

BOC Certification Exam Resource Guide

Section B – Operate Energy Using Systems for High Performance Citations

INTRODUCTION

Section B of the exam covers the critical work functions for **Operate Energy Using Systems for High Performance**. The reading list in this resource guide is targeted to the content of the exam questions in this section of the exam. It is organized by topic area as noted in the Table of Contents. Each section provides the source of the citation, a link to where it can be found online, and a set of study questions about the content in the citation, followed by a paragraph or two of the material specific to the exam question. The study questions serve as guidance for independent study as candidates prepare for the exam. In addition to the study questions, the reading list provides practice questions and answers from the early versions of the certification exam. The study questions and practice questions are also covered in the BOC Exam Prep Webinar Series (<http://www.theboc.info/certifications/exam/preparing-for-exam/>). Additional resources are provided in the form of PDF documents which provide further discussion and useful illustrations, tables and figures. We recommend exam candidates familiarize themselves with the content and be prepared to answer the questions posed in each section.

Study Questions: These questions provide guidance for independent study of the topics in the Resource Guide. Study questions do not represent actual questions on the certification exam. Study questions appear under each citation in this document.

Practice Questions: These are questions that appeared on earlier versions of the certification exam and which have been retired from circulation. Practice questions are provided on the last page of this document.

Section B - Exam Blueprint Skill Areas and Number of Questions

- **Operate equipment settings and system control points (16 questions)**
 - Verify proper operation of building systems and equipment.
 - Optimize system performance
 - Operate HVAC system components to optimize energy savings.
 - Review and revise sequence of operation for building systems.
 - Conduct a review of the building automation system to verify proper operation.
 - Implement lighting strategies to optimize energy performance.
 - Program control systems for efficient operation.
 - Read a controls diagram for pneumatic and DDC controls.

- Maintain an up-to-date controls sequence for pneumatic and DDC controls.
- Perform adjustments to equipment operation to optimize energy savings.
- **Measure and monitor energy performance (11 questions)**
 - Conduct measurement and verification activities.
 - Monitor key performance indicators (KPI) to optimize energy performance.
 - Install sensors to monitor building conditions.
 - Implement an energy management program
 - Analyze system performance
 - Identify cost saving measures
 - Respond to changing energy costs
- **Sustain energy performance (14 questions)**
 - Identify sustainability opportunities
 - Implement building energy management procedures.
 - Implement water conservation strategies.
 - Periodically review and revise building occupancy schedules.

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1. Building Systems
 - HVAC
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Reading List

1. Building Systems: HVAC Systems & Equipment

HVAC Systems & Equipment

Boiler Safety and Water-Pressure Relief Valves, Integrated, Construction Manuals

<https://constructionmanuals.tpub.com/14259/css/Boiler-Safety-and-Water-Pressure-Relief-Valves-236.htm>

STUDY QUESTIONS:

What is the purpose of the low water fuel cutoff and water feeding devices?

To ensure safe boiler operation, what maintenance checks should be undertaken for the following system components?

- Piping: _____
- Water columns and gauge glasses: _____
- Low water fuel cutoff: _____
- Steam gauge: _____

What are the recommended settings for boiler safety and water pressure relief valves?

What maintenance checks should be taken to ensure the settings are correct and the system is performing as it should? _____

What are the steps involved in these safety and pressure relief valve tests?

Who is qualified to perform these tests? _____

Boiler Safety and Water- Pressure Relief Valves

Steam and Water Piping Testing

While the boiler is operating, examine all steam and water piping, including connections to the columns, for leaks. If any leaks are found, determine if they are the result of excessive strains caused

by expansion and contraction or other causes. Listen for water hammer; if found, determine the cause. Look for undue vibration, particularly in piping connections to the boiler. Where excessive vibration of piping is found, examine connections and parts for crystallization.

Water Columns and Gauge Glasses

With steam on the boiler, blow down the water columns and gauge glasses and observe the action of the water in the glass to determine if the connection to the boiler or the blow off piping is restricted or not properly free. This will help you determine the true condition of high- and low- water alarms and of the automatic combustion equipment.

Devices

While the boiler is operating, the individual mechanisms of LOW-WATER FUEL CUTOFF and/or WATER-FEEDING DEVICES operate to assure they function properly. Where a float-operated, low-water cutoff or water-feeding device or a combination low-water fuel cutoff and water-feeding device is provided, its operation should be tested by opening the drain to the float bowl and draining the bowl to the low- water level of the boiler. When the low-water point is reached, the mechanism of the low-water fuel cutoff should function and shut off the fuel supply to the boiler until boiler water is added to the proper level. Also, at the low-water point, the mechanism controlling the feed water supply should function to start the feed water. Where there is a low-water fuel cutoff device controlled by excess temperature generated in a temperature element located inside the boiler, its operation may be tested by blowing off the boiler to its allowable low-water level. On or before the low-water level is reached, the device should function to shut off the boiler fuel supply until boiler water is added to the proper level. On high-temperature water boilers, the flow through the boiler should be restricted to the minimum allowed, as shown by the manufacturer's operating data. The point at which fuel cutoff takes place should be noted and adjustments made as required. With steam on the boiler, observe the STEAM GAUGE pointer for sticking or restriction of its movement. Blow down the pipe leading to the gauge to assure that it is free. Attach an approved test gauge to the pipe nipple provided for this purpose and compare the accuracy of each steam gauge on the boiler with that of the test gauge. When inaccuracy of any gauge is evidenced or suspected, it should be removed and calibrated by means of a deadweight gauge tester or other device designed for this purpose. When several boilers are in service and connected to a common steam main, compare the readings of the separate gauges. All TEMPERATURE-INDICATING DEVICES should be observed for indications of excessive temperature, particularly during and immediately after the time high-load demands are made on the boiler. While the boiler is operating under normal conditions, observe the operation of all METERING AND RECORDING DEVICES. When there is evidence that any such device is not functioning properly, it should be adjusted, repaired, or replaced as necessary.

Blow off Valves

Test the freedom of each blow off valve and its connections by opening the valve and blowing off the boiler for a few seconds. Determine if the valve is excessively worn or otherwise defective, and if there is evidence of restrictions in the valve or connected piping preventing proper blow off of the boiler.

Stop and Check Valves

While the boiler is operating, inspect the operating condition of each stop and check valve where possible. Serious defects of externally controlled stop valves may be detected by operating the valve when it is under pressure. Similarly, defects in check valves may be detected by listening to the operation of the valve or observing any excessive vibration of the valve as it operates under pressure.

Pressure-Reducing Valves

While there is pressure on the system, open and then close the bypass valve as safety and operating conditions permit. Also, observe the fluctuation of the pressure gauge pointer as an aid in determining possible defects in the operation of the pressure-reducing valve or the pressure gauge. Look for any evidence that may indicate improper condition of the relief or safety valves provided for the pressure-reducing valves.

Boiler Safety and Water- Pressure Relief

Valves Test the blow off setting of each safety valve for steam boilers and each water-pressure relief valve for hot-water boilers by raising the boiler pressure slowly to the blow off point. In turn, test the releasing pressure of each valve, gagging all other safety or relief valves except the one being tested. Observe the operation of each valve as blow off pressure is reached. Compare the blow off setting with setting requirements specified in paragraph 1 or 2 of this section, as applicable, and make adjustments where necessary. When the steam discharge capacity of a safety valve is questionable, it should be tested by one of the methods given in paragraph 3 of this section. When the pressure-relieving capacity of a pressure-relief valve is questionable, it should be tested according to the procedures given in paragraph 4 of this section.

1. **SAFETY VALVES SETTING REQUIREMENTS.** Note this word of caution: Before adjusting safety valves on electric steam generators, be sure that the electric power circuit to the generator is open. The generator may be under steam pressure, but the power line should be open while the necessary adjustments are being made. At least one safety valve should be set to release at no more than the maximum allowable working pressure of the steam boiler. Safety valves are factory set and sealed. When a safety valve requires adjustment, the seal should be broken, adjustments made, and the valve resealed by qualified personnel only. When more than one safety valve is provided, the remaining valve or valves may be set within a range of 3% above the maximum allowable working pressure. However, the range of the setting of all the safety valves on the boiler should not exceed 10% of the highest pressure to which any valve is

set. Each safety valve should reseal tightly with a blowdown of not more than 2 psig or 4% of the valve setting, whichever is greater. In those cases where the boiler is supplied with feed water directly from the pressure main without the use of feeding apparatus (not including return traps), no safety valve should be set at a pressure greater than 94% of the lowest pressure obtained in the supply main feeding the boiler.

