 kg/h

Correct answer: (d) 10,608 kg/h.

Given: fuel = 600 kg/h; theoretical air = 13.9 kg/kg; excess air = 20%; ash-free fuel.

Formula: Actual air = theoretical air $\times$ (1 + EA/100); Flue gas = (actual air + 1) $\times$ fuel rate, by mass balance (all fuel mass leaves in the gas).

Substitution: $13.9 \times 1.20 = 16.68$ kg/kg; $(16.68 + 1) \times 600 = 17.68 \times 600$.

Result: **10,608 kg/h of flue gas.**

Why the other options are wrong: (a) 8,340 kg/h – is only the theoretical air flow, not the flue gas. (b) 10,008 kg/h – counts the actual air but forgets to add the mass of fuel burnt. (c) 8,940 kg/h – uses theoretical air and ignores the 20% excess air.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 5 – Material and Energy Balance.

25. In a Sankey diagram prepared after an energy balance of a process, what does the width of each band represent?

[2P1CEM025 | Chapter 5: Material and Energy Balance | Sankey diagram]

- a) The quantity of energy carried by that flow
- b) The temperature at which energy leaves the process
- c) The cost of energy carried by each stream
- d) The ease with which each loss can be recovered

Correct answer: (a) The quantity of energy carried by that flow.

A Sankey diagram is a flow chart of the energy balance. The input is drawn as one wide band that splits into useful output and the individual losses, and each band's width is proportional to the energy it carries.

It shows at a glance where the biggest losses are, so the auditor can prioritise. For example, in a furnace it shows flue gas loss, wall loss, opening loss and heat to stock.

It does not show temperature level or cost, which must be assessed separately when choosing recovery measures.

Why the other options are wrong: (b) Temperature level (energy quality) is not shown by band width. (c) The diagram shows energy quantities, not their rupee value. (d) Recoverability is judged afterwards and is not drawn to scale.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 5 – Material and Energy Balance.

26. For a continuous process that runs at steady state with no chemical reaction, how does the general balance 'input + generation = output + consumption + accumulation' simplify for each component?

[2P1CEM026 | Chapter 5: Material and Energy Balance | General material balance equation]

- a) Mass input equals output plus the accumulation term
- b) Mass input of each component equals its mass output
- c) Moles of reactants equal moles of products in each stream
- d) Mass input of each component is always greater than output

Correct answer: (b) Mass input of each component equals its mass output.

The guidebook's material balance is based on the law of conservation of mass: Input + Generation = Output + Consumption + Accumulation.

With no reaction, the generation and consumption terms are zero. At steady state nothing builds up or depletes in the system, so accumulation is zero. Hence for every component, mass in = mass out.

The auditor first fixes a basis and a clear system boundary, then writes this balance stream by stream to find the unknown flows.

Why the other options are wrong: (a) At steady state the accumulation term is zero by definition. (c) Moles need not balance even with reaction; mass of each component balances here. (d) Would mean continuous accumulation, which steady state rules out.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 5 – Material and Energy Balance.

27. In the energy action planning framework of the guidebook (make commitment, assess performance, set goals, ...), which step comes immediately after 'set goals'?

[2P1CEM027 | Chapter 6: Energy Action Planning | Energy action plan - sequence of steps]

- a) Create an action plan
- b) Assess performance and opportunities
- c) Recognise achievements
- d) Evaluate progress

Correct answer: (a) Create an action plan.

The guidebook's seven-step framework is: (1) make commitment (appoint an energy manager and team, and adopt an energy policy); (2) assess performance and opportunities (data, baseline, benchmarking, audit); (3) set goals; (4) create an action plan (technical steps, roles and resources); (5) implement the action plan (communication, awareness, capacity building, tracking); (6) evaluate progress; (7) recognise achievements.

The cycle then repeats for continual improvement.

Why the other options are wrong: (b) Assess performance and opportunities – comes before setting goals, since goals need a baseline. (c) Recognise achievements – is the last step of the cycle. (d) Evaluate progress – comes after the action plan has been implemented.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 6 – Energy Action Planning.

28. Which activity belongs to the step 'assess performance and opportunities' of an energy action plan?

[2P1CEM028 | Chapter 6: Energy Action Planning | Assess performance and opportunities]

- a) Publicising results and rewarding the best department
- b) Forming an energy team and appointing its leader
- c) Fixing a 5% cut in steam use for next year
- d) Collecting energy data and comparing it with a baseline

Correct answer: (d) Collecting energy data and comparing it with a baseline.

Assessing performance means understanding current energy use: collecting and tracking data on all energy sources, normalising it, establishing a baseline, benchmarking against similar facilities and analysing the data to find opportunities, often through an energy audit.

Only after this can realistic goals be set. Team formation and policy adoption come under commitment, and reward schemes come under recognition.

Why the other options are wrong: (a) Belongs to the step 'recognise achievements'. (b) Belongs to the step 'make commitment'. (c) Belongs to the step 'set goals'.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 6 – Energy Action Planning.

29. To be effective, a plant's energy policy should be formally signed and issued by whom?

[2P1CEM029 | Chapter 6: Energy Action Planning | Energy policy - endorsement]

- a) The accredited energy auditor
- b) The energy manager of the plant
- c) The chief executive or top management
- d) The State Designated Agency

Correct answer: (c) The chief executive or top management.

An energy policy is management's written commitment to energy efficiency. It sets objectives, assigns responsibility and commits resources.

It must be endorsed and signed by top management (the managing director or CEO) so that it carries authority across all departments. It is then communicated to all staff and reviewed periodically.

The energy manager drafts it, coordinates its implementation and reports progress.

Why the other options are wrong: (a) The accredited energy auditor – is an external or independent verifier, not the owner of the policy. (b) Drafts and implements the policy but cannot commit the organisation's resources. (d) The State Designated Agency – enforces the EC Act but does not issue company policies.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 6 – Energy Action Planning.

30. A heat pump water heater costs ₹ 18 lakh installed. It saves 52,000 kWh/yr at ₹8.00/kWh but needs an annual maintenance contract of ₹ 0.40 lakh. What is the simple payback period?

[2P1CEM030 | Chapter 7: Financial Management | Simple payback with added running cost]

- a) 4.42 years
- b) 3.95 years
- c) 4.79 years
- d) 4.33 years

Correct answer: (c) 4.79 years.

Given: investment = ₹18,00,000; gross saving = 52,000 × ₹8.00 = ₹4,16,000/yr; maintenance = ₹40,000/yr.

Formula: Simple payback = first cost ÷ (annual saving – annual cost of operation).

Substitution: net saving = ₹4,16,000 – ₹40,000 = ₹3,76,000; 18,00,000 ÷ 3,76,000 = 4.787.

Result: **4.79 years**. Payback ignores the time value of money and savings after payback.

Why the other options are wrong: (a) 4.42 years – adds one year's maintenance to the capital instead of reducing the yearly saving. (b) 3.95 years – adds the maintenance cost to the saving instead of deducting it. (d) 4.33 years – ignores the annual maintenance cost.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 7 – Financial Management.

31. A compressor will need a major overhaul costing ₹ 6 lakh at the end of year 4. At a discount rate of 10% a year, what is the present value of this future cost?

[2P1CEM031 | Chapter 7: Financial Management | Present value of a single future cost]

- a) ₹ 8.785 lakh
- b) ₹ 4.286 lakh
- c) ₹ 4.508 lakh
- d) ₹ 4.098 lakh

Correct answer: (d) ₹ 4.098 lakh.

Given: future amount = ₹6,00,000 at end of year 4; i = 10%.

Formula: $PV = FV \div (1 + i)^n$.

Substitution: $(1.10)^4 = 1.4641$; ₹6,00,000 ÷ 1.4641 = ₹4,09,808.

Result: **₹ 4.098 lakh**. Discounting such future outlays is needed when comparing options by life-cycle cost or NPV.

Why the other options are wrong: (a) ₹ 8.785 lakh – compounds forward to a future value instead of discounting. (b) ₹ 4.286 lakh – discounts at simple interest instead of compound interest. (c) ₹ 4.508 lakh – discounts for only three years.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 7 – Financial Management.

32. An energy project costs ₹ 10 lakh and saves ₹ 3 lakh at the end of every year. At a discount rate of 10%, what is its discounted payback period (interpolating within the year)?

[2P1CEM032 | Chapter 7: Financial Management | Discounted payback period]

- a) 3.33 years
- b) 3.67 years
- c) 4.26 years
- d) 5.00 years

Correct answer: (c) 4.26 years.

Given: cost = ₹10 lakh; saving = ₹3 lakh/yr; $i = 10\%$.

Formula: Discounted payback = year in which the cumulative PV of savings equals the investment; $PV_t = A \div (1 + i)^t$.

Substitution: cumulative PV (₹ lakh): Y1 2.727, Y2 5.207, Y3 7.461, Y4 9.510, Y5 11.372; balance after Y4 = 0.490; fraction = $0.490 \div 1.863 = 0.263$.

Result: **4.26 years.**

Why the other options are wrong: (a) 3.33 years – is the simple payback, which ignores the time value of money. (b) 3.67 years – adds one year of interest to the cost and then uses undiscounted savings. (d) 5.00 years – rounds up to the first whole year in which cumulative PV exceeds the cost.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 7 – Financial Management.

33. A 55 kW (shaft output) motor with 93% efficiency is to be replaced by a premium motor of 95% efficiency at the same load. It runs 6,000 h/yr at ₹8.00/kWh. What is the annual cost saving?

[2P1CEM033 | Chapter 7: Financial Management | Energy-efficient motor - annual saving]

a) ₹ 87,253

b) ₹ 52,800

c) ₹ 59,762

d) ₹ 56,774

Correct answer: (c) ₹ 59,762.

