G|PRO

MECHANICAL

TEST YOURSELF QUESTIONS: Answer Key

CHAPTER 1: Sustainability and Mechanical Systems

1. **Sustainable mechanical systems contribute to the four benefits of green building in what ways?**

   Economy: Developers, owners, and operators want higher performing buildings that save money, and sustainable mechanical systems can do this. HVAC is projected to be a leading sector in the green building industry.

   Green building offers new **job** opportunities for people with green building skills. The federal government and many local governments, institutions, and private companies now have energy efficiency standards or requirements for LEED certification. This creates a high demand for professionals who are knowledgeable about sustainable mechanical systems.

   Clean air on construction sites protects the **health** of workers, and fresh indoor air protects occupants who will live, work, learn, or shop in the building. Good indoor air quality is in large part determined by a well-functioning and efficient mechanical system.

   Reducing fuel, electricity use, and carbon emissions is essential to protecting the **environment.** The mechanical systems in a building use the bulk of its energy and are responsible for most of its carbon emissions. By adopting green practices and learning about green building technologies, you are also helping slow climate change, protect our natural resources, and help provide a more sustainable future. *(See pages 2-3)*

2. **How are green mechanical systems different from standard mechanical systems?**

   Maintaining the comfort and health of occupants while reducing energy use and environmental impacts is at the core of sustainable mechanical systems. Sustainable buildings may also incorporate solar heat, cogeneration, heat recovery, and demand control ventilation. Green mechanical systems may be more complex, these systems present more opportunities for improving performance. The efficiency of these systems is further increased by installing thicker insulation on more components, installing sensors to better control fluid flow, recover otherwise wasted heat, and replace energy-wasting single speed drives with variable speed ones. *(See page 3)*

3. **What is efficiency?**
   Efficiency is the ability of a device to deliver its service for the least possible input of energy. *(See page 6)*

4. **Describe some examples of how the whole-building approach can affect HVAC design in high performing buildings.**
   One of the most important green building concepts is the "whole-building approach." In well-designed, high-performing buildings, systems work together to provide a comfortable healthy environment as efficiently as possible.

   For example:
   - If a building uses high-efficiency light bulbs, which don't give off as much heat as incandescent or halogen bulbs, the building uses less energy for both lighting and for cooling.
   - In a building with a tight envelope, the occupants are more comfortable because the windows are less drafty, the heating, and cooling loads are reduced, and ventilation can be monitored, controlled, and tempered.
   - In green buildings, better indoor air quality may require more outside air and the HVAC system will be designed to accommodate the additional loads as efficiently as possible, for example, including heat recovery ventilation. *(See page 5)*

CHAPTER 2: Building Science Basics

1. **Describe energy, heat, and temperature.**
   Energy is the capacity to do work, and it comes in many forms. A fast-moving ball has "kinetic energy" and can do the work of breaking a window. A mass of water behind a dam high on a mountain has "potential energy" and can do work as it flows downhill through a turbine making electricity. Energy in the form of light from the sun can be converted into electric power in a solar cell or into thermal energy, also known as *heat,* as it strikes your face.

   Heat is energy spread out among the billions of atoms and molecules that make up matter. All those molecules are vibrating around all the time, and because they are moving, they have kinetic energy. That kinetic energy is one part of the heat, or thermal energy, in the material. The faster the molecules are vibrating, the more thermal energy is in the material.

   Temperature tells us how much thermal energy is in an object or some material. The higher the temperature, the faster all those molecules are vibrating, and the more energy is stored in the movement. *(See page 14)*

2. **Compare and contrast the different phases of matter: solids, liquids, and gases. Why are the phases important for HVAC?**

    In the *solid* phase, a sample of a substance will have a specific mass, volume, and shape.

    In the *liquid* phase, a sample of a substance will have a definite mass and volume, but no specific shape – it will flow to fill a container.

    In the *gas* (or *vapor*) phase, a sample of a substance will have a definite mass, but the volume can change a lot and there is no specific shape. The substance will expand or shrink to fit its container.

    The phases of matter are important for HVAC because much of the equipment is designed to manage phase changes. *(See page 15)*

3. **What are the different ways that heat is transferred?**

    Heat is transferred in three ways: conduction, convection, or radiation.

    Conduction is heat transfer through direct material contact.

    Convection occurs when heat is transferred through movement of air, water or other fluid. When fluids are warmed, they expand, and become less dense. This makes them lighter, so the warmer portion of the fluid weighs less, and rises. Cooler fluid (air, water, or whatever) flows in beneath it, and this motion of the fluid carries heat around the space.

    Radiation occurs when heat is transferred through direct line-of-sight electromagnetic waves (light or infrared). *(See page 15)*

4. **What are the safety and environmental issues associated with refrigerants?**

    Refrigerants pose safety concerns, but with care, they can be managed and used safely. Some refrigerants are flammable, and some are toxic. However, these issues have been a matter of concern for years, and as a result, there are many regulations dedicated to protecting the public.

    The two environmental concerns are ozone depletion and global warming.

