The following is a list of subjects for the SI CEM exam. The study guide will not lead you to answers to all of the questions, but it will certainly lead you to a very large number of correct answers. A person with the necessary experience who reviews the study guide should have a good chance of passing the exam.

The exam will be open book and will last four hours. All questions are 8 points each. The maximum exam score is 1040 points and passing score is 704. All candidates must answer Sections I and II: Energy Accounting and Economics, and Energy Audits and Instrumentation. The candidate should choose 9 of the remaining 13 sections. If more than 9 additional sections are marked, only the first 9 will be scored. After the first two mandatory sections, the thirteen sections remaining are as follows:

**Electrical Systems**
- Heating, Ventilating and Air Conditioning Systems

**Motor and Drive Systems**
- Industrial Systems

**Building Envelope**
- Combined Heat & Power Systems and Renewable Energy Systems

**Building Automation Systems**
- Thermal Energy Storage Systems

**Control Systems**
- Boiler and Steam Systems

**Lighting Systems**
- Financing, Performance Contracts, Measurement & Verification

**Maintenance and Commissioning**
- Combined Heat & Power Systems and Renewable Energy Systems

I. **ENERGY ACCOUNTING AND ECONOMICS**

- Life-cycle Cost Analysis
- Simple Payback Period
- Time Value of Money
- Present Worth
- Net Present Value
- Present Worth Method
- Internal Rate of Return
- Energy Accounting
- Point of Use Costs
- Discounted Cash Flows
- Energy Unit Conversions
- Interest Formulas and Tables
- Project Life
- Annual Worth Method
- Economic Performance Measures
- Minimum Annual Rate of Return
- Energy Use Index
- Efficiency Measures

II. **ENERGY AUDITS AND INSTRUMENTATION**

- Role of Audits
- Energy Management Measures
- Combustion Analysis
- Power Factor Correction
- Basic Thermodynamics
- Air Velocity Measurement
- Light Level Measurement
- Infrared Equipment
- Audit Equipment
- Load Factors
- Combustion Analyzers
- Electric Metering Equipment
- Temperature Measurement
- Pressure Measurement
- Humidity Measurement
- Data Loggers
Energy Rate Tariffs
Energy and Power Measurement
Fuel Choices
Energy Use Index
Level 1 Audit
Level 3 Audit
ASHRAE Standard 90.1
ASHRAE Standard 135
IEC

III. ELECTRICAL SYSTEMS

Demand and Energy
Real Power
Power Factor
Power Factor Correction
Rate Structure and Analysis
Variable Speed Drives
Voltage Imbalance
Harmonics

Load Factors
Reactive Power
Single- and Three-phase Systems
Peak Demand Reduction
Motors and Motor Drives
Affinity Laws (Pump and Fan Laws)
Power Quality
IEEE Power Quality Standard 519

IV. HEATING, VENTILATING, AND AIR CONDITIONING SYSTEMS

Heating Systems
Air Conditioning Systems
HVAC Equipment Types
Cooling Towers
Vapor Compression Cycle
Affinity Laws
Psychrometric Charts
Heat Transfer
Air- and Water-based Heat Flow
Demand Control Ventilation
Ventilation Heat Recovery

Ventilating Systems
Economizers
Chillers
Heaters
Absorption Cycle
Performance Ratings (COP, HSPF, EER, kW/ton, and more)
Heating and Cooling Degree Days
Air Distribution Systems (Reheat, Multizone, VAV)
Energy Consumption Estimates
ASHRAE Ventilation Standard 62.1
ASHRAE Thermal Comfort Standard 55

V. MOTOR AND DRIVE SYSTEMS

AC Induction Motors
DC Motors
Load Factor and Slip
Motor Speed Control
Fan and Pump Laws
Motor Selection Criteria
Motor Management Software

AC Synchronous Motors
High Efficiency Motors
Power Factor and Efficiency
Variable Frequency Drives
Variable Flow Systems
New vs Rewound Motors
Power Factor Correction