2. **PRESSURE-RELIEF VALVE SETTING REQUIREMENTS.** At least one pressure-relief valve should be set to release at not more than the maximum allowable working pressure of the hot-water boiler. When more than one relief valve is provided on either hot-water heating or hot-water supply boilers, the additional valve (or valves) may be set within a range not to exceed 20% of the lowest pressure to which any valve is set. Each pressure-relief valve should reseal tightly with a blowdown of not more than 25% of the valve setting.
3. **SAFETY VALVE CAPACITY TEST.** When the relieving capacity of any safety valve for steam boilers is questioned, it may be tested by one of the three following methods:
 - a) By the accumulation test, which consists of shutting off all other steam-discharge outlets from the boiler and forcing the fires to the maximum. The safety valve capacity should be sufficient to prevent a pressure in excess of 6% above the maximum allowable working pressure. This method should not be used on a boiler with a superheater or reheater.
 - b) By measuring the maximum amount of fuel that can be burned and computing the corresponding evaporative capacity (steam- generating capacity) upon the basis of the heating value of this fuel. These computations should be made as outlined in the code.
 - c) By determining the maximum evaporative capacity by measuring the feed water. When either of the methods outlined in (b) or (c) above is employed, the sum of the safety valve capacity should be equal to, or greater than, the maximum evaporative capacity (maximum steam-generating capacity) of the boiler.
 - d) If you discover that the relieving capacity is inadequate because of deficiencies in the valve, the valve should be repaired or replaced. If the relieving capacity of the valve is found to be satisfactory within the proper relieving range of the valve but inefficient for the steam- generating capacity of the boiler, additional safety valve capacity should be provided.
4. **D. PRESSURE-RELIEF VALVE—CAPACITY TEST.** When the relieving capacity of any pressure-relief valve for hot-water boilers is questioned, the capacity can be tested by turning the adjustment screw until the pressure-relief valve is adjusted to the fully open position. The pressure should not rise excessively. When the test is completed, reset the pressure-relief valve to the required setting. This test is made with all water discharge openings closed except the pressure- relief valve being tested. When the discharge is led through a pipe, determine at the time the valve is operating if the drain opening in the discharge pipe is not properly free, or if

there is evidence of obstruction elsewhere inside the pipe. If deemed necessary to determine the freedom of discharge from the valve, the discharge connection should be removed. After completing tests and adjustments, the inspector should seal the safety adjustment to prevent tampering.

Boiler Auxiliaries

While the boiler is operating under normal conditions, observe the operation of all boiler auxiliaries for any defects that may prevent proper functioning of the boiler or indicate a lack of proper maintenance of auxiliary equipment. The unnecessary use of multiple auxiliaries or the use of a large auxiliary during a light-load period (when a smaller auxiliary could be substituted) should be discouraged. The maximum use of steam-driven auxiliaries short of atmospheric exhaust should be encouraged. Steam leaks, wastage to atmosphere, and so forth, should be called to the attention of operating personnel. Particular attention should be given to deaerator venting practice. Venting should be held to the minimum required to preclude oxygen entrainment in the feed water. When intermittently operating condensate pumps are used, look for any tendency toward creation of a vacuum when a pump starts. If this happens, recommend installation of a small, continuously operating, float-throttled, condensate pump (in parallel with intermittently operating pumps) to assure a condensate flow at all times. If there are a number of intermittently operating condensate pumps, it may be possible to convert one of them (if of small enough capacity) to continuous throttled operation.

Circuit Setter Balance Valve

<https://www.nationalpumpsupply.com/117414lf-bell-gossett-cb-1-2-circuit-setter-balance-valve-1-2/>

STUDY QUESTION:

What is the purpose of a circuit setter balance valve?

The plumbing valve, in simple terms is what you use to control the flow of water in a water system.

The Circuit Setter Balance Valve is a calibrated balance valve designed specifically for pre-set or proportional system balance for use with terminal and fan coil units. This system balance method, assures optimum system flow balance at minimum pump operating horsepower. Terminal unit balance valves can be simply pre-set using the circuit setter curves and the system piping plan. With this procedure, system balance and start-up time is reduced dramatically.

When it comes to plumbing, a circuit setter valve is used to optimize the pressure between hot and cold water within the potable water system.

The earlier trends were to use a check valve and a ball valve. The check valve would close a hot or cold water flow if there was an impulsive fall in the pressure and the ball valve made use of a memory stop to control the flow.

This helped to avoid the cold or hot water bleed-over if case of increased or decreased pressure conditions in the piping system.

How to find the right circuit setter valve?

Before you buy a circuit setter you need to first determine these features:

- The adjustment range of the circuit setter valve
- The kinds of test ports available on the valve. The valves need to have a port for temperature and another one for pressure.
- The valves should allow provision for a partial shut down for isolation purposes.



Gasket Plate Heat Exchanger

<http://www.jiawei-phe.com/Gasket-Plate-Heat-Exchanger.html>



STUDY QUESTIONS:

How does a plate heat exchanger work?

What is the benefit of using a plate heat exchanger over a shell and tube unit?

Standard Design

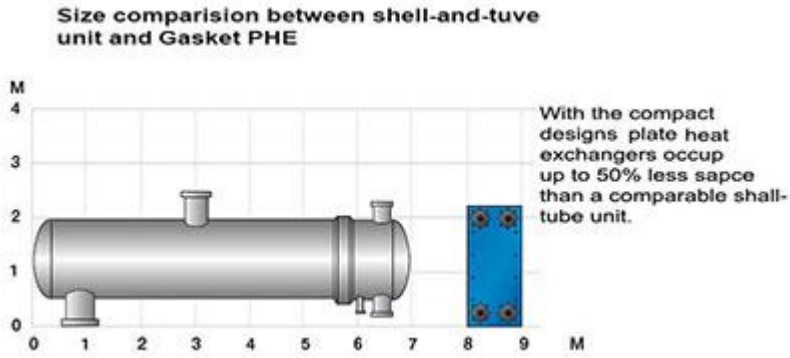
The plate heat exchanger consists of a pack of corrugated metal plates with portholes for the passage of the two fluids between which heat transfer will take place. The plate pack is assembled between a fix frame plate and a movable pressure plate and compressed by tightening bolts. The plates are fitted with a gasket which seals the inter plate channel and directs the fluids into alternate channels. The number of plates is determined by the flow rate, physical properties of the fluids, pressure drop and temperature program. The plate corrugations promote fluid turbulence and support the plates against differential pressure. The frame plate and the pressure plate are suspended from an upper carrying bar and located by a lower guiding bar, both of which are fixed to a support column. Connections are located in the frame plate or, if either or both fluids make more than a single pass within the unit, in the frame and pressure plates.

Working principle

Channels are formed between the plates and the corner ports are arranged so that the two media flow through alternate channels. The heat is transferred through the plate between the channels, and complete counter-current flow is created for highest possible efficiency. The corrugation of the plates provides the passage between the plates, supports each plate against the adjacent one and enhances the turbulence, resulting in efficient heat transfer.

Efficiency and Flexibility

- High heat transfer efficiency
- Easy to repair and cleaning
- Low fouling factor
- Compact structure, lightweight
- Easy to adjust heat transfer surface or plate arrangement
- Small temp. differential



Steam Traps, Energy Management Handbook

STUDY QUESTIONS:

What is the purpose of a steam trap?

What happens when a steam traps fails open?

Review discussion of Steam Traps on this page.

ENERGY MANAGEMENT HANDBOOK

- to work properly, the fact should be noted and the valve fixed by a boiler service representative at the first opportunity.
- Air supply* should be kept open so that the boiler can have enough combustion air at all times. Restricting combustion air by blocking the boiler air openings or by blocking all air openings into the boiler room can create a buildup of carbon monoxide and/or cause the boiler to operate inefficiently.
 - Low-water and high-water gauges and controls* should be flushed periodically to remove sludge. If sludge builds up in a float-operated valve, the valve can fail to operate, with expensive consequences to the boiler. The gauges should be flushed periodically and should not be allowed to get rusty or clogged.
 - Combustion controls* should be inspected regularly and adjusted if sooting or burner wear is taking place. Sooting causes a great drop in boiler efficiency (see Table 14.12), and burner wear can cause irregular firewall wear, inefficient combustion, and the need for increased boiler maintenance. It is generally worthwhile to have your combustion controls inspected at least annually.
 - Tubes* can be cleaned if scaling occurs by removing head plates at either end and running a special brush through each tube. For detailed procedures and necessary safety precautions, see your local boiler service representative. Tubes can be replaced if necessary, but the job calls for special skills and should be done by someone trained for this job.

14.2.3 Steam Traps⁸

A steam trap is a mechanical device used to remove air, carbon dioxide, and condensed steam and to prevent steam from flowing freely into the outside air from steam distribution systems. Steam traps are necessary for several reasons. If air is not removed from steam, the oxygen can dissolve in low-temperature steam condensate and help cause corrosion of the valves, pipes, and coils in the steam distribution system. If carbon dioxide is not removed, it can combine with steam condensate to form carbonic acid, another major source of corrosion in the steam distribution system. Air and carbon dioxide also act as insulators to impede heat transfer from the steam; their presence creates a partial pressure that lowers the steam temperature and the heat-transfer rate.

Perhaps the main function of steam traps, however, is to permit the removal of steam condensate from a system while simultaneously preventing the free escape of steam into the air outside the steam distribution system. In this last function, the energy of the steam is kept within the

system, and the amount of the live steam within the facility is controlled.

Steam traps occur as parts of nearly every steam distribution system. They are often not maintained, and this lack of maintenance can create a hidden cost that is significant. The cost of a steam trap failure is dependent upon the failure mode, with a strong dependence upon the original design. The two main failure modes are failing open and failing shut, and the design consideration of most maintenance interest is proper drainage. Consider these problems in turn.