    Ozone forms a shield against harmful UV radiation in the atmosphere. Refrigerants with high ozone depleting potential break down this shield, creating environmental and health issues.

    Some refrigerants have the potential to be global warming gases. Many refrigerants are far more effective at trapping heat than CO_2, and have high "global warming potentials" (GWP). *(See pages 17-18)*

5. **Describe the different types of heat exchangers.**

   Parallel flow (or co-flow) heat exchanger: Because the two fluids are flowing in the same direction, as heat moves from the warm fluid to the cool one, the temperature difference and the heat transfer get smaller. The result is a less effective heat transfer.

   Counterflow heat exchanger: When the fluids are arranged to flow in opposite directions. This is called “counterflow”. The temperature difference between fluids is large throughout the device, and heat exchange is much more effective. It’s common to find counterflow heat exchangers that move 90% of the heat from the warm to the cool fluid.

   Cross flow heat exchangers: when the incoming and outgoing air streams are typically at 90 degree angles to each other. The cross flow mode has a heat transfer efficacy of 50% - 70%, but is often easier to fabricate or integrate with other system components. *(See page 19)*

6. **Compare and contrast axial flow and centrifugal fans.**

   Axial fans consist of a cylindrical housing with the impeller mounted along the axis of the housing. The impeller consists of blades mounted around a central hub — the spinning blades force the air through the fan. A standard ceiling or box fan is an example of the axial configuration. Axial flow fans produce pressure by changing the velocity of air as it passes through the impeller. Axial fans are used in the outdoor units to provide large enough air flow to transfer the heat from the condensers to the outdoor air.

   Centrifugal fans consist of an impeller, mounted inside a round housing. Blades are arranged around the outer rim of the wheel. When it spins, the tendency of rotating objects to fly out in a straight line drives air out the exhaust duct. The general characteristic of centrifugal fans is their ability to develop air pressure and cause air flow in the duct distribution system. Centrifugal fans are commonly found in air handlers, or the indoor part of the mechanical system. *(See page 22)*

7. **Explain the differences between dew point, absolute humidity, and relative humidity.**

   Dew point is the temperature at which water vapor condenses into liquid water.

   Absolute humidity is the amount of water vapor that is present in the air. This combined with the air temperature determines the dew point. At any given temperature there is a maximum amount of water that can remain as vapor in air. The warmer the air is, the more water vapor can be held in the air.

Relative humidity is the amount of moisture suspended in the air as vapor at a specific temperature relative to the maximum amount of moisture that the air could hold at that temperature. *(See page 28)*

CHAPTER 3: Indoor Air Quality and Ventilation

1. **What are the IAQ problems connected to carbon dioxide (CO_2) and carbon monoxide (CO) and their associated solutions?**

   Carbon dioxide (CO_2), inert and harmless by itself, indicates the presence of people breathing. The level of CO_2 in a room provides a good indication of the degree of occupancy and relative air quality in the room. With high levels of CO_2, the resulting lack of oxygen can be toxic, impacting both performance and health. Providing more ventilation and fresh air can solve dangerous levels of CO_2. As long as it's measured and controlled, it won't be harmful within buildings.

   Carbon monoxide (CO), a toxic, odorless, tasteless, and colorless gas, is produced from incomplete combustion. Healthy buildings should have no CO in the air, but if present, it can kill people. At lower levels of exposure, CO causes headaches, dizziness, disorientation, nausea and fatigue. The required solution to repair a carbon monoxide leak, before it reaches dangerous levels, is a service call to repair faulty combustion equipment. *(See page 31)*

2. **What are the problems associated with high levels of relative humidity (RH)? Low levels?**

   When indoor RH is too high: During cooling conditions, if indoor RH is greater than 80% for more than a couple of weeks, mold growth on interior surfaces is likely. If indoor air is consistently greater than 55% RH, dust mites may colonize carpets and furniture.

   When indoor RH is too low:
   - Consistent RH conditions of less than 25 - 30% aggravate dry skin conditions such as eczema or psoriasis.
   - The likelihood of eye, nose, and throat irritation increases.
   - Even though winter has low relative humidity, the extreme surface temperatures still promote condensation and the subsequent mold growth that can accompany it. *(See pages 31-32)*

3. **What are the similarities and differences between ventilation and infiltration?**

   Both ventilation and infiltration refer to the introduction of outside air into the building. Infiltration refers to air that comes in, uncontrolled, through the crevices of the building envelope. Ventilation, on the other hand, is a system of bringing a measured quantity of outside air into the building to improve occupants' health.

4. Describe the different types of air cleaning devices and how they work.

Mechanical air filters remove particles by capturing them on filter materials. High efficiency particulate air (HEPA) filters are in this category.

Electronic air cleaners, such as electrostatic precipitators, use a process called electrostatic attraction to trap charged particles. They draw air through an ionization section where particles obtain an electrical charge. The charged particles then accumulate on a series of flat plates called a collector that has the opposite charge. Gas-phase air filters remove gases and odors by using a material called a sorbent, such as activated carbon, which adsorbs the pollutants through a chemical reaction. These filters typically remove a specific one or group of gaseous pollutants from the airstream. Because of this, they will not reduce concentrations of pollutants for which they were not designed.