VI. INDUSTRIAL SYSTEMS

Waste Heat Recovery
Industrial Energy Management
Fuel Choices
Steam Systems
Heat Exchangers
Turbines
Affinity Laws
Compressed Air Systems
Air Compressor Controls

Boilers and Thermal Systems
Pipe Insulation
Fuel Selection
Steam Tables
Steam Traps
Pumps
Compressors
Air Compressors
Compressed Air Leaks
### VII. BUILDING ENVELOPE

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XIII. BOILER AND STEAM SYSTEMS

Combustion Efficiency  Air to Fuel Ratio
Excess Air  Combustion Control
Steam Tables  Boiler Economizers
Steam Traps  Steam Leaks
Condensate Return  Boiler Blowdown
Waste Heat Recovery  Flash Steam
Scaling and Fouling  Turbulators
Condensing Boilers  Heat Transfer

XIV. MAINTENANCE AND BUILDING COMMISSIONING

Combustion Control  Compressed Air Leaks
Steam Leaks  Steam Traps
Insulation  Outside Air Ventilation
Group Relamping  Scheduled Maintenance
Preventive Maintenance  Proactive Maintenance
Boiler Scale  Water Treatment
Purpose of Commissioning  Commissioning New Buildings
Need for Commissioning  Real Time and Continuous Commissioning
Measurement & Verification  Commissioning Agent
Phases of Commissioning  Facility Design Intent
Commissioning Documentation  Re-commissioning
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XV. FINANCING, PERFORMANCE CONTRACTS, & MEASUREMENT AND VERIFICATION (M&V)

Sources of Capital  Project Finance Options
Leasing  Capital Lease
Performance Contracts  Energy Service Companies
Shared Savings  Utility Financing
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Baseline Energy Use  Post Retrofit Energy Use
Goals of M&V  M&V Baseline for Savings
Utility Bill Comparison  Calibrated Simulation Modeling
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EVO IPMVP  IPMVP M&V Options
Continuous Measurement  Spot Measurement
1. One of the most basic goals of an energy audit is to determine the cost of energy that a facility uses.
   (A) True  (B) False

2. What would be used to find the quantity of electric current in an electrical circuit?
   (A) Ohmmeter  (B) Ammeter
   (C) Wattmeter  (D) None of the above

3. If electricity costs $0.06 per kilowatt-hour and is used for electric heating with an efficiency of 100%, what is the equivalent price of natural gas per gigajoule if it can be burned with an efficiency of 80%?
   (A) $8.00/GJ  (B) $13.30/GJ
   (C) $15.10/GJ  (D) $21.20/GJ
   (E) $24.30/GJ

4. In operating a boiler with dual fuel capability, which is the lowest cost of fuel given the following?
   Natural gas $4.00/GJ efficiency = 92%,
   Fuel oil $123/ton efficiency = 88% (42,000 kJ/kg)
   (A) Natural gas  (B) Fuel oil

5. A 1000 square metre building consumes the following amounts of energy per year. What is the Energy Use Index in MJ per square metre per year?
   Natural Gas 500 GJ/year  Electricity 60,000 kwh/year
   (A) 716 MJ/m^2/yr  (B) 883 MJ/m^2/yr
   (C) 8150 MJ/m^2/yr  (D) 17,500 MJ/m^2/yr
   (E) 70,000 MJ/m^2/yr

6. An energy saving device will save $25,000 per year for 8 years. How much can a company pay for this device if the interest rate (discount rate) is 15%?
   (A) $112,180  (B) $53,590
   (C) $76,451  (D) $178,420

7. An energy saving device costs $34,500 and will save $9,000 per year for its full life of 8 years. What is the approximate internal rate of return?
   (A) 10%  (B) 12%
   (C) 15%  (D) 20%
   (E) 25%

8. A new device costs $40,000 installed. The device will last 10 years at which time it will have to be replaced. How much will it have to save each year to obtain a 15% internal rate of return before taxes?
   (A) $4,600  (B) $6,450
   (C) $7,970  (D) $9,460

9. An audit for one facility showed that the cosφ is almost always 70% and that the demand is 1000 kW. What capacitor size is needed to correct cosφ to 90%?
   (A) 266 kvar  (B) 536 kvar
   (C) 1,000 kvar  (D) 618 kvar
   (E) 1,214 kvar