Given: output = 55 kW; $\eta_1 = 0.93$; $\eta_2 = 0.95$; 6,000 h/yr; ₹8.00/kWh.

Formula: kW saved = output $\times (1/\eta_1 - 1/\eta_2)$; Saving = kW saved $\times$ hours $\times$ tariff.

Substitution: $55 \times (1/0.93 - 1/0.95) = 55 \times 0.02264 = 1.245$ kW; $\times 6,000$ h = 7,470 kWh; $\times ₹8.00 = ₹59,762$.

Result: **₹ 59,762 per year.**

Why the other options are wrong: (a) ₹ 87,253 – uses 8,760 h a year instead of the stated operating hours. (b) ₹ 52,800 – multiplies output by the efficiency difference instead of comparing inputs. (d) ₹ 56,774 – applies the efficiency difference to the old input power.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 7 – Financial Management.

34. A company evaluates energy projects at a nominal discount rate of 12%. If the cash flows are estimated in constant (today's) rupees and inflation is expected at 5% a year, what real discount rate should be used?

[2P1CEM034 | Chapter 7: Financial Management | Real and nominal discount rate]

a) 6.25%

b) 6.67%

c) 7.00%

d) 17.60%

Correct answer: (b) 6.67%.

Given: nominal rate = 12%; inflation = 5%.

Formula: $(1 + \text{nominal}) = (1 + \text{real}) \times (1 + \text{inflation})$, so $\text{real} = (1 + \text{nominal}) \div (1 + \text{inflation}) - 1$.

Substitution: $1.12 \div 1.05 - 1 = 1.06667 - 1 = 0.06667$.

Result: **6.67%**. Discount constant-rupee cash flows at the real rate and escalated (nominal) cash flows at the nominal rate. Mixing the two misstates NPV.

Why the other options are wrong: (a) 6.25% – divides by $(1 + \text{nominal rate})$ instead of $(1 + \text{inflation rate})$. (c) 7.00% – uses the simple subtraction approximation instead of the exact relation. (d) 17.60% – compounds inflation on top of the nominal rate instead of removing it.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 7 – Financial Management.

35. In the NPV analysis of an energy efficiency project, the discount rate used should best represent what?

[2P1CEM035 | Chapter 7: Financial Management | Discount rate in NPV analysis]

- a) The interest earned on a savings account
- b) The depreciation rate allowed on the equipment
- c) The expected escalation of electricity tariffs
- d) The investor's opportunity cost of capital

Correct answer: (d) The investor's opportunity cost of capital.

NPV discounts each future cash flow to today using the rate of return the investor could earn on an alternative investment of similar risk, i.e. its opportunity cost of capital, often its weighted cost of capital or hurdle rate.

A project with positive NPV at this rate earns more than the alternative. Tariff escalation and tax effects belong in the cash flows. A higher discount rate gives less weight to distant savings, which penalises long-life energy projects.

Why the other options are wrong: (a) Understates the return the firm could earn on comparable investments. (b)

Depreciation is a tax and accounting allowance, not a cost of capital. (c) Tariff escalation affects the cash flows, not the discount rate.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 7 – Financial Management.

36. Which way of financing an energy efficiency project needs neither fixed repayments to a lender nor any dilution of the owners' shareholding?

[2P1CEM036 | Chapter 7: Financial Management | Financing options - internal accruals]

- a) Internal accruals (retained earnings)
- b) Term loan from a bank
- c) Issue of fresh equity shares
- d) Capital lease of the equipment

Correct answer: (a) Internal accruals (retained earnings).

The guidebook lists financing options for energy projects: from the company's own funds (internal accruals or retained earnings), debt (term loans and bonds), equity, leasing (capital or operating lease) and performance contracting through ESCOs.

Internal funds carry no repayment schedule and no dilution, though they still carry an opportunity cost. Debt brings fixed repayment obligations, equity dilutes ownership, and leases involve fixed rentals.

Why the other options are wrong: (b) Requires fixed interest and principal repayments. (c) Dilutes the existing owners' shareholding. (d) Commits the firm to fixed lease rentals.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 7 – Financial Management.

37. What is the main limitation of a bar (Gantt) chart compared with a network (CPM/PERT) for scheduling an energy project?

[2P1CEM037 | Chapter 8: Project Management | Gantt chart - limitation]

- a) It cannot show the start and finish dates of activities
- b) It cannot be drawn for projects with fewer than ten activities
- c) It does not show the dependencies between activities clearly
- d) It shows only costs and not the duration of activities

Correct answer: (c) It does not show the dependencies between activities clearly.

A Gantt chart draws each activity as a bar on a time scale. It is simple and good for communicating progress, but it does not clearly show which activity depends on which.

As a result, the effect of a delay on the overall project, the critical path and the float cannot be read from it.

Network techniques (CPM and PERT) make the logic explicit, so they are preferred for planning and control. The Gantt chart is often derived from the network for presentation.

Why the other options are wrong: (a) A Gantt chart shows these directly as bar ends. (b) Gantt charts suit small projects well. (d) Bars show durations against a time scale.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 8 – Project Management.

38. PERT analysis of a boiler retrofit gives an expected duration of 30 weeks along the critical path, with a standard deviation of 3 weeks. What is the probability of completing it within 33 weeks?

[2P1CEM038 | Chapter 8: Project Management | PERT - probability of meeting a deadline]

- a) 84.1%
- b) 34.1%
- c) 15.9%
- d) 95.8%

Correct answer: (a) 84.1%.

Given: expected time $T_e = 30$ weeks; $\sigma = 3$ weeks; scheduled time $T_s = 33$ weeks.

Formula: $z = (T_s - T_e) \div \sigma$; probability = area under the normal curve to the left of z .

Substitution: $z = (33 - 30) \div 3 = 1.00$; from normal tables, $P(z \leq 1.00) = 0.8413$.

Result: **84.1% probability** of completing within 33 weeks. PERT assumes the project duration is normally distributed about the sum of expected times on the critical path.

Why the other options are wrong: (b) 34.1% – is the area between the mean and $z = 1$ only, omitting the 50% below the mean. (c) 15.9% – is the probability of NOT finishing within the deadline. (d) 95.8% – treats 3 weeks as the variance, so $\sigma = \sqrt{3}$.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 8 – Project Management.

39. Why is a dummy activity used in an activity-on-arrow network?

[2P1CEM039 | Chapter 8: Project Management | Dummy activity in a network]

- a) To represent waiting time for delivery of materials
- b) To mark activities that have zero total float
- c) To show a logical dependency without using time or resources
- d) To add a time buffer at the end of the project

Correct answer: (c) To show a logical dependency without using time or resources.

In activity-on-arrow (AOA) networks, a dummy (shown as a dashed arrow) has zero duration and uses no resources.

It is used to (i) show a dependency that cannot otherwise be drawn, for example when an activity depends on only some of the activities ending at a node, and (ii) give each activity a unique pair of start and end events when two activities run between the same nodes.

Dummies keep the network logic correct without changing the duration.

Why the other options are wrong: (a) A delivery wait takes time, so it is a real activity. (b) Zero float identifies critical activities, not dummies. (d) A dummy has zero duration and adds no buffer.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 8 – Project Management.

40. In critical path calculations, what does the backward pass through the network determine?

[2P1CEM040 | Chapter 8: Project Management | Backward pass in CPM]

- a) The latest finish and latest start of each activity
- b) The earliest start and earliest finish of each activity
- c) The optimistic and pessimistic durations of each activity
- d) The crash cost slope of each activity

Correct answer: (a) The latest finish and latest start of each activity.

The forward pass starts at the project start and gives each activity's earliest start (ES) and earliest finish (EF), which fixes the project duration.

The backward pass starts from the project end time and works back to give the latest finish (LF) and latest start (LS) of each activity without delaying the project.

Total float = $LS - ES = LF - EF$. Activities with zero total float form the critical path.

Why the other options are wrong: (b) These come from the forward pass. (c) These are PERT estimates supplied as inputs. (d) Cost slope comes from normal and crash cost data.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 8 – Project Management.

41. A non-critical activity with a total float of 5 days is delayed by 3 days. What is the effect, other things unchanged?

[2P1CEM041 | Chapter 8: Project Management | Delay within total float]

- a) Project is delayed by 3 days since every delay adds
- b) Total float of every critical activity rises by 3 days
- c) Activity becomes critical and project slips by 2 days
- d) Project completion is unaffected because the delay is within float

Correct answer: (d) Project completion is unaffected because the delay is within float.

Total float is the time by which an activity can be delayed without delaying project completion.

A 3-day delay against 5 days of total float leaves 2 days of float on that path. The project end date is unchanged, although the float available to later activities on the same path is reduced, and some successors may start later if the free float was smaller.

If the delay exceeded 5 days, the excess would extend the project.

Why the other options are wrong: (a) Only delays beyond total float extend the project. (b) Critical activities keep zero float. (c) Remaining float is 2 days, so no project delay occurs.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 8 – Project Management.

42. A bottling plant's monthly electricity use follows $E = 2.4P + 18,000$ (E in kWh, P in kL). Its capacity is 10,000 kL/month, but this month it bottled 7,500 kL. What is the specific energy consumption this month?

[2P1CEM042 | Chapter 9: Energy Monitoring and Targeting | Specific energy consumption from an E-P relation]

- a) 4.20 kWh/kL
- b) 3.60 kWh/kL
- c) 2.40 kWh/kL
- d) 4.80 kWh/kL

Correct answer: (d) 4.80 kWh/kL.

Given: $E = 2.4P + 18,000$; $P = 7,500$ kL.

Formula: $SEC = E \div P = \text{slope} + \text{intercept} \div P$.

Substitution: $E = 2.4 \times 7,500 + 18,000 = 36,000$ kWh; $SEC = 36,000 \div 7,500 = 4.800$.