Some air cleaners use ultraviolet (UV) light technology to destroy pollutants in indoor air. Examples are ultraviolet germicidal irradiation (UVGI) cleaners and photocatalytic oxidation (PCO) cleaners. UVGI cleaners use ultraviolet radiation from UV lamps that may destroy biological pollutants such as viruses, bacteria, allergens, and molds that are airborne or growing on HVAC surfaces (e.g., found on cooling coils, drain pans, or ductwork). If used, they should be applied along with filtration systems.
(See pages 35-37)

5. What are the three forms of energy recovery ventilation?

Enthalpy Recovery: Energy in air comes in two forms, heat and moisture. Enthalpy recovery systems transfer both the heat and the moisture from one air stream to the other. In winter, it will transfer warmth and moisture from the exhaust air to the incoming outside air, and in the summer, it will reverse the process.

Sensible-only: For some exhaust streams, like toilet exhaust, the risk of potentially contaminating in the air mix with the water vapor restricts the ability to move energy directly from the exhaust to the ventilation air. In this case, sensible-only wheels transfer only the heat energy from one stream to another. There is less of an energy benefit, but it protects the occupants' health.

Desiccant: In the last form, we may only want to move moisture from one stream to the other, or may use a different heating/cooling system, but still want to reduce our need for energy to maintain humidity. Desiccant wheels use specifically designed surface material properties to capture water vapor in one stream and transfer it to another with a minimum of energy input. *(See page 39)*

6. What is a CIAQ plan?

In a Construction Indoor Air Quality (CIAQ) Plan, a contractor ensures clean, safe air during construction for the contractors involved in constructing the building, and for the future occupants. The plan outlines the specific strategies that the entire team will follow to maintain a safe construction environment, the processes that they will follow when activities deviate from the plan, and the quality control procedures that will track progress. *(See page 41)*

CHAPTER 4: Cooling Systems

1. **How does the vapor compression refrigeration cycle work?**
   In the vapor compression refrigeration cycle, liquid refrigerant at a high pressure is delivered to a metering device**.** The metering device causes a reduction in pressure, and therefore a reduction in the saturation (boiling) temperature of the refrigerant. The refrigerant then travels to the evaporator. Heat is absorbed from the air passing over the evaporator and causes the refrigerant in the evaporator to boil from a liquid to a vapor. At the outlet of the evaporator, the refrigerant is now low temperature, low pressure vapor. The refrigerant then travels to the inlet of the compressor. The refrigerant vapor is then compressed and moves to the condenser. The refrigerant is now at a high temperature, high-pressure super heated vapor. As the refrigerant transfers its heat to the outside air, the refrigerant condenses to a liquid. At the condenser outlet, the refrigerant is a high-pressure liquid. The high pressure liquid refrigerant is delivered to the metering device, and the sequence begins again. The saturation temperature is the temperature at which a liquid will change to a vapor or vapor to a liquid. The saturation temperature of a given liquid will vary as the pressure changes. *(See pages 25-26)*

2. **What are the four most common types of direct expansion (DX) systems?**
   Air to air: Here air flows over both the condenser and the evaporator, directly supplying heat to the evaporator and removing it from the condenser.

   Water to water: In larger buildings it is useful to discard the waste heat on top of the building. A simple way to do this is to circulate cooling water through the condenser, and to then pipe it to the outdoors, where the heat can be rejected to the ambient air in either a dry or wet cooling tower. At the same time, water can circulate over and be cooled by the evaporator. This chilled water can then be circulated throughout the building to air handlers that pass room air over chilled, finned tube coil heat exchangers.

   Water to air: In this configuration, water carries heat away from the condenser to be rejected, but room air circulating over the evaporator is cooled by direct expansion. This allows individual cooling units to be placed anywhere the condensing water pipes can be installed, and is common in interior spaces.

   Air to water: It is also possible to have a water-cooled evaporator and air-cooled condenser. *(See pages 42-43)*

3. **Describe packaged and split systems. What are their advantages and disadvantages?**

    A “packaged” unit includes the evaporator, compressor, condenser, and metering device, all mounted in one casing that is piped, wired, and charged with refrigerant and ready for use when installed.

    Being a single, packed unit makes these systems easy to install and reliable, but they require substantial openings in the walls of buildings, which are likely to allow excessive

    A “split” system, found in residential and some commercial applications, will have the compressor and condenser (condensing unit) outside the building with an evaporator and metering device inside the building. The outdoor component is commonly referred to as the condensing section, while the indoor unit is known as the air handler. Split systems are in the “air-to-air” category, and must include a drain to dispose of water condensed on the evaporator.