10. The amount of reactive power that must be supplied by capacitors to correct a cosφ of 84% to 95% in a 300 kW motor at 75% load and 98% efficiency is:
    (A) 72.8 kvar  (B) 82.5 kvar
    (C) 92.4 kvar  (D) 90.0 kvar
    (E) 123.4 kvar

11. Power factor (Cos φ) correcting capacitors may be located:
    (A) At the inductive load
    (B) At load control centres
12. One disadvantage of metal halide lamps is a pronounced tendency to shift colours as the lamp ages.
   (A) True  (B) False

13. A lighting survey of a 400 square metre office building identified the following fixtures:
    30 - 4 tube fixtures @ 192 watts/fixture
    10 - 100 watt incandescent floodlights
    20 - 75 watt task lamps
What is the lighting density in W/m² of this facility?
   (A) 82.7  (B) 46.7
   (C) 56.4  (D) 20.7
   (E) 10.1

14. A building currently has the following lighting system:
    Present: 196 mercury vapour light fixtures
    Size: 250 watt/lamp, 285 watt/fixture, including ballast

    You have chosen to replace the existing system with the following:
    Proposed: 140 high pressure sodium fixtures
    Size: 150 watt/lamp, 185 watt/fixture, including ballast

    The facility operates 24 hours/day. Approximate the heating effect if the heating system efficiency is
    80%, fuel costs $5.00/GJ and there are 200 heating days in a year.
    (A) $4,446/yr  (B) $2,490/yr
    (C) $6,900/yr  (D) $5,290/yr
    (E) $3,240/yr

15. You find that you can replace a 50 kW motor with a 5 kW motor by cutting the total air flow
    requirements. Calculate the total dollar savings, given the information below:
    Runtime: 8,760 hours/year
    Motor Efficiency: 90% (both motors)
    Electrical Rate: $9.00/kW-month & $0.05/kWh
    Fuel Cost Adjustment: $0.005/kWh
    (A) $29,490  (B) $20,400
    (C) $22,090  (D) $14,010
    (E) $6,460

16. In a facility audit you find one large air handling unit delivering 200 m³/min conditioned air. The air is
    delivered to two manufacturing areas. One has been discontinued, so you find you can close some
    dampers and cut air flow to 150 m³/min. What will be the size required for the new motor if the old one
    was 20 kW?
    (A) 45.12 kW  (B) 13.67 kW
    (C) 8.44 kW  (D) 5.82 kW
    (E) 2.0 kW

17. A 75 kW rotary screw air compressor (and motor) generates approximately how much heat as it
    compresses the air?
    Assume the air compressor only produces 10% of its input in the form of useful work with compressed
    air.
    (A) 1000 kJ/hr  (B) 10,000 kJ/hr
    (C) 100,000 kJ/hr  (D) 250,000 kJ/hr
    (E) 500,000 kJ/hr

18. In calculating heat flows, metal generally provides little resistance to heat flow compared to insulation
    or even air films.
    (A) True  (B) False
19. Air at 20.6 °C dry bulb and 50% relative humidity flows at 3,185 L/s and is heated to 32.2°C dry bulb. How many kW is required in this heating process?
   (A) 4.67 kW  (B) 26.56 kW  (C) 44.33 kW  (D) 69.33 kW  (E) 75 kW

20. Estimate the seasonal energy consumption for a building if its design heating load has been determined to be 105 kW for a design temperature difference of 30°C if the heating season has 1,800 degree days. The heating unit efficiency is 80%.
   (A) 700.0 GJ/yr  (B) 350.1 GJ/yr  (C) 462.2 GJ/yr  (D) 720.6 GJ/yr  (E) 680.4 GJ/yr

21. An absorption chiller system with a COP of 0.8 is powered by hot water that enters at 90°C and leaves at 80°C at a rate of 2 L/s. The chilled water operates on a 5°C temperature difference and the condenser water on a 10°C temperature difference. Calculate the water flow.
   (A) 0.8 L/s  (B) 1.6 L/s  (C) 3.2 L/s  (D) 3.6 L/s  (E) 2.4 L/s