Problems if Trap Fails Open

If a trap fails open, live steam flows directly from the steam system through the trap, and either a pressure buildup is caused in the condensate return system—if the trap exits to that system—or the steam is released directly to the air. In the first case, the back pressure in the condensate lines may cause other steam traps to fail, and the condensate may not be removed from the steam distribution system. In the second case, steam discharging to air costs as much as any other kind of steam leak and creates pressure losses. These costs can be estimated using Table 14.17 and the formula

$$C = \text{waste} \times \frac{1100 \text{ Btu/lb}}{\text{boiler eff.}} \times \frac{\text{energy cost/million Btu}}{1,000,000}$$

where

C = energy cost per month due to steam loss

waste = number of pounds of steam wasted per month, from Table 14.17

1100 Btu/lb = approximate value for total heat in saturated steam at 100 psi

boiler eff. = boiler efficiency, usually 60 to 80%

energy cost/million Btu = cost that can be obtained from your fuel supplier

These figures are close estimates for steam at 100-psia pressure; for other pressures between 50 and 200 psi, the cost is nearly proportional to the pressure, using 100 psi and Table 14.17.

Problems if Trap Fails Shut

If a steam trap fails shut, it acts like a plug in that part of the steam system. Condensate builds up and cools, heat transfer stops, and noncondensable gases dissolve in the water and create corrosion in the pipes and in the equipment served

Ventilation Systems

http://www.trane.com/content/dam/Trane/Commercial/global/products-systems/education-training/engineers-newsletters/airside-design/admapn003en_0502.pdf

Review the link above or the PDF provided titled “Commercial Building Pressurization_Trane.”

STUDY QUESTIONS:

What are the forces that affect building pressure?

Why does pressurization matter?

What are differences between relief air flow, exhaust air flow, and intake air flow?

Applications and Exception for Air Side Economizers

<https://www.pnnl.gov/projects/om-best-practices/air-side-economizers>

STUDY QUESTION:

What are the seven ASHRAE recommended applications for air side economizers?

What are the exceptions?

BOC 1001 – Energy Efficient Operation of HVAC Systems

An airside economizer is defined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) as, "A device that, on proper variable sensing, initiates control signals or actions to conserve energy." A high limit shut-off must be used and it will stop economizer operation when cooling loads can't be reduced by using outdoor air. The figure below defines the high limit shut-off points for various readings. “CZ” is climate zone.

ASHRAE 90.1 Economizer High Limits



Economizer Device Type	Limit	Note
Fixed Dry Bulb	OAT > 70F	Not allowed CZ 5A (So. Illinois)
Differential Dry Bulb	OAT > RAT	Not allowed CZ 5A
Fixed Enthalpy	OAH > 28 BTU / #	
Electronic Enthalpy	(OAT, OA rh) > A	OAT RH exceeds the "A" setpoint curve
Differential Enthalpy	OAH > RAH	Outdoor air enthalpy exceeds return air enthalpy
Dew-point and dry-bulb temperatures	Dew point OA > 55F OAT > 75F	OAT exceeds 75F or outside dewpoint exceeds 55F

VAV System Static Pressure Setpoint Reset

Steven T. Taylor, P.E., Fellow ASHRAE, Air System Engineering & Technology Conference, March 2018

<https://www.amca.org/assets/resources/public/pdf/Taylor%20VAV%20Design%20Tips.pdf>

STUDY QUESTIONS:

What is static pressure reset?

Reset can generate _____% fan energy savings compared to fixed setpoints?

What is fan surge?

Supply air fans on variable air volume (VAV) systems are typically controlled to maintain static pressure in the duct system at a given setpoint. Since 1999, ASHRAE Standard 90.11 has required that this setpoint be reset for systems with direct digital controls (DDC) at the zone level, specifically:

Setpoint Reset. For systems with direct digital control of individual zone boxes reporting to the central control panel, static pressure setpoint shall be reset based on the zone requiring the most pressure; i.e., the setpoint is reset lower until one zone damper is nearly wide open.

California's Title 24 Energy Standards include a similar requirement. This article discusses the energy benefits of static pressure setpoint reset and describes successful setpoint reset control sequences.

Energy Savings

Figure 1 (see PDF at link above or provided here titled ASHRAE Supply Air Reset) depicts the part load energy performance of a typical centrifugal fan with a variable speed drive at various static pressure setpoints. These curves include the impact of variable speed drive and motor efficiency as a function of load and fan efficiency as a function of operating point, but for simplicity they assume pressure drop varies as the square of airflow. The figure shows that the lower the setpoint, the lower the fan energy and the lower the minimum airflow rate before the fan operates in the surge region. Fans operating in surge can experience substantial vibrations, noise and a drop in fan efficiency. For systems with DDC at the zone level, Standard 90.1 and Title 24 require that static pressure setpoint be dynamically reset so that one damper is nearly wide open, depicted schematically in Figure 2 (see PDF at link above). This is clearly the most efficient operating condition since the fan need not generate any more pressure than required to satisfy the "critical" zone (the zone that requires the most pressure). It also improves fan efficiency, which drops off as the fan operates at low load and high static pressure, in particular if the fan operates in surge. If the static pressure is perfectly reset, at zero airflow, zero static pressure would be required and the system would operate on the "Ideal" line (Figure 1). Because of their complex physical layouts, varying system geometry as VAV dampers open and close, non-simultaneous variations in zone loads, and other factors, real fan systems will not perform quite this well. Nevertheless, reset can generate fan energy savings on the order of 30% to 50% compared to fixed setpoints.

Refrigeration Systems

Performance and efficiency terminology related to heat pumps and air conditioning systems.

http://www.engineeringtoolbox.com/cooling-heating-efficiency-d_410.html

STUDY QUESTIONS:

The higher the COP rating for a cooling equipment product indicates what?

How does IPLV differ from standard COP and EER ratings?

For what equipment is it commonly used as the rating?

What is the difference between Heating Seasonal Performance Factor and SEER?

Commonly used performance and efficient terminology in connection with cooling and heating systems:

Operating Mode	Design Rated Conditions	Seasonal Average Conditions
Cooling	COP EER kW/ton	COP IPL SEER
Heating	COP E _c E _t	AFUE COP HSPF

SEER - Seasonal Energy Efficiency Ratio

The term SEER is used to define the average annual cooling efficiency of an air-conditioning or heat pump system. The term SEER is similar to the term EER but is related to a typical (hypothetical) season rather than for a single rated condition. The SEER is a weighted average of EERs over a range of rated outside air conditions following a specific standard test method. The term is generally applied to systems less than 60,000 Btu/h. The units of SEER are Btu/Wh. It is important to note that this efficiency term typically includes the energy requirements of auxiliary systems such as the indoor and outdoor fans. For purposes of comparison, the higher the SEER the more efficient the system. Although SEERs and EERs cannot be directly compared, the SEERs usually range from 0.5 to 1.0 higher than corresponding EERs.

COP - Coefficient of Performance

[COP - Coefficient of Performance](#) is the ratio of cooling or heating to energy consumption and can be expressed as

$$COP = \text{useful energy transferred to the system per hour} / \text{energy applied to the system per hour}$$

A refrigerator with a COP of 2 moves 2 Watts of heat for every Watt of electricity consumed. An air conditioner with a COP of 4 moves 4 Watts of heat for every watt consumed.

COP may also be used for domestic heating. An electric heater has a COP of 1. Each watt of power consumed produces 1 Watt of heat. Conventional heat pumps have COP of 2 - 5, delivering 2 to 5 times the energy they consume.

Example - Hot Water Radiator System

$$COP = 500 q dt / 3143 P \quad (1)$$

where

q = hot water flow (gal/min)

dt = temperature difference between supply and return water (°F)

P = input power to pump (kW)

EER - Energy Efficiency Ratio

Room air conditioners in general range from 5,000 Btu per hour to 15,000 Btu per hour. Select room air conditioners with [EER](#) of at least 9.0 for mild climates. In a hot climates, select air conditioners with EER over 10.

[kW/t](#)

IPLV - Integrated Part-Load Value

The term IPLV is used to signify the cooling efficiency related to a typical (hypothetical) season rather than a single rated condition. The IPLV is calculated by determining the weighted average efficiency at part-load capacities specified by an accepted standard. It is also important to note that IPLVs are typically calculated using the same condensing temperature for each part-load condition and IPLVs do not include cycling or load/unload losses. The units of IPLV are not consistent in the literature; therefore, it is important to confirm which units are implied when the term IPLV is used. ASHRAE Standard 90.1 (using ARI reference standards) uses the term IPLV to report seasonal cooling efficiency for both seasonal COPs (unit-less) and seasonal EERs (Btu/Wh), depending on the equipment capacity category; and most chillers manufacturers report seasonal efficiency for large

chillers as IPLV using units of kW/ton. Depending on how a cooling system loads and unloads (or cycles), the IPLV can be between 5 and 50% higher than the EER at the standard rated condition.