Result: **4.80 kWh/kL**. Because of the fixed part, SEC rises when output falls, so SEC must be judged against the E–P line, not against a single fixed number.

Why the other options are wrong: (a) 4.20 kWh/kL – computes SEC at full capacity, not at this month's output. (b) 3.60 kWh/kL – divides by rated capacity instead of the actual production. (c) 2.40 kWh/kL – is only the slope (variable part) and ignores the fixed consumption.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 9 – Energy Monitoring and Targeting.

43. Which of the following is NOT one of the elements of a monitoring and targeting (M&T) system?

[2P1CEM043 | Chapter 9: Energy Monitoring and Targeting | Elements of monitoring and targeting]

- a) Reporting results and taking corrective action
- b) Tendering for new energy-efficient equipment
- c) Recording energy use against production
- d) Setting targets for reduced energy use

Correct answer: (b) Tendering for new energy-efficient equipment.

The guidebook lists the essential elements of M&T as: recording (measuring and recording energy consumption), analysing (correlating energy with output), comparing (with benchmarks or past performance), setting targets, monitoring (comparing consumption with target regularly), reporting (results and variances) and controlling (corrective action).

Buying equipment may follow from M&T findings, but procurement is not an M&T element.

Why the other options are wrong: (a) Reporting and controlling are core elements. (c) Measuring and recording is the first element. (d) Target setting is a core element.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 9 – Energy Monitoring and Targeting.

44. When monthly energy use is plotted against production and a straight line $E = mP + c$ is fitted, what does the intercept c represent?

[2P1CEM044 | Chapter 9: Energy Monitoring and Targeting | Intercept of the energy-production line]

- a) Energy consumed regardless of production, such as lighting and idling
- b) Energy lost only during start-up of the process each month
- c) The target energy saving to be achieved in the next month
- d) Energy used per unit of product at full capacity

Correct answer: (a) Energy consumed regardless of production, such as lighting and idling.

In $E = mP + c$, the slope m is the variable energy needed per unit of production, and the intercept c is the fixed (base or non-production-related) energy.

The fixed part covers building services, lighting, idle running, standby losses and heating of systems.

A large intercept relative to total use shows poor energy control at low output. Reducing c through switching off idle equipment and better scheduling is a key M&T objective, besides reducing m .

Why the other options are wrong: (b) Start-up is one part of the fixed load, not its definition. (c) Targets are set separately from the fitted line. (d) Per-unit use is the slope m , not the intercept.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 9 – Energy Monitoring and Targeting.

45. Which Kyoto Protocol mechanism allows an industrialised (Annex I) country to earn emission credits from a project that reduces emissions in a developing country such as India?

[2P1CEM045 | Chapter 10: Energy Efficiency and Climate Change | Kyoto Protocol flexible mechanisms]

- a) Joint Implementation
- b) International Emissions Trading
- c) Montreal Protocol Fund
- d) Clean Development Mechanism

Correct answer: (d) Clean Development Mechanism.

The Kyoto Protocol has three flexible mechanisms. (i) Joint Implementation (JI): emission-reduction projects in one Annex I country financed by another, earning ERUs. (ii) Clean Development Mechanism (CDM): projects in non-Annex I (developing) countries earn Certified Emission Reductions (CERs) usable by Annex I countries, while supporting sustainable development in the host country. (iii) Emissions Trading among Annex I parties.

India hosted a large number of CDM projects.

Why the other options are wrong: (a) Joint Implementation – covers projects between two Annex I countries. (b)

International Emissions Trading – trades assigned amounts among Annex I countries, not project credits. (c) Montreal Protocol Fund – funds the phase-out of ozone-depleting substances, not GHG credits.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 10 – Energy Efficiency and Climate Change.

46. Which of the following is NOT one of the six greenhouse gases in the Kyoto Protocol basket?

[2P1CEM046 | Chapter 10: Energy Efficiency and Climate Change | Kyoto basket of greenhouse gases]

- a) Carbon monoxide (CO)
- b) Sulphur hexafluoride (SF₆)
- c) Nitrous oxide (N₂O)
- d) Perfluorocarbons (PFCs)

Correct answer: (a) Carbon monoxide (CO).

The six Kyoto gases are carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF₆).

Their emissions are converted to tonnes of CO₂ equivalent using their global warming potentials. Carbon monoxide is an air pollutant and a sign of incomplete combustion; it is not in the basket.

CFCs are controlled under the Montreal Protocol because they deplete ozone.

Why the other options are wrong: (b) Sulphur hexafluoride (SF₆) – is a Kyoto gas with a very high GWP. (c) Nitrous oxide (N₂O) – is a Kyoto gas from fertilisers and combustion. (d) Perfluorocarbons (PFCs) – is a Kyoto gas from aluminium smelting.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 10 – Energy Efficiency and Climate Change.

47. What does the 'additionality' requirement for a CDM project mean?

[2P1CEM047 | Chapter 10: Energy Efficiency and Climate Change | Additionality in CDM projects]

- a) It must use technology not yet available in the host country
- b) Its emission cuts must exceed what would happen without the project
- c) It must add new generating capacity to the national grid
- d) It must be in addition to the host country's legal obligations

Correct answer: (b) Its emission cuts must exceed what would happen without the project.

A CDM project earns CERs only for reductions that are real, measurable and additional, i.e. below the baseline emissions that would have occurred without the registered project activity.

The project proponent must show that barriers such as investment, technology or prevailing practice would have prevented the project without CDM revenue.

This protects environmental integrity, because credits for reductions that would happen anyway would let Annex I countries emit more without any real global benefit.

Why the other options are wrong: (a) New technology is not a requirement of additionality. (c) Additionality concerns emissions, not capacity. (d) Legal compliance is relevant, but the test is the emissions baseline.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 10 – Energy Efficiency and Climate Change.

48. A hostel installs solar water heaters to supply 3,000 litres/day of water heated from 25 °C to 60 °C, replacing electric geysers of 95% efficiency, on 300 days a year. What is the annual electricity saved?

[2P1CEM048 | Chapter 11: New and Renewable Energy Sources | Solar water heater - electricity displaced]

- a) 36,628 kWh
- b) 46,909 kWh
- c) 38,556 kWh
- d) 34,797 kWh

Correct answer: (c) 38,556 kWh.

Given: water = 3,000 L/day ($\approx$ 3,000 kg); $\Delta T = 60 - 25 = 35$ °C; $C_p = 1$ kcal/kg °C ($\approx$ 4.19 kJ/kg·K); geyser $\eta = 0.95$; 300 days/yr.

Formula: Heat = $m \times C_p \times \Delta T$; electricity = heat $\div$ ($860 \times \eta$) $\times$ days.

Substitution: $3,000 \times 1 \times 35 = 1,05,000$ kcal/day; $1,05,000 \div 860 \div 0.95 = 128.52$ kWh/day; $\times 300 = 38,556$ kWh.

Result: **38,556 kWh/yr** of electricity displaced.

Why the other options are wrong: (a) 36,628 kWh – ignores the geyser efficiency. (b) 46,909 kWh – uses 365 days instead of the stated 300 days. (d) 34,797 kWh – multiplies by the efficiency instead of dividing by it.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 11 – New and Renewable Energy Sources.

49. A canal-drop small hydro site has a flow of 4 m³/s and a net head of 25 m. If the overall turbine-generator efficiency is 0.85, what electrical output can be expected?

[2P1CEM049 | Chapter 11: New and Renewable Energy Sources | Small hydro power output]

- a) 833.9 kW
- b) 981.0 kW
- c) 708.8 kW

d) 85.0 kW

Correct answer: (a) 833.9 kW.

Given: $Q = 4 \text{ m}^3/\text{s}$; $H = 25 \text{ m}$; $\eta = 0.85$; $\rho = 1,000 \text{ kg/m}^3$; $g = 9.81 \text{ m/s}^2$.

Formula: $P \text{ (kW)} = \rho g Q H \eta \div 1,000 = 9.81 \times Q \times H \times \eta$.

Substitution: $9.81 \times 4 \times 25 \times 0.85 = 833.85 \text{ kW}$.

Result: **833.9 kW** ($\approx 0.83 \text{ MW}$). Small hydro is attractive because the head and flow are available round the clock in canal drops, giving a higher capacity factor than solar or wind.

Why the other options are wrong: (b) 981.0 kW – is the hydraulic power, which ignores the turbine-generator efficiency. (c) 708.8 kW – applies the efficiency twice, although 0.85 is already the overall turbine-generator value. (d) 85.0 kW – omits $g = 9.81 \text{ m/s}^2$ from the power equation.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 11 – New and Renewable Energy Sources.

50. Which statement about a fuel cell is correct?

[2P1CEM050 | Chapter 11: New and Renewable Energy Sources | Fuel cells]

- a) Its efficiency is limited by the Carnot efficiency of a heat engine
- b) It stores electricity like a battery and is recharged from the grid
- c) It burns hydrogen in a small turbine to drive a generator
- d) It converts fuel's chemical energy directly into electricity without combustion

Correct answer: (d) It converts fuel's chemical energy directly into electricity without combustion.

A fuel cell is an electrochemical device. Hydrogen (or a hydrogen-rich fuel) is oxidised at the anode, and oxygen from air is reduced at the cathode. Ions pass through the electrolyte and electrons flow through the external circuit as direct current. The by-products are water and heat.

Since there is no combustion, it is not limited by the Carnot efficiency and has very low emissions. Types include PEM, phosphoric acid, molten carbonate and solid oxide cells.

Why the other options are wrong: (a) It is not a heat engine, so the Carnot limit does not apply. (b) A fuel cell runs as long as fuel and oxidant are supplied. (c) There is no combustion or turbine in a fuel cell.

Ref: BEE Guidebook Book 1 (Paper 1), Ch. 11 – New and Renewable Energy Sources.