22. A wall has a total thermal resistance of 2.64 m²·°C/W. Determine the annual cost of the heat loss per square metre in a climate having 2,500 heating degree days. The heating unit efficiency is 70% and the fuel cost is $5.00/GJ.
   (A) $0.41/m²  (B) $0.33/m²  (C) $0.58/m²  (D) $0.20/m²  (E) $0.06/m²

23. The k value for a particular piece of insulation changes with temperature.
   (A) True  (B) False

24. When a large insurance call center has an unmanned server room, it produces 340,000 kJ per hour of heat from equipment and lights. How many kW of air conditioning is needed just to remove this heat from the equipment and lights?
   (A) 17.13 kW  (B) 44.70 kW  (C) 94.44 kW  (D) 134.37 kW  (E) 189.29 kW

25. 5000 L/s of air leaves an air handler at 10°C. It is delivered to a room at 18°C. How many kW of air conditioning capacity was lost in the ductwork?
   (A) 48 kW  (B) 20 kW  (C) 36 kW  (D) 60 kW  (E) 3 kW

26. The refrigerant in a vapour compression air conditioner is always in the vapour state.
   (A) True  (B) False

27. Given the parameters below, estimate the percent outside air in this simple single zone heating system.
   Outside Air Temperature = 5 °C
   Return Air Temperature = 22 °C
   Mixed Air Temperature= 18.3 °C
   (A) 27.2 %  (B) 21.8 %  (C) 36.5 %  (D) 5.0%  (E) 86.5 %

28. A large commercial building will be retrofitted with a closed loop air heat pump system. Individual meters will measure costs at each department. Demand billing a small part of the total electrical cost. Would you recommend a TES?
   (A) Yes  (B) No
29. With a load levelling TES strategy, a building manager will:
   (A) Not operate the chiller during peak hours
   (B) Essentially base load the chiller (i.e., operate at a high load most of the time)
   (C) Operate only during the peaking times
   (D) Operate in the “off” season

30. What is the percentage fuel savings in a natural gas fired boiler if the installation of turbulators reduces the stack temperature from 250°C to 200°C? Assume the boiler is operating with 20% excess air.
   (A) 1.10 %   (B) 1.95%
   (C) 2.65%   (D) 3.65%

31. Which of the following methods could be used to detect failed steam traps?
   (A) Ultrasonic equipment to listen to the steam trap operation
   (B) Infrared camera to detect the change in temperature
   (C) Real time MMS using conductance probes
   (D) All the above

32. Given the same amount of excess air and the same flue gas temperature, which fuel provides the highest combustion efficiency?
   (A) Natural Gas   (B) No.2 Fuel Oil
   (C) No.6 Fuel Oil   (D) Coal
   (E) Propane

33. A boiler is rated at 300 kW (output) and 80% efficient. What is the input rating?
   (A) 325,000 J/s   (B) 375,000 J/s
   (C) 10,000 J/s   (D) 1,050,000 J/s
   (E) 8,068,000 J/s

34. Which of the following is not a positive displacement air compressor?
   (A) Helical compressor
   (B) Reciprocating compressor
   (C) Sliding vane compressor
   (D) Axial compressor
   (E) none of the above

35. Which of the following heat exchanger types is most likely to allow cross contamination between heat exchange fluids?
   A) Shell & tube   B) Heat pipe
   C) Heat wheel   D) Recuperator

36. How does steam injection into a gas turbine affect the operation?
   (A) Increases thermal efficiency
   (B) Reduces NOx
   (C) Increases NOx
   (D) A and B
   (E) A and C

37. How much will an air leak cost a facility annually in energy if it has a leak hole that is 6.35 mm in diameter at a pressure of 690 kPa and it goes unrepaired for three months? (based upon 7 cents per kWh)
   (A) $935.00
   (B) $2390.00
   (C) $1620.00
   (D) $5390.00