    An advantage of split systems is that they need only a small wall penetration, large enough for two refrigerant tubes and one condensate tube, so air leaks are not a problem. A disadvantage is that installation is more complex than for packaged systems, since piping, refrigerant, and wiring must be field installed. *(See page 44)*

4. **Name and describe the different types of compressors.**

    Reciprocating compressor: These operate more or less like an automobile engine, with a set of pistons connected to a crankshaft and valves to allow refrigerant to flow into a cylinder from the evaporator when the piston is descending and to direct it out to the condenser when the piston is rising. Once common, they are relatively inefficient and are rare in new installations.

    Centrifugal compressor: Centrifugal compressors consist of a centrifugal impeller (sometimes called vane) with blades arranged around a central axis, which is also the main shaft of the motor. (Their configuration is similar to jet engines and combustion turbines, but there is no combustion.) As the blades spin, refrigerant vapor is sucked in one end, compressed, and forced out the other end, all by the action of the blades. Because they just spin, they are capable of greater efficiency than reciprocating compressors. In their original version, the spinning shaft was supported at several points by bearings that required a steady supply of oil to minimize friction.

    Positive displacement compressor: called “positive displacement” compressors because as the piston goes up and down, the volume occupied by the refrigerant gets smaller and larger, and there are no appreciable pathways for leaks. *(See page 46)*

5. **What are the advantages and disadvantages of absorption chillers?**

   These efficiencies are substantially lower than those of vapor compression systems, so why would anyone use them? The first area where absorption machines have an advantage is in places where high summer cooling loads stress the electric grid. The local utility may charge a high price for power during peak loads, so being able to move some of the cooling load off electric power may save a lot of money.

   The other common application is where there is waste heat from some ongoing process, or hot water produced in a solar collector. Instead of throwing the heat away in a cooling tower, it can be used to produce chilled water, if other aspects of the location and HVAC systems are appropriate. This application will lower or eliminate any carbon footprint for cooling. *(See page 47)*

6. **Describe how ice builders work.**

   One approach to cold storage is to operate a chiller during off-peak hours to create ice for use during the day to cool the building. In the simplest form of these systems, called “ice builders,” a brine, chilled to well below freezing, passes through a tube immersed in pure water, and ice forms on the outside of the tube. This goes on most of the night, creating a substantial block of ice. Then, during the day, brine is passed through the tube and cooled by the ice, and then passed to air handlers where it contributes to space cooling, powered only by the pumps that circulate the brine. *(See page 52)*

7. **Describe chilled beams. What makes a system active or passive?**

   Chilled Beams are a technology that provides cooling from above. Cooled by chilled water, the “beam”, is a rectangular unit one to two feet wide and two to several feet in length. Suspended near the ceiling, the beam conductively cools air, which then falls through natural convection to the lower, occupied region of the space. In addition, the cold surface of the beam supplies some radiative cooling effect, although substantially less than the conductive/convective cooling.

   A “passive” beam is simply cold, with no fans or forced airflow. Air coming in contact with it is cooled and falls. The only control, and the only connection made during installation, is to manage the flow of chilled water through the beam.

   An “active” chilled beam, incorporates controlled airflow, driven either by fans located in the beam or by a supply of ducted cold air. An active chilled beam will have either electrical connections to drive fans, or ducted connections to provide previously chilled air, in addition to the water loop. *(See page 54)*

8. **What are a few practical steps that can help to reduce the environmental problems of ozone depletion and global warming potential?**

- Fix any refrigerant leaks
- Don’t vent synthetic refrigerants to the atmosphere
- Reduce charge to reduce leakage
- GreenChill

  (See pages 57-58)

9. **What makes natural refrigerants sustainable? Name the natural refrigerant options.**

   Natural refrigerants, such as hydrocarbons, water, CO_2, ammonia, and air, are being used as cooling agents without harming the ozone layer and have a negligible climate impact. *(See page 59)*

CHAPTER 5: Heating Systems

1. **What are indirect heating systems? Direct heating systems?**

   Heating systems with a distribution system are called indirect systems.

   In direct heating systems, heat is transferred from the heat source directly into the air being heated. *(See page 61)*

2. **Most heating systems are composed of what three main parts?**
   - The boiler, furnace, heat pump or other source where heat is generated,
   - The distribution system consisting of air handlers and ducts or pumps and pipes to carry the heat around the building, and
   - Heat transfer devices or “terminal units” that release the heat into the conditioned space, including radiators, convectors, and fan-coil units. *(See page 61)*

3. **Describe hot air distribution systems. How can they be improved?**

   Heat distribution systems based on forced air and ducts, designed to work for both heat in winter and cooling in summer. Older systems will be constant air volume (CAV), while newer systems will have variable air volume (VAV) capability, either through dampers and vanes or, for very recent installations, variable speed drives. Normally a central furnace provides the hot air, but if the system also provides cooling, there may be reheat coils in the ducts that provide some or all of the heat. There are disadvantages to using air as a heat transfer medium. The first step in improving the performance of a hot air distribution system is to find and correct all leaks, and make sure the ducts are insulated. The next step up would be to convert CAV systems to VAV systems based on VSDs. *(See page 62)*

4. **What are the benefits of condensing boilers?**

   Operation of a temperature modulating hydronic system can be made even more efficient by using a condensing boiler.