..... End of Section I

Section – II: SHORT DESCRIPTIVE QUESTIONS

Marks: $8 \times 5 = 40$

(i) Answer all Eight questions

(ii) Each question carries Five marks

S-1 A State distribution company (DISCOM) reports the following data for a year.

[2P1CEM051 | Chapter 1: Energy Scenario | Aggregate Technical & Commercial (AT&C) losses of a DISCOM]

Parameter	Value
Energy input to the distribution system	1,200 MU
Energy billed to consumers	960 MU
Amount billed	₹ 5,280 crore
Amount realised (collected)	₹ 4,910.4 crore

- (a) Calculate the billing efficiency and the T&D loss (%). [1 Mark]
- (b) Calculate the collection efficiency and the AT&C loss (%). [2 Marks]
- (c) APDRP aimed to bring AT&C losses down to 15%. If collection efficiency is raised to 99%, what billing efficiency is needed to reach this target? [1 Mark]
- (d) State any two features of the Availability Based Tariff (ABT). [1 Mark]

S-1 Ans

(a) [1 mark]

Given: energy input = 1,200 MU; energy billed = 960 MU; amount billed = ₹ 5,280 crore; amount realised = ₹ 4,910.4 crore.

Formula: Billing efficiency = energy billed ÷ energy input; T&D loss = 1 – billing efficiency.

Substitution: $960 \div 1,200 = 0.80$.

Result: **billing efficiency = 80%; T&D loss = 20% (240 MU).** (1 mark)

(b) [2 marks]

Formula: Collection efficiency = amount realised ÷ amount billed; AT&C loss = $[1 - (\text{billing efficiency} \times \text{collection efficiency})] \times 100$.

Substitution: collection efficiency = $4,910.4 \div 5,280 = 0.930$ (93.0%) (1 mark); AT&C = $[1 - (0.80 \times 0.93)] \times 100 = [1 - 0.744] \times 100$.

Result: **AT&C loss = 25.6%;** energy effectively realised = $1,200 \times 0.744 = 892.8$ MU. (1 mark)

(c) [1 mark]

Formula: $1 - \text{BE} \times \text{CE} = 0.15$, so $\text{BE} = 0.85 \div \text{CE}$.

Substitution: $\text{BE} = 0.85 \div 0.99 = 0.8586$.

Result: **billing efficiency $\geq 85.9\%$,** i.e. T&D loss must fall to about 14.1%. (1 mark)

(d) [1 mark]

Any two (½ mark each): (i) performance-based tariff for supply by centrally owned generating stations, with capacity charges linked to declared availability; (ii) generators and beneficiaries commit to day-ahead schedules; (iii) deviations are settled through unscheduled interchange charges that vary with grid frequency, i.e. a system of rewards and penalties; (iv) schedule revisions are allowed if notified 1½ hours in advance; (v) has reduced voltage and frequency fluctuations and emphasises prompt payment of dues. (1 mark)

Marking scheme (5 marks): a) BE and T&D loss 1. b) Collection efficiency 1, AT&C 1. c) Required BE 1. d) Two ABT features, ½ each.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 1 – Energy Scenario.

S-2 A dyeing machine needs a batch of 6,000 kg of water heated from 30 °C to 85 °C. Two options are compared:

(1) direct injection of dry saturated steam (total enthalpy 656 kcal/kg), whose condensate mixes with the batch;

(2) electric immersion heaters of 95% efficiency. Steam costs ₹2.40/kg and electricity ₹8.50/kWh. Take C_p of water = 1 kcal/kg °C and neglect losses from the vessel.

[2P1CEM052 | Chapter 3: Basics of Energy and its Various Forms | Batch water heating - direct steam injection versus electric heating]

(a) Calculate the heat required per batch. [1 Mark]

(b) Calculate the steam required per batch for direct injection. [2 Marks]

(c) Calculate the electricity required per batch and compare the energy cost of the two options. [1 Mark]

(d) Give one advantage and one limitation of direct steam injection. [1 Mark]

S-2 Ans

(a) [1 mark]

Given: $m = 6,000$ kg; $T_1 = 30$ °C; $T_2 = 85$ °C; $C_p = 1$ kcal/kg °C (≈ 4.19 kJ/kg·K).

Formula: $Q = m \times C_p \times (T_2 - T_1)$.

Substitution: $6,000 \times 1 \times (85 - 30) = 6,000 \times 55$.

Result: **Q = 3,30,000 kcal ($\approx 1,382$ MJ) per batch.** (1 mark)

(b) [2 marks]

Given: steam enthalpy = 656 kcal/kg ($\approx 2,747$ kJ/kg); the condensate stays in the batch at 85 °C (enthalpy ≈ 85 kcal/kg (≈ 356 kJ/kg)).

Formula: $m_s \times (h_g - h_{\text{final}}) = Q$, so $m_s = Q \div (h_g - h_{\text{final}})$.

Substitution: $m_s = 3,30,000 \div (656 - 85) = 3,30,000 \div 571$.

Result: **$m_s = 577.9$ kg of steam per batch;** the batch grows to 6,578 kg, which must be allowed for in the recipe. (2 marks)

(c) [1 mark]

Formula: $kWh = Q \div (860 \times \eta)$.

Substitution: $3,30,000 \div (860 \times 0.95) = 403.9 \text{ kWh}$; electric cost = $403.9 \times ₹8.50 = ₹3,433$; steam cost = $577.9 \times ₹2.40 = ₹1,387$.

Result: **electricity 403.9 kWh (₹3,433) vs steam 577.9 kg (₹1,387)**; steam injection is cheaper by ₹2,046 per batch (60%). (1 mark)

(d) [1 mark]

Advantage (½ mark): nearly all the steam enthalpy, including the condensate heat, is transferred to the batch, with no heat-exchange surface and very fast heating.

Limitation (½ mark): the condensate is lost (it dilutes the batch and cannot be returned), so make-up water and its treatment cost rise; also, steam purity must be compatible with the product, and noise and hammering need sparger design. (1 mark)

Marking scheme (5 marks): a) 1. b) Formula ½, substitution 1, result ½. c) kWh and cost comparison 1. d) One advantage ½, one limitation ½.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 3 – Basics of Energy and its Various Forms.

S-3 A power boiler is designed for coal of 4,500 kcal/kg GCV. Two coals are available. The boiler needs a fuel heat input of 450 crore kcal (4.5×10^9 kcal) per day.

[2P1CEM053 | Chapter 5: Material and Energy Balance | Material balance for blending two coals]

Coal	GCV (kcal/kg)	Ash (%)	Delivered price (₹/t)
A (washed/imported)	5,600	16	9,800
B (high-ash domestic)	3,700	42	4,200

(a) Find the mass fraction of each coal in a blend that gives exactly 4,500 kcal/kg. [2 Marks]

(b) Calculate the daily quantity of each coal and the ash generated per day. [2 Marks]

(c) Compare the fuel cost per million kcal (Gcal) of the blend with that of each coal alone, and state why the cheapest coal alone is not simply fired. [1 Mark]

S-3 Ans**(a) [2 marks]**

Given: Coal A GCV 5,600 kcal/kg ($\approx 23,446 \text{ kJ/kg}$), ash 16%; Coal B GCV 3,700 kcal/kg ($\approx 15,491 \text{ kJ/kg}$), ash 42%; blend GCV 4,500 kcal/kg ($\approx 18,841 \text{ kJ/kg}$).

Formula: Energy balance on 1 kg blend: $x \cdot \text{GCV}_A + (1 - x) \cdot \text{GCV}_B = \text{GCV}_{\text{blend}}$, so $x = (\text{GCV}_{\text{blend}} - \text{GCV}_B) \div (\text{GCV}_A - \text{GCV}_B)$.

Substitution: $x = (4,500 - 3,700) \div (5,600 - 3,700) = 800 \div 1,900 = 0.4211$.

Result: **Coal A = 42.11%, Coal B = 57.89% by mass.** (2 marks)

(b) [2 marks]

Formula: Blend required = daily heat input $\div$ blend GCV; ash in blend = $x \cdot \text{ash}_A + (1 - x) \cdot \text{ash}_B$ (material balance on ash).

Substitution: $4.5 \times 10^9 \div 4,500 = 10,00,000 \text{ kg} = 1000 \text{ t/day}$; $A = 1000 \times 0.4211 = 421.1 \text{ t}$; $B = 1000 \times 0.5789 = 578.9 \text{ t}$; ash = $0.4211 \times 16 + 0.5789 \times 42 = 31.05\%$.

Result: **A = 421.1 t/day, B = 578.9 t/day; blend ash = 31.05%, i.e. 310.5 t of ash per day.** (2 marks)

(c) [1 mark]

Substitution: Cost per Gcal: $A = ₹9,800/\text{t} \div 5.6 \text{ Gcal/t} = ₹1,750.0$; $B = ₹4,200 \div 3.7 = ₹1,135.1$; blend = $(₹6,557.9/\text{t}) \div 4.5 = ₹1,457.3$.

Result: **blend ₹1,457.3/Gcal vs A ₹1,750.0 and B ₹1,135.1.** Coal B alone is cheapest per Gcal, but its GCV of 3,700 kcal/kg ($\approx 15,491 \text{ kJ/kg}$) and ash of 42% are outside the boiler design: mill and fan capacity limit firing rate, unburnt carbon and

erosion rise, and ash handling increases, so efficiency and output fall. Blending meets the design GCV at a lower cost than coal A. (1 mark)

Marking scheme (5 marks): a) Energy balance equation 1, fractions 1. b) Daily quantities 1, ash balance 1. c) Cost per Gcal and reasoning 1.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 5 – Material and Energy Balance.

S-4 A foundry will replace its cupola blower and induction furnace controls for ₹ 40 lakh. 70% of the cost is financed by a bank term loan at 11% a year, repayable in 5 equal annual instalments (principal plus interest) at year-ends; the balance is the foundry's own equity. Net energy saving is ₹ 14 lakh a year. Ignore taxes.