38. What is the flow rate of 16°C water through a control valve with a flow coefficient of 0.01 and a pressure difference across the valve of 100 kPa?
39. The difference between the setting at which the controller operates to one position and the setting at which it changes to the other is known as the:
   (A) Throttling range   (B) Offset
   (C) Differential       (D) Control Point

40. Devices using 4-20 mA current loops are using digital data transmission.
   (A) True               (B) False
EXAM REVIEW SOLUTIONS

1. (A) True

2. (B)

3. (B) 
   \((0.06/\text{kWh}) \times (277.8 \text{kWh/GJ}) = (16.67/\text{GJ})\)
   \(= (X/\text{GJ}) \times (1/0.8)\)
   \(X = 13.30/\text{GJ}\).

4. (B) For natural gas
   
   \((4.00/\text{GJ})(1.0/0.92) = 4.35/\text{GJ}\)
   
   For fuel oil
   
   \((123/\text{ton})(1 \text{ton}/1000 \text{kg})(1 \text{kg}/42,000 \text{kJ})(1/0.8)\)
   
   \((1,000,000 \text{kJ}/\text{GJ}) = 3.33/\text{GJ}\)
   
   Choose fuel oil

5. (A) Gas \((600 \text{ GJ/yr})(1000 \text{ MJ/GJ}) = 500,000 \text{ MJ/yr}\)
   
   Elect \((60,000 \text{ kWh/yr})(3.6 \text{ MJ/kWh}) = 216,000 \text{ MJ/yr}\)
   
   EUI = \((716,000 \text{ MJ/yr})/1000 \text{ m}^2 = 716 \text{ MJ/m}^2 \text{ yr}\)

6. (A) 
   
   \[ P = A \times \left[ P/A, I, N \right] \]
   
   \[ P = 25,000 \times \left[ P/A, 15\%, 8 \right] \]
   
   \[ = 25,000 \times [4.4873] = 112,182 \text{ (round off)} \]
   
   or \$112,175 (depending on tables)

7. (D) 
   
   \[ P = A \times \left[ P/A, IRR, 8 \right] \]
   
   \[ P = 34,500 \times [P/A, IRR, 8] = 9000 \times [P/A, IRR, 8] \]
   
   \[ [P/A, IRR, 8] = 34500/9000 = 3.833 \]

   From the Interest Tables – Look for P/A and 8 years
   
   For 1 = 20% table; \( P/A = 3.83 \) so IRR = 20%

8. (C) 
   
   \[ P = A \times \left[ P/A, I, N \right] \]
   
   \[ 40,000 = A \times \left[ P/A, 15\%, 10 \right] \]
   
   \[ A = 40,000/[5.0188] = 7970 \]

9. (B) 
   
   \[ \text{kVAR} = 1,000 \text{ kW} \times [\tan (\cos^{-1} 0.7) - \tan (\cos^{-1} 0.9)] \]
   
   \[ \text{kVAR} = 1,000 \text{ kW} \times [0.3172 \text{ (from table)}] = 536 \text{ kvar} \]

10. (A) 
    
    \[ \text{kW} = (300 \text{ kW}) \times 0.75/0.98 = 229.6 \text{ kW} \]
    
    \[ \text{kvar} = 229.6 \text{ kW} \times [\tan (\cos^{-1} 0.84) - \tan (\cos^{-1} 0.95)] = 72.8 \text{ kvar} \]

11. (D) 

12. (A) True

13. (D) 
   
   \[ W = [(30 \times 192) + (10 \times 10) + (20 \times 75)] \]
   
   \[ = 8260 \text{ watts} \]
   
   \[ W/m^2 = 8260 \text{ W}/400 \text{ m}^2 = 20.67 \text{ W/m}^2 \]

14. (E) 
   
   \[ \text{kW saved} = 196 \text{ fix} \times (0.285 \text{ kW/fix}) \]
   
   \[ - 140 \text{ fix} \times (0.185 \text{ kW/fix}) = 30 \text{ kW} \]

   Heating effect
   
   \[ (30 \text{ kW}) \times (24 \text{ h/day}) \times (1/0.8) \times (200 \text{ days/yr}) \times (3.6 \text{MJ/kWh}) = 648,000 \text{ MJ/yr} = 648 \text{ GJ/yr} \]