IPLV can be expressed as:

$$IPLV = 1 / (0.01 / A + 0.42 / B + 0.45 / C + 0.12 / D) \quad (2)$$

where

$A = \text{kW/ton at 100\%}$

$B = \text{kW/ton at 75\%}$

$C = \text{kW/ton at 50\%}$

$D = \text{kW/ton at 25\%}$

n_c or E_c - Combustion Efficiency

For fuel-fired systems, this efficiency term is defined as the ratio of the fuel energy input minus the flue gas losses (dry flue gas, incomplete combustion and moisture formed by combustion of hydrogen) to the fuel energy input. In the U.S., fuel-fired efficiency are reported based on the higher heating value of the fuel. Other countries report fuel-fired efficiency based on the lower heating value of the fuel. The combustion efficiency is calculated by determining the fuel gas losses as a percent of fuel burned. [$E_c = 1 - \text{flue gas losses}$]

Thermal Efficiency (n_t or E_t)

This efficiency term is generally defined as the ratio of the heat absorbed by the water (or the water and steam) to the heat value of the energy consumed. The combustion efficiency of a fuel-fired system will be higher than its thermal efficiency. See ASME Power Test Code 4.1 for more details on determining the thermal efficiency of boilers and other fuel-fired systems. In the U.S., fuel-fired efficiency are typically reported based on the higher heating value of the fuel. Other countries typically report fuel-fired efficiency based on the fuel's lower heating value. The difference between a fuel's higher heating value and its lower heating value is the latent energy contained in the water vapor (in the exhaust gas) which results when hydrogen (from the fuel) is burned. The efficiency of a system based on a fuel's lower heating value can be 10 to 15% higher than its efficiency based on a fuel's higher heating value.

HSPF - Heating Seasonal Performance Factor

The term HSPF is similar to the term SEER, except it is used to signify the seasonal heating efficiency of heat pumps. The HSPF is a weighted average efficiency over a range of outside air conditions following a specific standard test method. The term is generally applied to heat pump systems less than 60000 Btu/h (rated cooling capacity.) The units of HSPF are Btu/w-h. It is important to note that this efficiency term typically includes the energy requirement of auxiliary systems such as the indoor and outdoor fans. For purposes of comparison, the higher the HSPF the more efficient the system.

Enthalpy

http://www.engineeringtoolbox.com/psychrometric-terms-d_239.html; The Engineering ToolBox,

STUDY QUESTIONS:

TIP: Be able to read a psychrometric chart using two given properties to determine a state point.

What is enthalpy?

How is it determined on the psychrometric chart?

Psychrometry is the science of studying thermodynamic properties of moist air and the use of these to analyze humid air conditions and processes. Air conditioning processes can be determined with psychrometric charts and Mollier diagrams. Common properties in the charts include:

- dry-bulb temperature
- wet-bulb temperature
- relative humidity (RH)
- humidity ratio
- specific volume
- dew point temperature
- enthalpy

With at least two known properties it is possible to characterize the air in the intersection of the property lines - the state-point. With the intersection point located on the chart or diagram other properties can be read directly.

Enthalpy - h

Enthalpy is the measure of the total thermal energy in air.

Energy content is expressed as energy per unit weight of air (Btu/lbair, J/kgair).

Enthalpy in the psychrometric chart can read from where the appropriate wet-bulb line crosses the diagonal scale above the saturation curve.

Air with the same amount of energy may either be drier hotter air (higher sensible heat) or cooler moister air (higher latent heat).

Moist air is a mixture of dry air and water vapor. In atmospheric air water vapor content varies from 0 - 3% by mass. The enthalpy of moist and humid air includes the

- enthalpy of the dry air - the sensible heat
- enthalpy of the evaporated water in the air - the latent heat

The total enthalpy - sensible and latent - is used when calculating cooling and heating processes.

Refrigeration tons to BTU per hour conversion

<https://www.rapidtables.com/convert/power/btu-to-ton.html>

STUDY POINTERS:

- Understand how to convert Refrigeration tons (RT) to BTU per hour (BTU/hr).
- Review the formulas and conversion table below.
- Be prepared to read the table and perform a conversion.

How to convert tons to BTU/hr:

One refrigeration ton is equal to 12000 BTUs per hour:

$$1 \text{ RT} = 12000 \text{ BTU/hr}$$

One BTU per hour is equal to 8.33333×10^{-5} refrigeration ton:

$$1 \text{ BTU/hr} = 8.33333 \times 10^{-5} \text{ RT}$$

So the power P in BTUs per hour (BTU/hr) is equal to 12000 times the power P in refrigeration tons (RT):

$$P_{(\text{BTU/hr})} = 12000 \times P_{(\text{RT})}$$

Example

Convert 2 RT to BTU/hr:

$$P_{(\text{BTU/hr})} = 12000 \times 2 \text{ RT} = 24000 \text{ BTU/hr}$$

Tons to BTU/hr conversion table

Power (tons)	Power (BTU/hr)
0.1 RT	1200 BTU/hr
0.2 RT	2400 BTU/hr
0.3 RT	3600 BTU/hr
0.4 RT	4800 BTU/hr
0.5 RT	6000 BTU/hr
0.6 RT	7200 BTU/hr
0.7 RT	8400 BTU/hr
0.8 RT	9600 BTU/hr
0.9 RT	10800 BTU/hr
1 RT	12000 BTU/hr
2 RT	24000 BTU/hr
3 RT	36000 BTU/hr
4 RT	48000 BTU/hr
5 RT	60000 BTU/hr

Hot Gas By Pass

https://www.trane.com/content/dam/Trane/Commercial/global/products-systems/education-training/engineers-newsletters/direct-expansion-systems/adm_apn007_en_0503.pdf

Paul Solberg & Brenda Bradley, Blessing or Curse – Hot Gas By Pass, Trane Engineering Newsletter – Vol. 32, No.2, American Standard, Inc. 2003. See PDF at the link above or provided here titled “Hot Gas Bypass_Trane” for page 2, Figure 1.

STUDY QUESTIONS:

What is hot gas bypass?

When is it appropriate to implement HGBP?

Why is HGPB best to avoid?

Apply HGBP as a last resort. Only use hot gas bypass if all other design options fail to meet the demands of the application. To make this determination, it is critical to:

Understand the year-round loads and requirements of the system.

“Most comfort cooling applications can operate between steps of loading without loss of temperature or humidity control.” Not only does this statement hold true between the third and fourth steps of cooling, when the outdoor latent load is high, but it also holds true for the step between off and first-stage cooling when the outdoor latent load is comparatively low.

Choose the right arrangement. Hot gas bypass is arranged in one of two ways (see the comparison in Table 1, p. 4); both require special care during design and installation.¹ HGBP to the evaporator inlet delivers hot refrigerant vapor between the expansion valve and the distributor (Figure 1). During HGBP operation, the expansion valve meters enough liquid refrigerant to both de-superheat the bypassed vapor and satisfy the evaporator load. The resulting refrigerant flow rate is sufficient to carry oil through the coil and suction line. HGBP to the suction line bypasses both the condenser and the evaporator, diverting hot vapor from the compressor discharge directly to the suction line (Figure 2). A liquid-injection valve meters liquid refrigerant into the stream of bypassed vapor, cooling it enough to prevent the compressor motor from overheating.

Do not oversize the system. An oversized system quickly meets the sensible load without satisfying the latent load. Adding HGBP may mitigate this error ... but at the expense of unnecessarily high power bills. Once again, understanding the year round loads and properly sizing the system to match them is paramount to providing thermal comfort (controlling temperature and humidity) and eliminating the need for HGBP.

Select equipment with multiple-step refrigerant circuits. The logic for avoiding system oversizing also supports the choice of multiple-step refrigerant circuit(s) whenever possible. The capacity of an unloading refrigerant circuit will attempt to match a reduced load at better balance points.

Select an evaporator coil that can maintain a high suction temperature to permit the system to aggressively stage down before a frost condition develops. In all cases, the design should maximize the suction temperature while maintaining the desired conditions. For comfort cooling applications, the minimum saturated suction temperature at design should be 43°F to 45°F for variable-volume air distribution (VAV), or 40°F to 43°F for constant-volume air distribution (CV). Coils with intertwined circuits tend to reduce the risk of coil frosting because they use more of the available fin surface (than face-split coils) at part-load conditions. This allows the system to operate at higher suctions and more reliable balance points.

Figure 1. Hot gas bypassed to evaporator inlet (preferred arrangement for HGBP)

Keys to successful implementation:

1. Position the HGBP valve above the discharge line, near the compressor. If the system includes pump-down, provide a means to shut off refrigerant flow.
2. Pitch the line upstream of the HGBP valve to drain oil back into the discharge line.
3. Pitch the line downstream of the HGBP valve toward the evaporator, away from the valve.
4. If the HGBP line includes a riser, regardless of height, provide a drain leg of the same diameter as the riser. Add an oil-return line 1 in. (25 mm) from the bottom of the trap; use tubing that is 1/8 in. (6 mm) and at least 5 ft (300 mm) long. Pre-charge the trap with oil.
5. Divert hot gas to each active distributor at the expected operating points for hot gas bypass.
6. If the HGBP line feeds multiple distributors, provide a check valve for each distributor.
7. Insulate the entire length of the HGBP line.

Chilled Water Reset Schedule

<https://www.elliottenergyconsulting.com/articles/chilled-water-reset>

STUDY QUESTIONS:

What is chilled water reset?

Reset can generate _____% energy savings compared to fixed setpoints?