Condensing boilers work very well in DHW supply systems, and can be set up as single- purpose DHW supply systems with the condensing boiler integrated into the storage tank, or with a storage tank connected as one zone on a boiler serving a heating system. In any case, the feed water for DHW is cold enough to ensure that all the water vapor is condensed, offering the highest possible efficiency, over 97%.

Condensing boilers are quite efficient when used for heating, too depending on the heating load. On mild days, when the heating load is low, the controls will lower the supply water temperature, and the return water will be at a temperature low enough to allow nearly complete condensation. *(See page 67)*

5. **What are the efficiency ratings for fossil fuel systems?**
   - Combustion efficiency (CE): Based on measuring the flow of heat up the stack and comparing it to the energy content of the fuel. It is the test that is most easily carried out on a boiler or furnace that is installed and operating in a building.

     CE = Fuel energy – Exhaust heat Fuel energy

   - Thermal efficiency (TE): A more direct measurement of how much thermal energy leaves a boiler in the water or steam being delivered to the distribution system. It is based on measuring the heat actually delivered to hot water or steam when the boiler is operating at full load and normal temperature. It must be carried out in a laboratory on individual boilers chosen to represent their particular model.

   - Annual fuel utilization efficiency (AFUE): Gives indication of how efficiently a boiler will operate on an annual average basis. It is a test that can only be done in a lab. *(See pages 68-69)*

6. **What are the three types of heat pumps?**
   Air source heat pumps: Uses outdoor air as a heat source for wintertime heating and as a heat sink for summertime cooling.

   Distributed water-source heat pumps: Uses a loop connected to an array of local water-to-air heat pumps distributed within the building, and allows for the removal of heat from the center that can be used to warm the perimeter.

   Ground-source heat pumps: Uses the earth as a seasonal thermal storage system.
(See page 71-73)

7. **Describe radiators, convectors, and air handlers.**
   Radiators: Modern hot water radiators are made of steel and are relatively thin and light, since the hot water itself provides thermal mass.

Convectors are considerably smaller than radiators, and consist of a finned tube inside a protective metal jacket. The tube is commonly heated by water, but can also be used with steam. The fins transmit heat from the tube into the air between them, which expands as it's heated, becomes lighter, and rises through openings in the jacket into the surrounding space. In this way, heat is transferred out of the device by natural convection, the tendency of warm air to rise. Because they do not transfer heat as effectively as a large radiator, they require relatively hot supply water, commonly 180°F, and for this reason are less desirable in sustainable buildings.

Air handlers are metal boxes containing components such as fans, heating or cooling coils, dampers, duct connections, and controls. Air handlers commonly connect the chiller and furnace to the distribution system, although there can be individual air handlers for individual ones. They are fairly complex systems with dampers, controls, economizers, and filters to mix outdoor and return air, heat or cool it, and supply it to the conditioned space. *(See page 64)*

4. How are steam systems classified?

Steam systems may be classified in several different ways. They may use either one or two pipes for distribution. Steam systems are also divided into "upfeed" and "downfeed." *(See page 64)*

5. What are the different types of cogeneration?

Reciprocating engine: The most common type of cogen unit uses a reciprocating engine to drive the electrical generator. Reciprocating engines provide heat in the form of hot water.

Microturbine: Smaller-scale turbine engines derived from automotive turbochargers. The thermal output is hot exhaust gases.

Large-scale cogeneration: Gas turbines are common in large applications (above 1 MW). These are more common in industrial applications and in district generation systems than as part of a single building's infrastructure.

Trigeneration: Combined Cooling, Heat, and Power (CCHP), also known as trigeneration, combines cogeneration with an absorption chiller to produce electricity, cooling, and heating from a single machine fueled by such natural gas, biomass, or other fuels.

(See pages 77-78)

CHAPTER 6: Insulation

1. **What are the benefits of insulation?**
   - Mechanical insulation is one of the few products that save more energy over its lifespan than it takes to create and install it (called net positive energy).

- Insulated systems quickly pay for themselves in reduced energy costs. Pipe insulation for both hot and cold pipes provides a very quick return on investment.
- Insulation increases the life of the HVAC system.
- Proper insulation will ensure that the system is operating in accordance with the Owner's Project Requirements and the Engineer's Basis of Design.
- Aids in condensation control *(See page 80)*

2. What are the different types of insulation?

Fibrous insulation: fibers are typically made of glass, rock wool, slag wool, or aluminum silica, and are held together by a binder. It can be coated or made up of multiple materials, to have specific properties, including include weather resistance, chemical resistance, and reflectivity.

Cellular insulation: made up of individual cells. The base material often consists of glass, plastic, rubber, and a variety of foaming agents.

Flake insulation: made up of small particles or flakes, which may be loose or bonded together. Flake insulation is typically used in trenching when pipes are buried underground.