   Added cost = \((648 \text{ GJ/yr})(\$5/\text{GJ}) = \$3,240/\text{yr} \]

15. (A) 
   
   \[ \text{kW saved} = (45) \times 1/0.9 = 50 \text{ kW} \]
   
   \[ \text{kWh saved} = 50 \text{ kW} \times 8760 \text{ hours/yr} \]
   
   \[ = 438,000 \text{ kWh} \]
   
   \[ $ saved = 50 \text{ kW} \times $ 9/\text{kW/mo} \times 12 \text{ mo/yr} \]
   
   \[ + 438,000 \text{ kWh} \times $ 0.055/\text{kWh} \]
   
   \[ = \$29,490/\text{yr} \]

16. (C) 
   
   \[ \text{kWh} = 20 \times (150/200)^3 = 8.44 \text{ kW} \]

17. (D) 
   
   \[ \text{kJ}/\text{h} = (75 \text{ kW})(3600 \text{ kJ/h/kW})(0.9) = 243,000 \text{ kJ/h} \]

18. (A) True

19. (C) 
   
   \[ q = \text{LPS} \times 1.2 \times \text{DT} = (3185)(1.2)(32.2-20.6) = 44.3 \text{ kW} \]

20. (E) 
   
   \[ q = \text{UA DT}; \]
   
   \[ \text{UA} = 105 \text{ kW}/30 \text{C} = 3.5 \text{ kW/C} \]
   
   Also,
   
   \[ Q = \text{UA} \times 24 \times \text{DD} \]
   
   \[ = (3,500) \text{ W/C} \times 24 \text{ h/day} \times 1,800 \text{ C-day/yr} \times 1/0.8 \]
   
   \[ = 189,000 \text{ kWh/yr} = 680.4 \text{ GJ/yr} \]
21. (C) \[ q = LPS \times 4.2 \times DT \]
\[ q_{in} = (2)(4.2)(90-80) = 84 \text{ kW} \]
\[ q_{out} = \text{COP} \times q_{in} = 0.8 \times 84 \text{ kW} = 67.2 \text{ kW} \]
\[ 67.2 = (LPS)(4.2)(5) \]
\[ LPS_{out} = 3.2 \text{ LPS} \]

22. (C) \[ Q = UA \times 24 \times DD \]
\[ = (1/2.64) \text{ W/m}^2\text{C} \times 24 \text{ h/day} \times 2,500 \text{ C-day/yr} \]
\[ \times 1/0.7 \times 0.0036 \text{ MJ/Wh} \times $0.005/\text{MJ} = $0.584/\text{m}^2\text{ yr} \]

23. (A) True

24. (C) \[ kW = (340,000 \text{ kJ/h})/(3600 \text{ kJ/kWh}) \]
\[ = 94.44 \text{ kW} \]

25. (A) \[ q = LPS \times 1.2 \times DT \]
\[ = 5000 \times 1.2 \times 10 = 60,000 \text{ W} = 60 \text{ kW} \]

26. (B) False

27. (B) \[ % = (\text{RAT} - \text{MAT})/(\text{RAT} - \text{OAT}) \]
\[ = (22 - 18.3)/(22 - 5) = 21.8\% \]

28. (B) No

29. (B) False

30. (C) From combustion chart
\[ \text{Eff}_{OLD} = 80.5\% \quad \text{Eff}_{NEW} = 82.7\% \]
\[ \% \text{savings} = (\text{Eff}_{NEW} - \text{Eff}_{OLD})/\text{Eff}_{NEW} \]
\[ = (82.7 - 80.5)/82.7 = 2.65\% \]

31. (D)

32. (D)

33. (B) Input = 300 kW \times (1/0.8) = 375 kW = 375,000 \text{ J/s}

34. (D)

35. (C)

36. (D)

37. (C)

38. (A) \[ L/s = C_v \sqrt{P}D = 0.01 \sqrt{100} = 0.1 \text{ L/s} \]

39. (C)

40. (B) False