Chilled Water Reset Schedule – An automated control logic that raises or lowers the supply temperature of the chilled water leaving the chiller, in response to another variable such as outside air temperature.

Freeze Stats

http://en.wikipedia.org/wiki/Freeze_stat

STUDY QUESTIONS:

What is the purpose of a freeze stat?

What are typical applications?

How do mechanical and digital versions of freeze stats compare?

When might it be advantageous to use a mechanical stat v. digital?

A **freeze stat** is a [temperature sensing device](#) for [HVAC](#) that monitors a [heat exchanger](#) to prevent its coils from [freezing](#). Freeze stats can be used on both [freon-to-air](#), and freon-to-[liquid](#) type heat exchangers and serve different purposes with similar goals for each.

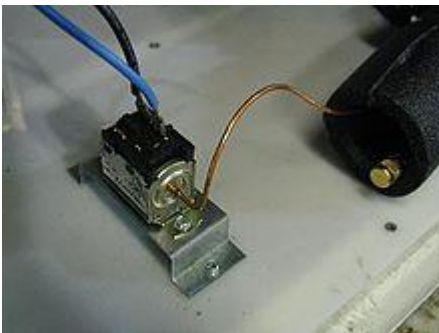
Air coil

The purpose of an **air coil freeze stat** is to keep the refrigerant-to-air heat exchanger (commonly called [air coils](#)) from freezing. This kind of freeze stat is typically used for heating coils which are exposed to outside air and is usually installed on the supply air side of the coil.https://en.wikipedia.org/wiki/Freeze_stat_-_cite_note-1 To accomplish this, they typically shut down the flow of outside air to a [mixing box](#) when the temperature reaches a predetermined [setpoint](#). The setpoint for air coil freeze stats is typically about 38 degrees Fahrenheit which is approximately when the [dew point](#) temperature of the air starts to drop below freezing point.

Water coil

The **water coil freeze stat** performs a similar function to the air coil freeze stat, but is used on a different type of HVAC system. Its function is to keep the freon-to-liquid heat exchanger (commonly called *liquid coils*) from freezing. In practical situations, when an air coil freeze stat is not used, bypassed, or defeated, the air coil can freeze, and this causes a lack of air flow to the facility. By contrast, when a water coil freeze stat is not used, the water coil can get so cold that it can freeze the cooling liquid in the exchanger and burst the exchanger. A ruptured heat exchanger mixes contaminants such as freon and [oil](#) into the coolant. The intrusion of coolant into the delicately balanced [refrigeration system](#) can cause expensive damage to components such as the [freon compressor](#), and the [reversing valve](#).

Mechanical freeze stat



Conceptually, mechanical freeze stats are constructed with a [diaphragm](#), a [capillary tube](#) and bulb, and an electric [switch](#). The capillary tube allows gas movement to and from the capillary bulb and the diaphragm with a fall or rise in temperature, respectively. When the temperature reaches a specific

setpoint, the pressure in the diaphragm will trip a switch which typically shuts down the flow of outside air while the capillary bulb's temperature is at or below the setpoint. Mechanical freeze stats can have more than one set of [contacts](#), and the contacts can be [NO](#) or [NC](#).

Disadvantages

- Capillary tube easily kinked during installation limiting effectiveness
- Sensing bulb must be mounted horizontally
- Diaphragm case must be mounted in a separate, warmer location for effective operation

Advantages

- Typically inexpensive
- Easily understood wiring

Digital freeze stat



Digital freeze stats, also known as *electronic* or *solid state* freeze stats, use an electronic circuit, [microprocessor](#), or [microcontroller](#) in place of the mechanical freeze stat's diaphragm and switch. They also use one or more electric or electronic sensors in place of the capillary tube and bulb for temperature sensing. Digital freeze stats utilizing microcontrollers or microprocessors can also perform more advanced functions than simply opening or closing switch contacts. Digital freeze stats can perform seemingly intelligent operations such as reversing the refrigerant flow and using some building heat to thaw a freon-to-liquid heat exchanger and then restoring the refrigerant flow to its normal direction once the danger of freezing the water coil has been averted.

Disadvantages

- Requires power to operate
- Typically higher cost than mechanical freeze stats
- More complex wiring installation

Advantages

- Multiple sensors
- Sensors can be near or far
- No capillary tube kinking issue
- No capillary tube leaking issue
- Operate in any position
- Operate in varying temperatures
- Programmable actions and setpoints
- Can perform functions other than opening or closing a single switch

Cooling Tower Management

Best Management Practice #10: Cooling Tower Management, U.S. Department of Energy:
<http://energy.gov/eere/femp/best-management-practice-10-cooling-tower-management>

STUDY QUESTIONS:

What are the two biggest sources of water loss in a cooling tower system? (A: blowdown and evaporation)

What are "cycles of concentration"?

Increasing the number of cycles offers what two benefits?

Increasing cycles from three to six reduces cooling tower make-up water by _____% and cooling tower blowdown by _____%.

Monitoring and controlling the _____ provides the most significant opportunity to conserve water in cooling tower operations.

Why is it important to read conductivity and flow meters regularly?

What information should be recorded in a cooling tower maintenance log?

(A: make-up and blowdown quantities, conductivity, and cycles of concentration.)

Is acid recommended for water treatment?

Be familiar with recommended cooling tower retrofit options.

Cooling towers dissipate heat from recirculating water used to cool chillers, air conditioners, or other process equipment to the ambient air. Heat is rejected to the environment from cooling towers through the process of evaporation. Therefore, by design, cooling towers use significant amounts of water.

Overview

The thermal efficiency and longevity of the cooling tower and equipment depend on the proper management of recirculated water. Water leaves a cooling tower system in one of four ways.

1. **Evaporation:** The primary function of the tower and the method that transfers heat from the cooling tower system to the environment.
2. **Drift:** A small quantity of water may be carried from the tower as mist or small droplets. Drift loss is small compared to evaporation and blowdown and is controlled with baffles and drift eliminators.
3. **Blowdown:** When water evaporates from the tower, dissolved solids (such as calcium, magnesium, chloride, and silica) remain in the recirculating water. As more water evaporates, the concentration of dissolved solids increases. If the concentration gets too high, the solids can cause scale to form within the system. The dissolved solids can also lead to corrosion problems. The concentration of dissolved solids is controlled by removing a portion of the highly concentrated water and replacing it with fresh make-up water. Carefully monitoring and controlling the quantity of blowdown provides the most significant opportunity to conserve water in cooling tower operations.
4. **Basin leaks or overflows:** Properly operated towers should not have leaks or overflows. Check float control equipment to ensure the basin level is being maintained properly, and check system valves to make sure there are no unaccounted for losses. The sum of water that is lost from the tower must be replaced by make-up water:

$$\text{Make-Up} = \text{Evaporation} + \text{Blowdown} + \text{Drift}$$

A key parameter used to evaluate cooling tower operation is "cycle of concentration" (sometimes referred to as cycle or concentration ratio). This is determined by calculating the ratio of the concentration of dissolved solids in the blowdown water compared to the make-up water. Because dissolved solids enter the system in the make-up water and exit the system in the blowdown water, the cycles of concentration are also approximately equal to the ratio of

volume of make-up to blowdown water.

From a water efficiency standpoint, you want to maximize cycles of concentration. This will minimize blowdown water quantity and reduce make-up water demand. However, this can only be done within the constraints of your make-up water and cooling tower water chemistry. Dissolved solids increase as cycles of concentration increase, which can cause scale and corrosion problems unless carefully controlled.

In addition to carefully controlling blowdown, other water efficiency opportunities arise from using alternate sources of make-up water. Water from other facility equipment can sometimes be recycled and reused for cooling tower make-up with little or no pre-treatment, including:

- Air handler condensate (water that collects when warm, moist air passes over the cooling coils in air handler units). This reuse is particularly appropriate because the condensate has a low mineral content and is typically generated in greatest quantities when cooling tower loads are the highest
- Water used once through a cooling system
- Pretreated effluent from other processes provided that any chemicals used are compatible with the cooling tower system
- High-quality municipal wastewater effluent or recycled water (where available). U.S. Environmental Protection Agency (EPA) WaterSense at Work cooling towers best management practice.

Operation and Maintenance

To maintain water efficiency in operations and maintenance, federal agencies should:

- Calculate and understand "cycles of concentration." Check the ratio of conductivity of blowdown and make-up water. Work with your cooling tower water treatment specialist to maximize the cycles of concentration. Many systems operate at two to four cycles of concentration, while six cycles or more may be possible. Increasing cycles from three to six reduces cooling tower make-up water by 20% and cooling tower blowdown by 50%.
- The actual number of cycles of concentration the cooling tower system can handle depends on the make-up water quality and cooling tower water treatment regimen. Typical treatment programs include corrosion and scaling inhibitors along with biological fouling inhibitors.
- Install a conductivity controller to automatically control blowdown. Work with a water treatment specialist to determine the maximum cycles of concentration the cooling tower system can safely achieve and the resulting conductivity (typically measured as micro Siemens per centimeter, $\mu\text{S}/\text{cm}$). A conductivity controller can continuously measure the conductivity of the cooling tower water and discharge water only when the conductivity set point is exceeded.