Granular insulation: has small nodules with hollow spaces.
(See pages 81-82)

3. Properly installing insulation includes?

- Use the correct materials for the application
- Use the correct thickness of material
- Apply the appropriate vapor barrier
- Don't leave gaps or holes between insulating materials
- Insulate continuously at all joints
- Leave enough space for the insulation.
- If the insulation material is compressed, the performance will be severely reduced.
- When the pipe is attached to a wall, make sure there is enough room to continuously insulate pipe through the penetration and within mounting systems
- Use proper adhesives
- Apply appropriate pipe jackets or duct coverings
- All-service jacket (paper), should be sealed completely to eliminate air intrusion
- Weather protect all outside insulation
- Install washable PVC covers in clean areas (such as hospitals)
(See page 83)

4. When designing for maintainability, what should be considered?

- Continuous sealing of weather barriers

- Allowance for expansion and contraction of the insulation
- Access for inspection
- Access for repair and/or replacement of the insulated equipment
- Requirements for wash down
  (See page 84)

CHAPTER 7: Instrumentation & Controls for HVAC

1. **What are the four categories of automatic HVAC controls?**

   Pneumatic: Systems rely on sensors, actuators, and devices powered by compressed air to deliver comfort. They provide good comfort control, stability, and power. However, the compression of air requires an energy input and the devices require a high level of maintenance to avoid leaks in the system.

   Analog: Systems that start and stop equipment through switches or change the level of voltage or current to an output device. Have better energy performance than pneumatics because they do not require the energy input of an air compressor. They have relatively low maintenance requirements and cost much less than pneumatics or digital systems to install. They cannot communicate between and among components, and they have lower reliability than pneumatic devices.

   Direct digital controls (DDC): Systems that offer all levels of control functionality and significant capacity for interoperability. They communicate over a network in order to provide information to other portions of the control system operating related equipment, or to a facilities operator at a local or remote location. Systems reduce central equipment operation based upon activity in zones. However, the system consists of small computer hardware that responds poorly to fluctuations in electrical power, and devices can fail at rates higher than pneumatic components if not monitored and maintained.

   Hybrid: Combined available technology that creates enhanced systems, which further reduce energy costs. For example, in a building renovation, the existing pneumatic system may be too costly to fully replace all at once. In this circumstance, most of the basic output actuation (e.g., relays, damper, and valve control) can be left under the pneumatic system while a higher-level decision-making DDC system can be installed to integrate all the functions for more efficient operation.
   (See pages 87-88)

2. **What is a building management system? Energy management system?**

   Centralized control systems that employ DDC to create comfort and efficiency go by many names. BMS (building management system) refers to a system that enables the building operators to manage and control the building HVAC, Lighting and other systems throughout the facility.

An EMS (energy management system) specifically helps operators manage the energy used within the facility. *(See page 88)*

3. **What are the installation issues associated with sensor and mechanical hardware installation? Accessibility?**

   HVAC contractors install valves and dampers, so must coordinate with the controls installer to ensure that all damper actuators fully close and seal properly. Contractors must also coordinate locations for flow measuring devices (airflow stations and water flow meters) and wells for water temperature measurement in spots that allow for accurate reading. In addition to the coordination drawings, the contractor must review each sensor location with the controls installer and possibly the device manufacturer prior to installation.

   Modern control systems require accurate sensing to work effectively. However, it is very difficult to obtain both an accurate and instantaneous reading, especially if the property being measured, such as air or water flow, fluctuates rapidly. In addition, when the response relies on several inputs that the system must mathematically calculate to determine the output, the accuracy challenges are multiplied. Often times, sensors will require a specific length of straight ductwork or pipe in order to deliver the desired accuracy. Ignoring this coordination can result in significant rework that costs time and money.

   Accessibility: The installation of HVACR equipment and infrastructure requires significant coordination with several other contractors on a job. Very often, control system components find their way into the ceilings, closets, and chases within a building instead of a centralized control room, the HVACR contractor must coordinate all of their pipes, ducts, and equipment to make certain that building operators can access controls hardware. *(See page 90)*

CHAPTER 8: Testing, Adjusting & Balancing

1. **During TAB, what is the role of testing?**

   The initial system testing usually occurs after the mechanical contractor has started all equipment and verified that the equipment will operate safely and without damage due to overloading, when the building is empty or only partially occupied. The testing process verifies that the equipment will produce the required quantities of fluids (air, water, or refrigerant) at the right temperatures and pressures. *(See page 91)*

2. **To prepare for TAB, what should be done with the air system?**

   Prior to TAB for air systems, the installer should walk the air handling system, making sure that all ducts are complete, all air outlets are installed, and all volume control devices and dampers are installed and open. Take along a set of approved contractor shop drawings for reference, noting any changes made during construction. Prior to starting any air handling systems, all fan rooms should be cleaned of debris, since any trash and discarded material could later be drawn into the fan and cause damage. Ensure air filters are clean. Ensure all cabinet panels are in place and secure. Ensure that any birdscreen(s) or such are free of obstructions. *(See page 93)*