[2P1CEM054 | Chapter 7: Financial Management | Debt financing of an energy project - instalment and equity payback]

- (a) Calculate the capital recovery factor and the annual loan instalment. [2 Marks]
- (b) Split the first instalment into interest and principal. [1 Mark]
- (c) Calculate the annual cash surplus after the instalment and the payback period on the equity invested. [1 Mark]
- (d) State one advantage and one risk of debt financing for such projects. [1 Mark]

S-4 Ans

(a) [2 marks]

Given: loan = 70% × ₹40 lakh = ₹28 lakh; $i = 11\%$; $n = 5$ years.

Formula: $CRF = i(1+i)^n \div [(1+i)^n - 1]$; instalment = loan × CRF.

Substitution: $(1.11)^5 = 1.68506$; $CRF = 0.11 \times 1.68506 \div (1.68506 - 1) = 0.27057$; instalment = ₹28 lakh × 0.27057.

Result: **CRF = 0.2706; annual instalment = ₹ 7.576 lakh (₹7,57,597).** (2 marks)

(b) [1 mark]

Formula: interest (year 1) = opening balance × i ; principal = instalment – interest.

Substitution: interest = $28 \times 0.11 = ₹3.08$ lakh; principal = $7.576 - 3.08 = ₹4.496$ lakh.

Result: **interest ₹ 3.08 lakh, principal ₹ 4.496 lakh**; closing balance = ₹23.504 lakh. (1 mark)

(c) [1 mark]

Formula: surplus = annual saving – instalment; equity payback = equity ÷ surplus.

Substitution: surplus = $14 - 7.576 = ₹6.424$ lakh/yr; equity = $40 - 28 = ₹12$ lakh; payback = $12 \div 6.424$.

Result: **surplus ₹ 6.42 lakh/yr; equity payback = 1.87 years** (against 2.86 years simple payback on the full cost). (1 mark)

(d) [1 mark]

Advantage (½ mark): the project is financed largely from its own savings; leverage raises the return on the owner's equity and keeps internal funds free for other uses; interest is tax-deductible in practice.

Risk (½ mark): instalments are fixed, so if savings fall short (lower production, tariff change or poor performance) the firm must still pay; this adds to its debt burden and may need collateral. (1 mark)

Marking scheme (5 marks): a) CRF 1, instalment 1. b) Interest and principal 1. c) Surplus and equity payback 1. d) One advantage ½, one risk ½.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 7 – Financial Management.

S-5 A government department is buying 2,000 split air conditioners for its offices. A 5-star model consumes 1,180 kWh/yr and costs ₹9,000 more than an unlabelled model consuming 1,850 kWh/yr under the same usage. Electricity costs ₹7.50/kWh. Use 860 kcal/kWh and 1 toe = 10^7 kcal.

[2P1CEM055 | Chapter 2: Energy Conservation Act, 2001 and Related Policies | Star-labelled appliance procurement - savings and labels]

- (a) Calculate the annual energy and cost saving per unit and the simple payback of the extra price. [2 Marks]

- (b) Calculate the total annual saving for the whole purchase in kWh and in toe. [1 Mark]
- (c) Distinguish between comparative and endorsement labels, and explain Minimum Energy Performance Standards (MEPS). [2 Marks]

S-5 Ans**(a) [2 marks]**

Given: unlabelled = 1,850 kWh/yr; 5-star = 1,180 kWh/yr; tariff = ₹7.50/kWh; extra price = ₹9,000.

Formula: kWh saved = $E_{\text{old}} - E_{\text{new}}$; ₹ saved = kWh saved $\times$ tariff; payback = extra price $\div$ ₹ saved.

Substitution: $1,850 - 1,180 = 670$ kWh; $670 \times 7.50 = ₹5,025$; $9,000 \div 5,025 = 1.79$.

Result: **670 kWh/yr and ₹5,025/yr per unit; payback = 1.79 years.** (2 marks)

(b) [1 mark]

Formula: total kWh = kWh per unit $\times$ number; toe = kWh $\times 860 \div 10^7$.

Substitution: $670 \times 2,000 = 13,40,000$ kWh; $13,40,000 \times 860 \div 10^7 = 115.24$ toe.

Result: **13,40,000 kWh/yr = 115.2 toe/yr ($\approx 4,823$ GJ/yr), worth ₹100.50 lakh a year.** (1 mark)

(c) [2 marks]

Comparative label ($\frac{1}{2}$ mark): lets consumers compare the energy performance of all models of a product on a scale (e.g. 1 to 5 stars with annual kWh), so they can make an informed choice.

Endorsement label ($\frac{1}{2}$ mark): a seal that marks a product as efficient when it meets the minimum criteria in the product schedule; it does not rank models against each other.

MEPS (1 mark): Minimum Energy Performance Standards prescribe the minimum efficiency (or maximum energy use) that every model of a product must meet. They specify performance, not technology or design, and are reviewed and raised periodically to remove the least efficient products from the market.

Marking scheme (5 marks): a) Savings $\frac{1}{2} + \frac{1}{2}$, payback 1. b) kWh and toe 1. c) Comparative $\frac{1}{2}$, endorsement $\frac{1}{2}$, MEPS 1.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 2 – Energy Conservation Act, 2001 and Related Policies.

S-6 A float-glass plant produced 1,20,000 t of glass last year and used the energy below. Use 1 kcal = 4.1868 kJ and the emission factors given (fuel factors are on NCV basis).

[2P1CEM056 | Chapter 10: Energy Efficiency and Climate Change | Plant greenhouse gas inventory and emission intensity]

Energy source	Annual use	NCV	Emission factor
Coal (to gasifier)	40,000 t	4,100 kcal/kg	95.0 tCO ₂ /TJ
Natural gas	60,00,000 Sm ³	8,500 kcal/Sm ³	56.1 tCO ₂ /TJ
Grid electricity	2.5 crore kWh (25,000 MWh)	—	0.79 tCO ₂ /MWh

- (a) Calculate the CO₂ emissions from coal and natural gas combustion (direct emissions). [2 Marks]
- (b) Calculate the CO₂ emissions from purchased electricity (indirect emissions), the total and the emission intensity per tonne of glass. [2 Marks]
- (c) Suggest two measures to reduce this intensity. [1 Mark]

S-6 Ans**(a) [2 marks]**

Given: coal = 40,000 t at NCV 4,100 kcal/kg ($\approx 17,166$ kJ/kg), EF 95.0 tCO₂/TJ; natural gas = 60 lakh Sm³ at NCV 8,500 kcal/Sm³ (≈ 35.6 MJ/Sm³), EF 56.1 tCO₂/TJ.

Formula: Energy (TJ) = quantity $\times$ NCV $\times 4.1868 \times 10^{-9}$ (kcal $\rightarrow$ TJ); CO₂ = TJ $\times$ EF.

Substitution: coal = 4×10^7 kg $\times 4,100 = 1.64 \times 10^{11}$ kcal = 686.6 TJ $\rightarrow 686.6 \times 95.0 = 65,230$ t; gas = $6 \times 10^6 \times 8,500 = 5.1 \times 10^{10}$ kcal = 213.5 TJ $\rightarrow 213.5 \times 56.1 = 11,979$ t.

Result: **direct CO₂ = 65,230 + 11,979 = 77,209 tCO₂/yr.** (2 marks)

(b) [2 marks]

Formula: indirect CO₂ = MWh purchased × grid emission factor; intensity = total ÷ production.

Substitution: 25,000 MWh × 0.79 = 19,750 t; total = 77,209 + 19,750 = 96,959 t; intensity = 96,959 ÷ 1,20,000 = 0.808.

Result: **total = 96,959 tCO₂/yr; intensity = 0.808 tCO₂ per tonne of glass.** (2 marks)

(c) [1 mark]

Any two (½ mark each): (i) recover furnace waste heat to preheat batch/cullet or generate power; (ii) raise the cullet (recycled glass) ratio, which lowers melting energy; (iii) shift more firing from coal (gasifier) to natural gas, which has a lower emission factor; (iv) oxy-fuel firing or better furnace insulation; (v) buy renewable power or install rooftop solar to cut indirect emissions. (1 mark)

Marking scheme (5 marks): a) TJ conversion 1, direct CO₂ 1. b) Indirect 1, total and intensity 1. c) Two measures ½ each.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 10 – Energy Efficiency and Climate Change.

S-7 A dairy farm collects 1,500 kg of fresh cattle dung a day and feeds it to a biogas plant. The gas yield is 0.036 m³ per kg of fresh dung and the biogas calorific value is 4,800 kcal/m³. The biogas burners have 60% efficiency. The farm canteen and milk-boiling section now use LPG (GCV 11,500 kcal/kg, burner efficiency 65%) bought in 14.2 kg cylinders at ₹950 each. The plant runs 365 days a year.

[2P1CEM057 | Chapter 11: New and Renewable Energy Sources | Biogas plant for a dairy farm - LPG replacement]

(a) Calculate the daily biogas production and the useful heat it can deliver. [2 Marks]

(b) Calculate the LPG that can be replaced (kg/day and cylinders a year) and the annual saving. [2 Marks]

(c) Give two benefits of the digested slurry or two factors that affect biogas yield. [1 Mark]

S-7 Ans

(a) [2 marks]

Given: dung = 1,500 kg/day; yield = 0.036 m³/kg; CV = 4,800 kcal/m³ (≈ 20.1 MJ/m³); η_{burner} = 0.6.

Formula: biogas = dung × yield; useful heat = biogas × CV × η.

Substitution: 1,500 × 0.036 = 54 m³/day; 54 × 4,800 × 0.6 = 1,55,520 kcal/day.