- Install flow meters on make-up and blowdown lines. Check the ratio of make-up flow to blowdown flow. Then check the ratio of conductivity of blowdown water and the make-up water (handheld conductivity meters can be used to determine the relative mineral concentration of the recirculating and make-up water). These ratios should match the target cycles of concentration. If both ratios are not about the same, check the tower for leaks or other unauthorized draw-off. If the system is not operating at, or near, the target cycles of concentration, check system components including conductivity controller, make-up water fill valve, and blowdown valve.
- Read conductivity and flow meters regularly to quickly identify problems. Keep a log of make-up and blowdown quantities, conductivity, and cycles of concentration. Monitor trends to spot deterioration in performance.
- Consider using acid treatment such as sulfuric, hydrochloric, or ascorbic acid where appropriate. When added to recirculating water, acid can reduce the scale buildup potential from mineral deposits and allow the system to run at higher cycles of concentration. Acid treatment lowers the pH of the water and is effective in converting a portion of the alkalinity (bicarbonate and carbonate), a primary constituent of scale formation, into more readily soluble forms. Make sure workers are fully trained in the proper handling of acids. Also note that acid overdoses can severely damage a cooling system. The use of a timer or continuous pH monitoring via instrumentation should be employed. It is important to add acid at a point where the flow of water promotes rapid mixing and distribution.
- Select a water treatment vendor with care. Tell vendors that water efficiency is a high priority and ask them to estimate the quantities and costs of treatment chemicals, volumes of blowdown water, and the expected cycles of concentration ratio. Keep in mind that some vendors may be reluctant to improve water efficiency because it means the facility will purchase fewer chemicals. In some cases, saving on chemicals can outweigh the savings on water costs. Vendors should be selected based on "cost to treat 1,000 gallons of make-up water" and "highest recommended system water cycle of concentration." Treatment programs should include routine checks of cooling system chemistry accompanied by regular service reports that provide insight into the system's performance.
- Ask the water utility if it provides sewer credits for evaporative losses, which can be calculated as the difference between metered make-up water minus metered blowdown water.
- Implement a comprehensive air handler coil maintenance program. As coils become dirty or fouled, there is increased load on the chilled water system to maintain conditioned air set point temperatures. Increased load on the chilled water system not only has an associated increase in electrical consumption, it also increases the load on the evaporative cooling process, which uses more water.

Retrofit Options

The following retrofit options help federal agencies maintain water efficiency across facilities:

- Consider installing a side-stream filtration system. These systems filter silt and suspended solids and return the filtered water to the recirculating water. This limits the fouling potential for the tower system, which is particularly helpful if the cooling tower is located in a dusty environment.
- Install a make-up water or side-stream softening system when hardness (calcium and magnesium) is the limiting factor on cycles of concentration. Water softening removes hardness using an ion exchange resin and can allow you to operate at higher cycles of concentration.
- Install covers on open distribution decks on top of the tower. Reducing the amount of sunlight on tower surfaces can significantly reduce biological growth such as algae.
- Consider alternative water treatment options, such as ozonation or ionization and chemical use. Be careful to consider the life cycle cost impact of such systems.
- Install automated chemical feed systems on large cooling tower systems (more than 100 tons). The automated feed system should control chemical feed based on make-up water flow or real-time chemical monitoring. These systems minimize chemical use while optimizing control against scale, corrosion, and biological growth.

Replacement Options

The following replacement options help federal agencies maintain water efficiency across facilities.

- Get expert advice to help determine if a cooling tower replacement is appropriate. New cooling tower designs and improved materials can significantly reduce water and energy requirements for cooling. Replacing a cooling tower involves significant capital costs, so be sure to investigate every retrofit and operations and maintenance option available, and compare the costs and benefits to a new tower.
- For specifics, consult with experts in the field. The first resource should be local or headquarters engineers, but do not overlook input from experienced contractors or other government agencies.

Cooling Tower VFD's

Why a VFD is Beneficial for Cooling Towers

http://conservonline.com/why-a-vfd-is-beneficial-for-cooling-towers#.VetKKKPn_Dc

STUDY QUESTIONS:

How does use of VFD's on cooling tower fans save energy?

What are other benefits?

Why is it good practice to perform a vibration analysis on a VFD-controlled cooling tower fan?

Fan motor horsepower (HP) requirement varies as the cube of the speed, so the slower the fan speed--the less energy required. A fan running at 80% speed will consume only _____% of the power of a fan running at full speed.

On cooling towers, Variable Frequency Drives (VFDs) eliminate many of the drawbacks associated with starter-controlled fans. There are many benefits, including reduced energy consumption, resulting in lower utility costs; reduced maintenance requirements which decreases personnel & equipment replacement costs; and process water temperature stabilization.

The fan may be spinning when a VFD is commanded to start. A VFD must correctly identify motor rotation, slow the motor down to zero speed (when opposite rotation is detected), accelerate the motor in the correct direction and not trip on an over-voltage or over-current condition. Mechanical brakes or anti-ratcheting devices can be used to ensure that a fan doesn't rotate in the wrong direction. A VFD eliminates mechanical and electrical brakes as well as anti-ratcheting devices, time delay relays, etc. In extremely cold weather, tower icing can be averted by running the fan more slowly than required, raising the tower and process water temperatures. It is also common to reverse a cooling tower fan, keeping the heat in the tower.

VFDs accomplish this function & eliminate reversing starters. Likewise, on hot days, when the air is thinner, fans can be run above 60 Hz, providing additional cooling capacity. The VFDs current and/or torque limit function will limit the current of the motor such that the nameplate FLA rating is not exceeded. This is impossible without a VFD.

On fan loads, the HP requirement varies as the cube of the speed, so the slower the fan speed--the less energy required. A fan running at 80% speed will consume only 50% of the power of a fan running at full speed. At 50% fan speed, power consumption is only 16%. A minimum speed of 20-25% is usually possible on an existing motor. For direct connected or belted cooling tower fans, this minimum speed is usually not a concern. However, when a gearbox is used, the minimum speed is more critical, as the gearbox may depend on an internal oil slinger for lubrication. Consult the manufacturer of the cooling tower for minimum speed requirements.

VFD controlled cooling tower fans operate over many speeds as opposed to the fans on a single or two-speed motor starter. As such, it is a good practice to perform a vibration analysis on the fan and tower assembly, as a mechanical resonance may develop at certain speeds. Identified problem speeds may be programmed into the drive and "locked out". Vibration switches are often wired into a drive or control system, shutting down the cooling tower if a problem arises.

Cooling Tower Float Valve Adjustment

<https://www.kosen-valves.com/news/the-role-of-the-cooling-tower-float-valve-28575839.html>

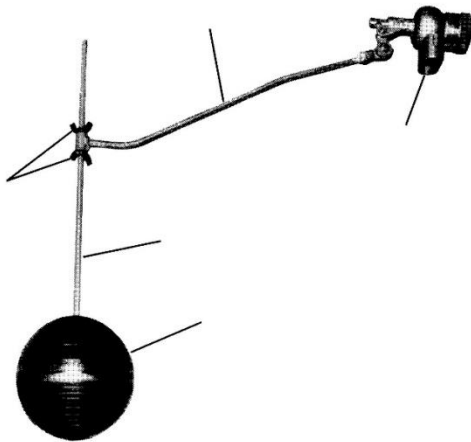
<https://www.universaltowerparts.com/part-1-cooling-tower-essentials/>

STUDY QUESTIONS:

What is the purpose of a cooling tower float valve?

What is the recommended adjustment setting?

To set the initial basin water level, adjust the wing nuts so the make-up valve is completely closed when the water level is 1/2" below the overflow connection. This setting should produce operating levels as shown in your manufacturer's Operation and Maintenance Manual. Set the bleed rate for desired cycles of concentration and begin operation. Allow 24 hours of operation, check and readjust operating level, if required. Remember, supply pressure must be maintained at 15 to 50 psi for proper float valve operation.



Building Controls

Understanding Building Automation and Control Systems, Advanced Control Corporation

<https://www.advancedcontrolcorp.com/understanding-building-automation-and-control-systems/>

STUDY QUESTION:

What is the difference between a BAS and EMS?

Understanding Building Automation and Control Systems

Building Automation Systems (BAS) are centralized, interlinked, networks of hardware and software, which monitor and control the environment in commercial, industrial, and institutional facilities. While managing various building systems, the automation system ensures the operational performance of the facility as well as the comfort and safety of building occupants.

Typically, such control systems are installed in new buildings or as part of a renovation where they replace an outdated control system.

Related Terms

You may hear any of the following terms to describe the control or automation of buildings:

- Building Automation and Control Systems (BACS), Building Control System (BCS), and/or Building Management System (BMS)—same as “Building Automation System” or the subject of this page.
- Controls—This term is appropriate in describing discrete devices that control particular pieces of equipment or processes.
- Direct Digital Control (DDC)—describes the communication method used in modern devices (hardware and software). Collectively, DDC products control various building systems and form the automation system.
- Energy Management System (EMS)—generally understood to be the same as a “Building Automation System” but may have special emphasis on energy metering/monitoring
- Energy Management and Control System—well, you’re getting the idea.
- Smart (Intelligent) Building—a building equipped with a data-rich BAS.

What is Controlled?