3. **Why is TAB important to commissioning?**
   TAB is an important part of the commissioning process. The TAB contractor will complete functional performance testing (FPT) of the HVAC equipment and components, while the commissioning agent (CxA) witnesses it. The CxA, whose responsibility is to verify that the HVAC, fire protection, lighting, plumbing and electrical systems, and the building envelope operate together in a holistic way, will depend on the TAB contractor's findings to complete the Cx process. Typically, the CxA will directly verify a minimum of 30% of the final balancing report. *(See page 94)*

CHAPTER 9: Commissioning & Energy Performance

1. **What is the commissioning agent's (CxA) role during the design stage on new construction projects?**
   The CxA will perform design reviews of the design documents checking to make sure that the project team is following the OPR, that interdisciplinary coordination is occurring, and that maintainability is being designed into the project. Additionally, the CxA will develop commissioning specifications that will inform contractors what their responsibilities will be during construction. This all leads to a design that is clear to the contractor and easy to take care of. *(See pages 95-96)*

2. **What is the key document in the commissioning process?**
   The key document is the commissioning plan. The CxA creates a detailed commissioning plan based on the owner's project requirements (OPR); basis of design (BOD); and the design documents, plans, drawings, and equipment specification sheets. The plan includes all required tests, inspections, and results. *(See pages 97-98)*

3. **What are the different standards for measurement and verification?**
   Efficiency Valuation Organization (EVO): The EVO publishes the International Performance Measurement and Verification Protocol (IPMVP), a set of books that are available for free online. These protocols are required in M&V plans for LEED certification.

   ASHRAE: ASHRAE also publishes an M&V standard, Guideline 14: Measurement of Energy and Demand Savings. It is similar in many respects, but not regularly updated and used less often.

IPMVP Protocols: The IPMVP covers a wide range of possibilities to provide assurance that savings reported in one circumstance will be comparable to savings reported in another. IPMVP requires a thorough M&V plan, describing the types of savings and the measurement techniques. *(See pages 101-102)*

4. **What are the four options the IPMVP offers for M&V?**
   - Option A. Retrofit Isolation: Key Parameter Measurement (For retrofits of a single system)
   - Option B. Retrofit Isolation: All Parameter Measurement (For retrofits of a single system)
   - Option C. Whole Facility (For retrofits of a whole building)
   - Option D. Calibrated Simulation (For new construction)
     (See page 102)

5. **Why is managing the documentation from the tests important?**
   Managing the documentation from the tests is vital because these tests represent the baseline operating condition. This baseline demonstrates that proper functionality was achieved and that contractual requirements were met. This proof helps facilitate final acceptance and turnover to the owner or end-user. *(See pages 99-100)*

6. **What is the importance of M&V?**
   Measurement and Verification (M&V) helps to prove that a building performs as it was designed. *(See pages 100-101)*

CHAPTER 10: Corrective, Preventive & Predictive Maintenance

1. **Describe the three types of building maintenance programs.**
   Corrective: The default procedure on many buildings is corrective maintenance – when something breaks, fix it.

   Preventative (PM): Helps the system run more efficiently and increases the lifespan of its component parts. PM technicians make regular inspections to catch and fix problems before they arise.

   Predictive (PdM): The most advanced form of maintenance. In addition to PM maintenance practices, PdM technicians determine the equipment's condition and remaining life expectancy. *(See pages 103-104)*

2. **Who is involved on a PM program?**
   Facilities managers are responsible for setting up a PM program. It is important that building management and facilities operators have a clear plan for the building's

maintenance. Installers need to leave enough room for maintenance to be able to access equipment. Building maintenance personnel must cooperate and collaborate with maintenance technicians. HVAC maintenance technicians need to monitor all equipment to make sure everything is working. Only trained, qualified maintenance personnel should perform maintenance. All parties involved must be aware of, and sign off on, the plan for maintaining and replacing equipment. *(See page 103)*

3. **What are the two separate categories of maintenance techniques?**

   Actions that extend the life of equipment: lubrication, cleaning, adjusting, and replacement of minor components like belts, filters, etc.

   Actions that avoid unnecessary failure: inspections, vibration analysis, infrared testing, oil, and analysis. *(See page 106)*

CHAPTER 11: Green Construction Management

1. **What are tasks that contractors may be required to complete on green buildings during pre-construction? During construction?**

   When working on high-performing buildings, contractors and subcontractors become involved during pre-construction. Their specific knowledge and expertise is critical in assisting the design team and CM/GC with cost estimates and feasibility information. The HVAC contractor can also help the team achieve LEED credits by providing information about lifecycle costs, including system maintenance requirements and future decommissioning or replacement issues.