Result: **54 m³/day of biogas; useful heat = 1,55,520 kcal/day (≈ 651 MJ/day).** (2 marks)

(b) [2 marks]

Formula: LPG replaced = useful heat ÷ (GCV_{LPG} × η_{LPG}); cylinders = LPG × 365 ÷ 14.2.

Substitution: 1,55,520 ÷ (11,500 × 0.65) = 20.81 kg/day; 20.81 × 365 ÷ 14.2 = 535 cylinders/yr; 535 × ₹950 = ₹5,08,046.

Result: **20.81 kg LPG/day ≈ 535 cylinders a year, saving ≈ ₹ 5.08 lakh/yr.** (2 marks)

(c) [1 mark]

Any two (½ mark each): slurry is a good organic manure rich in nitrogen and phosphorus; it is free of weed seeds and odour, and it reduces pathogens compared with raw dung. Yield depends on digester temperature (mesophilic around 30–35 °C), pH (about 6.8–7.5), retention time, solids concentration and carbon-to-nitrogen ratio (about 25–30:1), and on avoiding toxic substances. (1 mark)

Marking scheme (5 marks): a) Gas 1, useful heat 1. b) LPG kg/day 1, cylinders and ₹ 1. c) Two points ½ each.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 11 – New and Renewable Energy Sources.

S-8 A multi-unit food processing company wants to set up a formal energy management function across its three plants.

[2P1CEM058 | Chapter 6: Energy Action Planning | Organising energy management - energy manager, information system and motivation]

(a) Where should the energy manager be located in the organisation, and what should be the role of the energy committee or task force? [2 Marks]

(b) What should the energy management information system contain, and what reports should it generate? [2 Marks]

(c) Suggest two ways to motivate employees to take part in energy conservation. [1 Mark]

S-8 Ans

(a) [2 marks]

Location (1 mark): the energy manager should report directly to top management (works director or CEO) or sit in a staff position close to it, not deep within one line department. This gives access to all departments, authority to collect data and push measures, and visibility for results. In a multi-plant company, a corporate energy manager coordinates plant energy managers.

Energy committee or task force (1 mark): it includes heads of production, maintenance, utilities, finance and purchase. It reviews energy performance, approves targets and projects, allocates resources, removes interdepartmental barriers and keeps the programme alive.

(b) [2 marks]

Contents (1 mark): metered energy use by source and by cost centre (electricity, fuel, steam, compressed air, water), production data, specific energy consumption, energy costs, targets and baselines, project status and savings.

Reports (1 mark): daily or weekly operating reports for supervisors (deviations from targets), monthly management reports (SEC trend, cost, variance against target and reasons), and annual reports for top management and statutory returns.

Information must be timely, accurate and in a form each level can act upon.

(c) [1 mark]

Any two (½ mark each): suggestion schemes with cash or non-cash rewards; recognising departments that meet targets; displaying energy performance on notice boards; including energy targets in performance appraisal; training and awareness campaigns (e.g. Energy Conservation Day, 14 December); and sharing part of the savings with the team. (1 mark)

Marking scheme (5 marks): a) Location 1, committee role 1. b) Contents 1, reports 1. c) Two motivation methods ½ each.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 6 – Energy Action Planning.

..... End of Section II

Section – III: LONG DESCRIPTIVE QUESTIONS

Marks: 6 × 10 = 60

(i) Answer all Six questions

(ii) Each question carries Ten marks

L-1 The activities for installing a waste-heat recovery boiler on a DG set, with durations and the number of skilled workers each activity needs every day, are given below.

[2P1CEM059 | Chapter 8: Project Management | CPM schedule and resource levelling]

Activity	Predecessor	Duration (days)	Workers per day
A	—	4	4
B	—	5	3
C	A	5	3
D	A	3	4
E	B, C	4	4
F	D	5	3
G	E, F	3	3

(a) Draw the network (activity-on-node), list all paths and identify the critical path and project duration. [3 Marks]

(b) Tabulate ES, EF, LS, LF, total float and free float for every activity. [3 Marks]

(c) Prepare the daily manpower profile if every activity starts at its earliest start, and state the peak requirement. [2 Marks]

(d) Level the resources using the available float so that the peak is as low as possible without extending the project. State the new schedule and peak. [2 Marks]

L-1 Ans

(a) [3 marks]

Given: A (—, 4 d), B (—, 5 d), C (A, 5 d), D (A, 3 d), E (B, C, 4 d), F (D, 5 d), G (E, F, 3 d).

Network (AON): Start → A and B; A → C and D; B and C → E; D → F; E and F → G → Finish.

Formula: path duration = sum of activity durations on the path; critical path = longest path.

Substitution: A–C–E–G = 16 days; A–D–F–G = 15 days; B–E–G = 12 days.

Result: **critical path A–C–E–G; project duration = 16 days.** (3 marks: network 1½, paths ½, CP and duration 1)

(b) [3 marks]

Formula: forward pass ES = max EF of predecessors, EF = ES + t; backward pass LF = min LS of successors, LS = LF – t; TF = LS – ES; FF = ES(earliest successor) – EF.

Activity	Duration	ES	EF	LS	LF	Total float	Free float
A	4	0	4	0	4	0	0
B	5	0	5	4	9	4	4
C	5	4	9	4	9	0	0
D	3	4	7	5	8	1	0
E	4	9	13	9	13	0	0
F	5	7	12	8	13	1	1
G	3	13	16	13	16	0	0

(3 marks: forward pass 1, backward pass 1, floats 1)

(c) [2 marks]

Formula: daily load = sum of workers of all activities in progress that day (ES schedule).

Substitution: days 1–4: 7; 5: 10; 6–7: 7; 8–9: 6; 10–12: 7; 13: 4; 14–16: 3 workers.

Result: **peak = 10 workers on day 5** (B, C and D overlap); minimum = 3. (2 marks)

(d) [2 marks]

Reasoning: the peak comes from D (4 workers) starting on day 5 while B and C are running. D has TF = 1 day and F has TF = 1 day on the same chain (FF of D = 0), so delaying D by 1 day (days 6–8) pushes F to days 9–13; F still finishes by its LF of 13, and G starts on day 14 as before.

Substitution: levelled profile, days 1–4: 7; 5: 6; 6–8: 7; 9: 6; 10–13: 7; 14–16: 3 workers.

Result: **peak falls from 10 to 7 workers with the project still 16 days;** the profile is smoother (non-critical chain D–F now has zero float and must be watched). (2 marks)

Marking scheme (10 marks): a) Network 1½, paths ½, critical path and duration 1. b) Forward pass 1, backward pass 1, floats 1. c) Profile 1, peak 1. d) Correct shift within float 1, new profile and peak 1.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 8 – Project Management.

L-2 A dairy's monthly steam use has been established from last year's data as $S = 0.18P + 260$ (S in tonnes of steam, P in kL of milk processed). Data for the first half of this year are given. Steam costs ₹2,300 per tonne, and each tonne of steam carries 6 lakh kcal (600 kcal/kg net of feed water).

[2P1CEM060 | Chapter 9: Energy Monitoring and Targeting | Monitoring and targeting - steam use in a dairy]

Month	Jan	Feb	Mar	Apr	May	Jun
Milk processed P (kL)	1,800	2,100	1,650	2,300	1,950	2,200
Actual steam S (t)	600	650	560	700	640	650

- (a) Calculate the expected steam use for each month, the deviation of actual from expected (t and %) and identify the months that need investigation (deviation above 3%). [4 Marks]
- (b) Calculate the SEC (t steam/kL) expected at 1,650 kL and at 2,300 kL a month, and explain why SEC alone is a misleading performance indicator here. [2 Marks]
- (c) Management decides to cut the fixed steam use by 25% (insulation, trap and leak repair) and the variable part by 8% (heat recovery in pasteurisers). Write the target equation and calculate the annual steam saving for 24,000 kL of milk, its value and the energy saved in toe. [4 Marks]

L-2 Ans**(a) [4 marks]**

Given: $S = 0.18P + 260$; monthly P and actual S as tabulated.

Formula: expected S = $0.18 \times P + 260$; deviation = actual – expected; % deviation = deviation ÷ expected × 100.

Month	P (kL)	Expected S (t)	Actual S (t)	Deviation (t)	Deviation (%)
Jan	1,800	584	600	+16	+2.7
Feb	2,100	638	650	+12	+1.9
Mar	1,650	557	560	+3	+0.5
Apr	2,300	674	700	+26	+3.9
May	1,950	611	640	+29	+4.7
Jun	2,200	656	650	-6	-0.9

Result: **Apr, May exceed +3% and must be investigated** (e.g. steam leaks, failed traps, poor condensate return, CIP practices, extra product changeovers). Jun is slightly better than expected. (4 marks: expected 1½, deviations 1½, identification 1)

(b) [2 marks]

Formula: $SEC = S \div P = \text{slope} + \text{intercept} \div P$.

Substitution: at 1,650 kL: $0.18 + 260/1,650 = 0.3376 \text{ t/kL}$; at 2,300 kL: $0.18 + 260/2,300 = 0.2930 \text{ t/kL}$.

Result: **SEC = 0.338 t/kL at low output and 0.293 t/kL at high output**; SEC changes with throughput because the fixed 260 t/month is spread over more or less product. A month with low output can look 'inefficient' even if operation is good.

Performance should be judged against the expected value from the E–P relation. (2 marks)

(c) [4 marks]

Formula: target S = (slope × 0.92)P + (intercept × 0.75); annual S = slope × ΣP + intercept × 12.

Substitution: target S = $0.1656P + 195$; baseline = $0.18 \times 24,000 + 260 \times 12 = 7,440 \text{ t}$; target = $0.1656 \times 24,000 + 195 \times 12 = 6,314.4 \text{ t}$; saving = 1,125.6 t/yr.