Generally, building automation begins with control of mechanical, electrical, and plumbing (MEP) systems. For instance, the heating, ventilation, and air-conditioning (HVAC) system is almost always controlled, including control of its various pieces of equipment such as:

- Chillers
- Boilers

- Air Handling Units (AHUs)
- Roof-top Units (RTUs)
- Fan Coil Units (FCUs)
- Heat Pump Units (HPUs)
- Variable Air Volume boxes (VAVs)

Lighting control is, likewise, low-hanging fruit for optimizing building performance. Other systems that are often controlled and/or brought under a complete automation system include:

- Power monitoring
- Security
- Close circuit video (CCTV)
- Card and keypad access
- Fire alarm system
- Elevators/escalators
- Plumbing and water monitoring

Data Type for Control System

<https://www.dpstele.com/blog/what-is-a-direct-digital-control-system.php>

STUDY QUESTIONS:

What are the three data types in a DDC system?

How do digital and analog data differ?

Data type is classified as digital, analog or accumulating. Digital data may also be called discrete data or binary data. The value of the data is either 0 or 1 and usually represents the state or status of a set of contacts. Analog data are numeric, decimal numbers and typically have varying electrical inputs that are a function of temperature, relative humidity, pressure or some other common HVAC sensed variable. Accumulating data are also numeric, decimal numbers, where the resulting sum is stored. This type of data is sometimes called pulse input.

Programmable Thermostats

https://www.energystar.gov/ia/partners/prod_development/revisions/downloads/thermostats/ProgramThermDraftI.pdf?dad2-f77c

Energy Star Program Requirements for Programmable Thermostats, Draft 1-Version 2.0

STUDY QUESTIONS:

What is the purpose of a programmable thermostat?

What is the difference between energy saving set points and comfort set points?

When might temperature override be used?

Definitions: Below are the definitions of the relevant terms in this document:

- **Programmable Thermostat:** A device that enables the user to set one or more time periods each day when a comfort setpoint temperature is maintained and one or more time periods each day when an energy-saving setpoint temperature is maintained. This device enables the user to save energy as the heating and cooling equipment is not running needlessly at a comfort temperature setpoint 24 hours per day. A programmable thermostat may be capable of controlling one or more zones of a conditioned space.
- **Comfort Setpoint Temperature:** The temperature setting in degrees Fahrenheit (F) or degrees Celsius (C) for the time period during which the residence and/or building is expected to be occupied, e.g., the early morning and evening hours.
- **Comfort Time:** The time period during which the conditioned space is expected to be occupied, e.g., the early morning and evening hours.
- **Conventional Recovery:** A feature of a programmable thermostat that activates the heating or cooling system at the comfort time set by the user.
- **Cycle Rate:** The number of times the heating or cooling unit goes on and off in a given hour. This is measured when the heating and air-conditioning equipment is operating at a 50% load condition, as measured under the National Electrical Manufacturers Association (NEMA) DC-3 standard titled “Residential Controls- Electrical Wall-Mounted Room Thermostats.” (Available for purchase at www.nema.org).
- **Default:** Default features should be activated when a power connection is made. Features that are shipped as defaults should be shipped pre-programmed and activated.
- **Energy-Saving Setpoint Temperature:** The setpoint temperature for the energy-saving periods usually specified for both the heating and cooling seasons.
 - **Setback Temperature:** The setpoint temperature for the energy-saving periods during the heating season, generally at night and during unoccupied hours. This is a lower setpoint temperature than the comfort setpoint temperature.

- Set-Up Temperature: The setpoint temperature for the energy-saving periods during the cooling season, generally at night and during unoccupied hours. This is a higher setpoint temperature than the comfort setpoint temperature.
- Multistage Heat Pump Recovery: A feature of a programmable thermostat that allows the heat pump to recover gradually from an energy-saving setpoint temperature to a comfort setpoint temperature. The heat pump recovery feature is designed to minimize the use of auxiliary heat while also minimizing the on-time of the system.
- Programming Periods: This feature allows the user to program different setback/setup schedules. Usually this feature is used to allow for different settings for weekday and weekend programming.
- Setpoint Temperature: The temperature setting in degrees Fahrenheit (F) or degrees Celsius (C) for any given time period.
- Setback: This action allows the consumer to decrease the heating temperature.
- Setup: This action allows the consumer to increase the cooling temperature.
- Temporary Program Override: This feature enables the user to override the programmable thermostat's temperature and time settings and choose a different temperature until the next part of the program begins.
- Long-Term Hold: A long-term hold may allow the user to set the programmable thermostat at a temperature for a fixed period of time (e.g., vacation, override, etc.).

Mechanical Time Switch

<https://tense.com.tr/en/what-is-a-mechanical-time-switch-how-does-it-work/>

STUDY QUESTION:

What is a mechanical time switch?

Skill 05: Be Familiar with the Trending Capabilities of Control Systems and Know How to Supplement Their Capabilities with Data Loggers

<https://av8rdas.wordpress.com/2014/01/14/key-retrocommissioning-skills/>

STUDY QUESTIONS:

Why is an understanding of trend logging with a BAS or data loggers an important skill for building operators?

I am fond of saying that the building frequently knows the reason for the issues we are observing in it; we just need to ask it what is going on. Trends are one of the ways buildings “talk” to us. Thus, understanding how to gather this critical information from a building is an important skill to develop. Plus, it’s a lot of fun (in a nerdy sort of way).

Trend logging is a diagnostic tool that uses data gathered at short intervals, such as every 15 minutes, to understand how a building or one of its systems is operating. This data can help identify potential efficiency problems.

Trend logs from your DDC provide valuable data about building operation. Most DDC systems allow trend logging of any control input or output such as temperature, pressure, and on/off status. Examining the trend log data can provide leads for investigating specific equipment or suggest potential changes to control sequencing.

Setback Temperature Control

<https://www.deq.nc.gov/environmental-assistance-and-customer-service/ias-energy-efficiency/opportunities/setback-temperature-control/download>

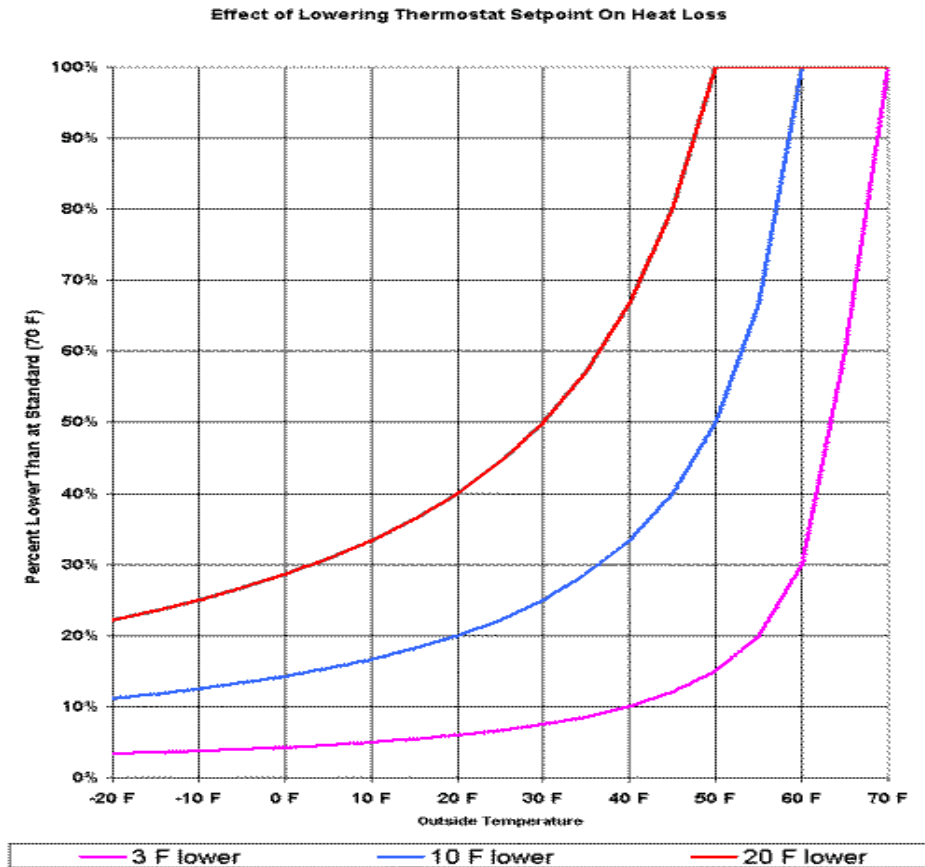
STUDY QUESTIONS:

What impact does setting back temperatures have on building heat loss?

Estimate cost savings from heating temperature setbacks.

Be familiar with effective setback strategies.

The graph at the right shows the effect a given temperature difference between a room set point temperature (70°F) and outside air temperature (70°F to –20°F) has on heat loss. A lower setback temperature results in less heat loss as the outside temperature drops through the night. The energy savings is much greater during the warmer months of the heating season, and less pronounced during the coldest time of the year. This graph is only representative for a heating load, as cooling loads are much more dependent on the Sun's radiant energy influence and building fenestration. From the graph it shows that a 20oF setback will result in a 67% lower heat loss than if there was no setback at all. The 10oF setback would result in a 33% less heat loss than at 70oF and the 3oF setback would only save about 4% of the energy loss as compared to no setback at all. How much to setback is often evaluated in terms of the building envelope's rate of heat losses (U) and the hvac equipment sizing capacity for next day loss recovery. However, the next day loss energy recovery is normally less than the heat loss if no setback had taken place, unless the building is poorly insulated.