   During construction, every member of the crew must be aware of the specific sustainability practices on the project. While the CM/GC may conduct an onsite orientation or "toolbox talk" to cover these issues, each worker should arrive on the site aware of:
   - The project's smoking and food policies
   - VOC requirements
   - Construction waste management procedures
   - Work practices that comply with the CIAQ Plan

   (See page 109)

2. **Why is the quality and air tightness of ductwork so important?**

   Without proper duct sealing, either the spaces won't receive the required amount of air or, the system will work harder to provide it, wasting energy. In addition, the choice of duct sealant must meet both the performance parameters and VOC limits. *(See page 110)*

3. **What measures should be taken to minimize migration of pollutants in occupied areas?**
   - Ensure proper ventilation and isolation of work areas to limit VOC and particulate

buildup.
- Depressurize the work area with exhaust fans.
- Pressurize occupied areas by increasing supply air via the existing system or by adding temporary supply fans.
- Erect barriers, such as temporary partitions and/or plastic sheeting, to contain the construction area.
- Allow materials such as carpeting and woodwork to out-gas off-site or in unoccupied spaces before installation.
- During exterior pollution-generating work, temporarily seal building openings to prevent fumes from entering open windows and air intakes.
- As necessary, move all pollutants to one area to focus the cleanup efforts. *(See page 113)*

CHAPTER 12: Energy Audits & Retrofits

1. **Who is involved on an energy audit?**

   Energy auditors conduct the audits. They must be trained and certified, with knowledge and skills in planning, conducting, documenting, and evaluating an energy audit in a variety of building types. They must be familiar with all types of mechanical and electrical systems, and various test instruments. A large, complex building might require a team of engineers to carry out the audit. An audit team may be composed of personnel from different departments, usually 3-5 people, including outside contractors, in-house maintenance personnel, accountants, production staff, and high-level managers.

   Energy auditors work with facility managers and building operators to obtain the most accurate information. During the retrofit process, auditors work with mechanical, electrical and plumbing contractors to perform upgrades. *(See page 119)*

2. **What are the benefits of an energy audit?**

   The main goal of an energy audit is improving energy efficiency and reducing utility costs, but this also leads to many additional benefits such as reduced maintenance costs and less downtime due to newer equipment. An audit will also improve occupant safety and comfort: improving lighting and HVAC systems improves indoor environments. Improving energy efficiency can also lead to a building being certified by ENERGY STAR or one of the green building rating systems we discussed in *Fundamentals*. *(See page 119)*

3. **What are the three primary types of energy audits?**

   LEVEL 1: PRELIMINARY AUDITS (WALK- THROUGH): Some limited measurements might be taken during the audit. Only major problems, such as significant leaks or inappropriate set points, will be uncovered during this type of audit. The end result is a simple report, focused on the most obvious energy conservation measures (ECMs), also called energy management opportunities (EMOs), easily identified during the audit. This approach is typically used for homes and for prescriptive replacement programs, such as standard commercial lighting upgrades. A Level 1 report will often identify measures that need further analysis and it satisfies the USGBC LEED-EB:O+M prerequisite.

LEVEL 2: GENERAL (INTERMEDIATE) AUDITS: This is a more sophisticated audit. It involves looking at a 2- to 3-year history of utility bills. Some system testing and short-term monitoring may also be performed at this stage. Additionally, computerized energy simulations are created to evaluate the current behavior of both individual systems and the entire building. Computer modeling of proposed measures can then be used to estimate potential energy and fuel savings. This type of audit is often used to develop more complex multi-system conservation plans. Measures are evaluated based on both client interest and financial analysis. This type of audit is done in larger homes and commercial buildings.

LEVEL 3: INVESTMENT-GRADE AUDITS: Very similar to the general audit, the investment-grade audit goes beyond the typical financial analysis. It may involve installation of meters for long-term (several months or years) monitoring of equipment and actual engineering of detailed measures in order to evaluate the recommended solutions more accurately. This type of audit is usually reserved for more capital-intensive measures in larger commercial projects where guaranteed savings are a major concern. *(See page 119-121)*

4. **Explain the two common ways of measuring cost effectiveness.**

Payback period. A type of assessment that includes calculations that compare savings to investments. Payback period refers to the period of time required for the annual financial benefit to “repay” the amount of money invested in the building or operation. Simple payback = cost of investment / annual savings.

Return on Investment (ROI). Allows the building owner to compare the savings produced by proposed upgrades to the return on another investment, as well as the *net present value* (*NPV*) of the annual savings, which represents the capital that the expected future savings would be worth today. ROI = Annual Savings / Cost of Investment. *(See page 115)*

5. **What are the differences between a renovation and a retrofit?**

A renovation seeks to take an existing building and completely repurpose it by replacing most of the existing structure and systems. A retrofit maintains a facility’s existing purpose, but replaces specific systems or components of systems. *(See page 117)*

6. **What is the purpose of improving the system balance?**

Even with an EMS or BMS providing improved control, building operators frequently find that some spaces will be perennially overheated, while others will be cold. This will typically result in substantial overheating to keep the coldest spaces comfortable, significant savings can be realized by improving the system balance. *(See page 124)*

7. Explain the differences between recommissioning and retro-commissioning.

If a building has been previously commissioned, *recommissioning* occurs to ensure that a building's systems are still operating as they were designed.

Retro-commissioning (*retro-Cx*) is a process meant for buildings that were never commissioned. It is the process of going into an existing building and performing a set of inspections and tests that mirror those used in Cx on a new building. *(See page 124)*