Value = $1,125.6 \times ₹2,300 = ₹25.89 \text{ lakh/yr}$; energy = $1,125.6 \times 1,000 \text{ kg} \times 600 \text{ kcal/kg} = 6.754 \times 10^8 \text{ kcal} (\approx 33.5 \text{ kJ}) \div 10^7$.

Result: **target S = 0.1656P + 195; saving = 1,125.6 t steam/yr worth ₹ 25.89 lakh, i.e. 67.5 toe/yr ($\approx 2,826 \text{ GJ/yr}$)**. (4 marks: equation 1, annual baseline and target 1½, saving and value 1, toe ½)

Marking scheme (10 marks): a) Expected 1½, deviations 1½, months flagged 1. b) SEC values 1, explanation 1. c) Target equation 1, baseline/target 1½, ₹ saving 1, toe ½.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 9 – Energy Monitoring and Targeting.

L-3 An ESCO offers a hotel a chiller-plant and lighting retrofit costing ₹ 60 lakh, fully funded by the ESCO. Verified savings are ₹ 28 lakh a year for the 6-year life. Under the shared-savings contract the ESCO receives 80% of savings for years 1–4 and spends ₹ 2 lakh a year on maintenance and M&V in that period; from year 5 the hotel keeps all savings but spends ₹ 1 lakh a year on maintenance. The ESCO's cost of capital is 12% and the hotel's is 10%. Ignore taxes and residual value.

[2P1CEM061 | Chapter 7: Financial Management | ESCO shared-savings contract - economics for ESCO and host]

- (a) Tabulate the ESCO's cash flows and calculate its NPV. [3 Marks]

- (b) Estimate the ESCO's IRR and comment on whether the deal suits the ESCO. [2 Marks]
- (c) Calculate the NPV to the hotel under the shared-savings contract. [2 Marks]
- (d) If the hotel instead finances the project itself (paying the ₹ 60 lakh and ₹ 1 lakh a year maintenance for all 6 years), calculate its NPV, compare the two routes and give two non-financial factors in the decision. [3 Marks]

L-3 Ans**(a) [3 marks]**

Given: investment ₹60 lakh at year 0; ESCO share = $0.8 \times 28 = ₹22.4$ lakh/yr less ₹2 lakh maintenance for 4 years; $i = 12\%$.

Formula: $NPV = -C_0 + A \times [1 - (1 + i)^{-n}] \div i$.

Substitution: net inflow = $22.4 - 2 = ₹20.4$ lakh for years 1–4; annuity factor (12%, 4) = 3.0373; $PV = 20.4 \times 3.0373 = 61.962$.

Result: **ESCO NPV = 61.962 – 60 = ₹ 1.96 lakh** (positive, but small). (3 marks)

(b) [2 marks]

Formula: IRR is the rate at which $NPV = 0$, i.e. $20.4 \times \text{annuity factor}(r, 4) = 60$, so annuity factor = 2.941.

Substitution: at 12% the factor is 3.0373 (NPV +1.96); at 14% it is 2.9137 (NPV -0.56); interpolating: $12 + 2 \times 1.96 \div (1.96 + 0.56) = 13.56\%$.

Result: **ESCO IRR ≈ 13.5%**, just above its 12% cost of capital. The margin is thin, so the ESCO is exposed to performance and payment risk and may ask for a longer contract or a larger share. (2 marks)

(c) [2 marks]

Given: hotel receives $20\% \times 28 = ₹5.6$ lakh for years 1–4 and $₹28 - 1 = ₹27$ lakh in years 5–6, with no investment; $i = 10\%$.

Formula: $NPV = \sum CF_t \div (1.10)^t$.

Substitution: $5.6 \times 3.1699 = 17.751$; $27 \times (0.6209 + 0.5645) = 32.006$.

Result: **hotel NPV (shared savings) = ₹ 49.76 lakh** with zero capital outlay. (2 marks)

(d) [3 marks]

Formula: $NPV = -60 + (28 - 1) \times \text{annuity factor}(10\%, 6)$.

Substitution: annuity factor = 4.3553; $27 \times 4.3553 = 117.592$; $NPV = 117.592 - 60$.

Result: **self-financed NPV = ₹ 57.59 lakh vs ₹ 49.76 lakh under the ESCO route**. Self-financing gives ₹7.84 lakh more value if the hotel has the capital and skills; the ESCO route needs no capital and transfers performance risk. (2 marks)

Non-financial factors, any two (½ mark each): performance risk and guarantee; availability of capital or borrowing limits; in-house technical capability for design, O&M and M&V; contract length and dispute risk; and the confidence that measured savings will be shared fairly. (1 mark)

Marking scheme (10 marks): a) Cash flows 1, PV 1, NPV 1. b) IRR 1½, comment ½. c) Hotel NPV 2. d) Self-finance NPV 1, comparison 1, two factors 1.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 7 – Financial Management.

L-4 A 1,000 kWe diesel generator set in a pharmaceutical plant was tested at full load with the following steady-state data. Take ambient temperature as the datum (30 °C), Cp of water = 1 kcal/kg °C, density of water = 1,000 kg/m³ and 1 kWh = 860 kcal.

[2P1CEM062 | Chapter 5: Material and Energy Balance | Energy balance of a DG set and exhaust heat recovery]

Parameter	Measured value
Electrical output	1,000 kWe
HSD consumption	230 kg/h, GCV 10,800 kcal/kg
Exhaust gas	7,000 kg/h at 480 °C, Cp 0.26 kcal/kg °C
Jacket cooling water	40 m³/h, temperature rise 10 °C
Lube oil cooler water	10 m³/h, temperature rise 8 °C
Charge-air cooler water	18 m³/h, temperature rise 7 °C

- (a) Calculate the fuel heat input, the electrical (generating) efficiency and the specific fuel consumption. [2 Marks]
- (b) Calculate each heat loss in kcal/h and as % of input; find radiation and unaccounted losses by difference. [3 Marks]
- (c) Present the energy balance as a table (Sankey data) and comment on the largest recoverable loss. [2 Marks]
- (d) A waste heat boiler is to cool the exhaust to 180 °C with 90% of the heat released reaching the steam. Calculate the steam generated (feed water 60 °C, steam enthalpy 660 kcal/kg) and the furnace oil saved in the existing boiler (efficiency 82%, GCV 10,200 kcal/kg) over 6,000 h/yr, and its value at ₹48/kg. [3 Marks]

L-4 Ans**(a) [2 marks]**

Given: output = 1,000 kWe; HSD = 230 kg/h at GCV 10,800 kcal/kg ($\approx 45,217$ kJ/kg).

Formula: $Q_{in} = \text{fuel} \times \text{GCV}$; $\eta_{gen} = (kWe \times 860) \div Q_{in}$; $\text{SFC} = \text{fuel} \div kWe$.

Substitution: $Q_{in} = 230 \times 10,800 = 24,84,000$ kcal/h; $\eta = 8,60,000 \div 24,84,000 = 0.3462$; $\text{SFC} = 230 \div 1,000$.

Result: **$Q_{in} = 24,84,000$ kcal/h ($\approx 2,888$ kW); $\eta_{gen} = 34.62\%$; $\text{SFC} = 0.230$ kg/kWh.** (2 marks)

(b) [3 marks]

Formula: exhaust loss = $m \times C_p \times (T_{ex} - T_{amb})$; cooling-water loss = $\text{flow} \times 1,000 \times \Delta T$; unaccounted = input – (electrical + all measured losses).

Substitution: exhaust = $7,000 \times 0.26 \times (480 - 30) = 8,19,000$ kcal/h (32.97%); jacket water = $40 \times 1,000 \times 10 = 4,00,000$ kcal/h (16.10%); lube oil cooler = $10 \times 1,000 \times 8 = 80,000$ kcal/h (3.22%); charge-air cooler = $18 \times 1,000 \times 7 = 1,26,000$ kcal/h (5.07%).

Unaccounted = $24,84,000 - (8,60,000 + 8,19,000 + 4,00,000 + 80,000 + 1,26,000) = 1,99,000$ kcal/h (≈ 231 kW).

Result: **radiation and unaccounted loss = 1,99,000 kcal/h (≈ 231 kW) (8.01%).** (3 marks)

(c) [2 marks]

Energy stream	kcal/h	% of input
Fuel input	24,84,000	100.00
Electrical output	8,60,000	34.62
Exhaust gas loss	8,19,000	32.97
Jacket cooling water	4,00,000	16.10
Lube oil cooler	80,000	3.22
Charge-air cooler	1,26,000	5.07
Radiation and unaccounted	1,99,000	8.01

Comment: the exhaust gas (33.0%) is the largest loss and, at 480 °C, the most useful for recovery (steam or thermic fluid).

Jacket water at low temperature (16.1%) can be used for hot water or vapour-absorption chilling. (2 marks)

(d) [3 marks]

Formula: heat recoverable = $m \times C_p \times (T_{ex} - T_{stack})$; steam = $\text{heat to steam} \div (h_g - h_{fw})$; oil saved = $\text{heat to steam} \div (\eta_{boiler} \times \text{GCV})$.

Substitution: $7,000 \times 0.26 \times (480 - 180) = 5,46,000$ kcal/h; $\times 0.9 = 4,91,400$ kcal/h; steam = $4,91,400 \div (660 - 60) = 819$ kg/h; oil = $4,91,400 \div (0.82 \times 10,200) = 58.75$ kg/h; $\times 6,000$ h = 352.5 t/yr; $\times ₹48/\text{kg}$.

Result: **steam ≈ 819 kg/h; furnace oil saved ≈ 352.5 t/yr, worth $\approx ₹ 1.69$ crore/yr.** (3 marks)

Marking scheme (10 marks): a) Input 1, efficiency and SFC 1. b) Exhaust 1, cooling circuits 1, unaccounted by difference 1. c) Balance table 1, comment 1. d) Recoverable heat 1, steam 1, oil saved and value 1.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 5 – Material and Energy Balance.

L-5 During a detailed energy audit of a municipal raw-water pumping station, two identical pumps run in parallel (a third is standby) for 20 hours a day, 365 days a year. Measured data for each running pump are given. Take $1 \text{ kg/cm}^2 \approx 10 \text{ m water column}$ and ignore the velocity head and the gauge-level difference.

[2P1CEM063 | Chapter 4: Energy Management and Audit | Detailed energy audit of a municipal water pumping station]

Measured parameter (each running pump)	Value
Flow (ultrasonic flow meter)	410 m ³ /h
Discharge pressure	4.2 kg/cm ² (g)
Suction pressure	0.3 kg/cm ² (g)
Motor input power (power analyser)	62 kW
Motor efficiency at this load (from test data)	93%

- Calculate the total head and the hydraulic (water) power of each pump. [2 Marks]
- Calculate the pump efficiency, the combined pump-motor efficiency and the specific energy consumption (kWh/m³). [3 Marks]
- The pumps are to be replaced by new pumps of 84% efficiency with IE3 motors of 95% efficiency at the same duty. Calculate the annual energy and cost saving for the two running pumps and the simple payback on an investment of ₹14 lakh. [3 Marks]
- List the instruments used for these measurements, and state in which phase of the detailed audit methodology this work falls. [2 Marks]

L-5 Ans

(a) [2 marks]

Given: flow = 410 m³/h; discharge = 4.2 kg/cm²(g) ($\approx 4.12 \text{ bar(g)}$); suction = 0.3 kg/cm²(g) ($\approx 0.294 \text{ bar(g)} = 29.4 \text{ kPa(g)}$); $1 \text{ kg/cm}^2 (\approx 0.981 \text{ bar} = 98.1 \text{ kPa}) \approx 10 \text{ m}$.

Formula: $H = (P_d - P_s) \times 10$; $P_h \text{ (kW)} = Q \text{ (m}^3/\text{s)} \times \rho \times g \times H \div 1,000$.

Substitution: $H = (4.2 - 0.3) \times 10 = 39 \text{ m}$; $P_h = (410 \div 3,600) \times 1,000 \times 9.81 \times 39 \div 1,000$.

Result: **H = 39 m; hydraulic power = 43.57 kW per pump.** (2 marks)

(b) [3 marks]

Given: motor input = 62.0 kW; motor efficiency = 93%.

Formula: shaft power = input $\times \eta_{\text{motor}}$; $\eta_{\text{pump}} = P_h \div \text{shaft power}$; $\eta_{\text{combined}} = P_h \div \text{input}$; SEC = input $\div \text{flow}$.

Substitution: shaft = $62.0 \times 0.93 = 57.66 \text{ kW}$; $\eta_{\text{pump}} = 43.57 \div 57.66 = 0.7557$; $\eta_{\text{combined}} = 43.57 \div 62.0 = 0.7028$; SEC = $62.0 \div 410 = 0.1512 \text{ kWh/m}^3$.

Result: **$\eta_{\text{pump}} = 75.6\%$; $\eta_{\text{combined}} = 70.3\%$; SEC = 0.151 kWh/m³.** (3 marks)

(c) [3 marks]

Formula: new input = $P_h \div (\eta_{\text{pump,new}} \times \eta_{\text{motor,new}})$; saving = (old – new input) $\times \text{pumps} \times \text{hours}$.

Substitution: new input = $43.57 \div (0.84 \times 0.95) = 54.60 \text{ kW}$; saving per pump = $62.0 - 54.60 = 7.40 \text{ kW}$; annual = $7.40 \times 2 \times 7,300 \text{ h} = 1,08,004 \text{ kWh}$; $\times ₹7.50 = ₹8,10,032$; payback = $14 \div 8.10$.

Result: **saving = 1,08,004 kWh/yr, ₹ 8.10 lakh/yr; simple payback = 1.73 years;** the new SEC is 0.133 kWh/m³. (3 marks)

(d) [2 marks]

Instruments (1 mark): clamp-on ultrasonic flow meter (flow); calibrated pressure gauges or transducers on suction and discharge; portable power analyser (kW, kVA, PF, voltage, current) at the motor terminals; tachometer for speed.

Optionally, a thermometer for water temperature.

Phase (1 mark): measurements and trials on major energy users, followed by analysis and cost-benefit evaluation of options, belong to Phase II (audit phase) of the three-phase detailed audit methodology. Implementing the replacement and verifying savings will be Phase III (post-audit).

Marking scheme (10 marks): a) Head 1, hydraulic power 1. b) Pump η 1, combined η 1, SEC 1. c) New input 1, kWh and ₹ saving 1, payback 1. d) Instruments 1, phase 1.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 4 – Energy Management and Audit.

L-6 An HT consumer's monthly (30-day, 720 h) bill data are: active energy 6,48,000 kWh; lagging reactive energy 4,20,000 kVarh; recorded maximum demand 1,420 kVA; contract demand 1,500 kVA. Tariff: demand charge ₹475/kVA on the higher of the recorded MD or 90% of the contract demand; energy charge ₹7.20/kWh; PF penalty of 1% of energy charges for every 0.01 by which the average PF (rounded to two decimals) is below 0.90; PF incentive of 0.5% of energy charges for every 0.01 above 0.95.

[2P1CEM064 | Chapter 3: Basics of Energy and its Various Forms | HT electricity bill analysis - power factor, capacitor sizing, penalty and incentive]

(a) Calculate the average power factor and the monthly bill (energy charge, demand charge and PF penalty). [3 Marks]

(b) Calculate the capacitor kVar needed to raise the average PF to 0.97 at average load and select a standard rating. [2 Marks]

(c) Assuming the PF at the time of maximum demand also improves to 0.97 with the same kW, calculate the new billing demand and the monthly and annual saving (penalty avoided, incentive earned and demand charge saved), and the payback on capacitors costing ₹600/kVar. [3 Marks]

(d) What further action on the contract demand would you recommend, and what is its additional monthly benefit if the contract demand is reduced to 1,300 kVA? Mention one technical benefit of PF improvement besides tariff savings. [2 Marks]

L-6 Ans

(a) [3 marks]

Given: kWh = 6,48,000; kVarh = 4,20,000; MD = 1,420 kVA; CD = 1,500 kVA.

Formula: $PF = kWh \div \sqrt{(kWh^2 + kVarh^2)}$; energy charge = kWh $\times$ rate; penalty = $(0.90 - PF) \times 100 \times 1\% \times$ energy charge.

Substitution: $\sqrt{(6,48,000^2 + 4,20,000^2)} = 7,72,207$ kVAh; $PF = 0.8392 \rightarrow 0.84$; energy charge = $6,48,000 \times 7.20 = ₹46,65,600$; billing demand = $\max(1,420, 1,350) = 1,420$ kVA $\rightarrow ₹6,74,500$; penalty = $6\% \times 46,65,600 = ₹2,79,936$.

Result: **average PF = 0.84; bill = ₹46,65,600 + ₹6,74,500 + ₹2,79,936 = ₹56,20,036 (₹ 56.20 lakh).** (3 marks)

(b) [2 marks]

Formula: $kVar = kW_{avg} \times (\tan \phi_1 - \tan \phi_2)$.

Substitution: $kW_{avg} = 6,48,000 \div 720 = 900$ kW; $\tan \phi_1 = kVarh \div kWh = 0.6481$; $\tan \phi_2 = \tan(\cos^{-1} 0.97) = 0.2506$; $kVar = 900 \times (0.6481 - 0.2506) = 357.8$.

Result: **≈ 358 kVar required; install 360 kVar** (e.g. automatic PF controller with 6 $\times$ 60 kVar steps). (2 marks)

(c) [3 marks]

Formula: kW at MD = MD $\times$ PF; new MD = kW $\div$ 0.97; billing demand = $\max(\text{new MD}, 0.9 \times CD)$; incentive = $(0.97 - 0.95) \times 100 \times 0.5\% \times$ energy charge.

Substitution: kW at MD = $1,420 \times 0.8392 = 1191.6$ kW; new MD = $1191.6 \div 0.97 = 1228.5$ kVA; billing demand = $\max(1228.5, 1,350) = 1350$ kVA $\rightarrow$ demand saving = $(1,420 - 1350) \times 475 = ₹33,250$; incentive = $1\% \times 46,65,600 = ₹46,656$; penalty avoided = ₹2,79,936.

Result: **monthly saving = ₹2,79,936 + ₹46,656 + ₹33,250 = ₹3,59,842; annual ≈ ₹ 43.18 lakh; capacitor cost = $360 \times ₹600 = ₹2,16,000$, payback ≈ 0.60 month.** Note that the demand saving is limited by the 90% minimum billing clause. (3 marks)

(d) [2 marks]

Recommendation: the improved MD (1228 kVA) is now well below the contract demand, so CD should be reduced. With CD = 1,300 kVA, the minimum billing is 1,170 kVA and the billing demand becomes the actual 1228 kVA.

Substitution: additional saving = $(1350 - 1228.5) \times 475 = ₹57,736$ per month.

Result: **extra ≈ ₹57,736/month (≈ ₹ 6.93 lakh/yr);** keep a margin for growth before reducing further. Technical benefit (any one): lower current and I^2R losses in cables and transformers, better voltage regulation, and released transformer and cable capacity. (2 marks)

Marking scheme (10 marks): a) PF 1, energy and demand charges 1, penalty 1. b) $\tan \phi$ values 1, kVar and rating 1. c) New MD and billing demand 1, savings 1, payback 1. d) CD recommendation and saving 1, technical benefit 1.

Ref: BEE Guidebook Paper 1 (Book 1: General Aspects of Energy Management and Energy Audit), Ch. 3 – Basics of Energy and its Various Forms.

..... End of Section III

Answer key — Section I

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