Electrical Systems & Lighting

Electrical One-Line Diagram

<http://www.archtoolbox.com/materials-systems/electrical/electrical-one-line-diagram.html>

STUDY QUESTIONS:

What are the components of an electrical one-line diagram?

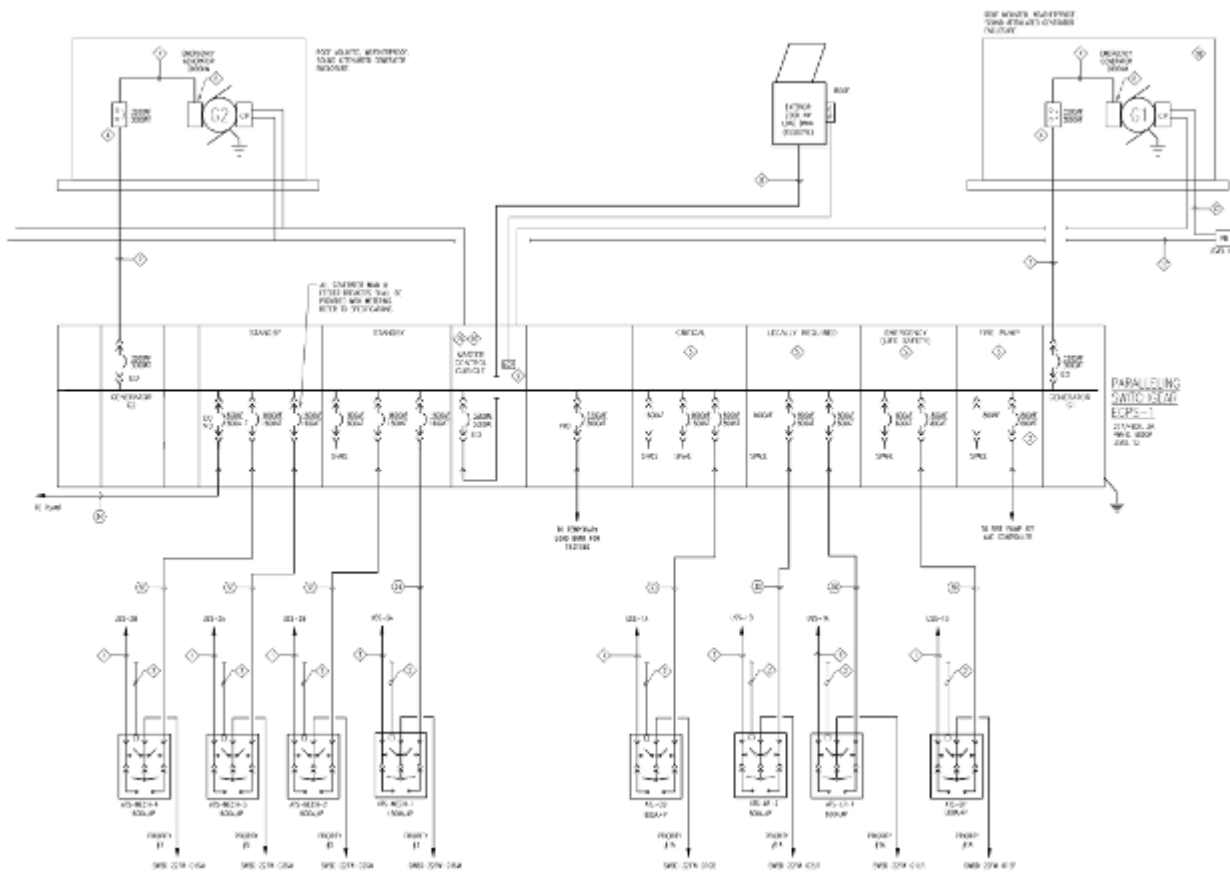
What information does the diagram provide?

One-line diagrams (also known as single-line diagrams) are used by a number of trades including HVAC and plumbing, but the electrical one-line diagram is the most common. HVAC and plumbing riser diagrams are essentially one-line diagrams, but they go by a different name.

Electrical One-Line or Single-Line Diagram

An electrical one-line diagram is a representation of a complicated electrical distribution system into a simplified description using a single line, which represents the conductors, to connect the components. Main components such as transformers, switches, and breakers are indicated by their standard graphic symbol. The overall diagram provides information on how the components connect and how the power flows through the system.

A one-line diagram can represent an entire building system or a complicated component of the overall system. Architects and building owners will appreciate the simplicity of the diagram, which will provide an overall description of the system on a single sheet of paper.



Current Transformers

http://www.ccontrols.com/w/CT_Installation_and_Wiring

http://www.ccontrols.com/w/CT_Selection

STUDY QUESTIONS:

What is the purpose of a CT?

How is the accuracy of CT's specified?

Why is accuracy important to monitor?

What is crest factor?

How does crest factor vary with resistive loads v. PF-corrected loads?

SAFETY WARNING! Current transformers (CTs) are typically installed in electrical equipment with lethal high voltage levels. Before attempting to install CTs read the [CT Installation Safety](#) page.

CAUTION! WattNode meters are designed to work only with CTs that have a 333 mV output. This type of CT has a built-in burden resistor that produces a safe low voltage output signal. The use of any other type of CT will result in incorrect power measurements, and may permanently damage the WattNode meter.

Key Points

- Install CTs on the phase conductor that corresponds to the voltage input phase.
- Install CTs with the arrow or label “THIS SIDE TOWARD SOURCE” facing towards the current source.
- Connect the white and black CT leads to the corresponding white and black CT input terminals.

Orientation And Polarity

CTs are marked with a symbol (arrow) or label which indicates the correct mechanical orientation of the CT on the conductor being measured. Find the arrow or label “THIS SIDE TOWARD SOURCE” on the CT and install the CT with the label or arrow facing toward the current source: generally the utility meter or the circuit breaker.

In addition to installing CTs with the correct mechanical orientation, electrical polarity, as indicated by their white and black wires must also be correct. Each pair of CT wires connects to the appropriate terminal on the to the black six position screw terminal block. The terminals are labeled ØA CT, ØB

CT, and ØC CT. The polarity of each pair of terminals is indicated by a white and black dot on the label. Be sure to connect the white wire to the phase terminal aligned with the white dot, and the black wire to the terminal with the black dot.

Remember that both the physical orientation and the electrical polarity of each phase must be correct for proper operation. If a phase is reversed either electrically or mechanically, and current flows in the reverse direction, the WattNode meter will measure, depending on the model, zero or negative energy for that phase.

Range of Currents

CT manufacturers generally specify CT accuracy down to 10% of rated current for standard CTs and down to 1% of rated current for revenue grade CTs. The upper limit is generally 100% or 120% of rated current. This is the range over which CTs are the most accurate, so depending on your accuracy requirements and the type of CTs being used, you should choose CTs so that the nominal currents fall within this range.

Most CTs are still reasonably accurate at lower currents. For example, the ACT-0750 models are very accurate down to 0.2% of rated current, and the CTS-1250 series are reasonably accurate down to 2-5% of rated current.

Many (but not all) CTs are also accurate for over-current conditions; however, the WattNode input circuitry clips at around 125% of rated current for sine wave currents and at even lower currents if the current has a high crest factor, so we always recommend selecting a CT with a rated current higher than you ever expect from the load (with the possible exception of very brief turn-on surges).

For example, suppose you are monitoring a 100A circuit with a compressor and fan. The turn-on surge reaches 85A, the normal load when the compressor is running is 65A, and when just the fan is running, 7A. The following table shows some options:

CT Model	Rated Amps	10% Point	100% Point	Comments
ACT-0750-100	100A	10A	100A	This CT has good accuracy specifications from 1% to 120% of rated current, so will be accurate at all operating currents.
CTS-0750-100	100A	10A	100A	This covers the range fairly well, but may be somewhat less accurate at the 7A low current condition.

CTS-0750-070	70A	7A	70A	This will be more accurate for the 7A condition, but may read a bit low during the turn-on surge.
CTT-0750-100	100A	10A	100A	Because this is a solid-core CT, it will be quite accurate even below 10% of rated current, so it should work well over the entire range.

As another example, suppose you are monitoring a compressor that typically draws 125A. You could use a 150A CT, but we'd recommend a 200A CT to allow more headroom for the turn-on surge and overload. Since the compressor will rarely draw much less than 100A when it's running, that will still be 50% of the CT rated current and the accuracy of the CT will be very good. The compressor current would have to drop below 20A before there would be accuracy concerns.

Crest Factor

See http://en.wikipedia.org/wiki/Crest_factor for an overview of crest factor.

The term “current crest factor” is used to describe the ratio of the peak current to the RMS (root mean square) current. Resistive loads like heaters and incandescent lights have nearly sinusoidal current waveforms with a crest factor near 1.4. Power factor corrected loads like PC power supplies typically have a crest factor of 1.4 to 1.5. Many common loads can have current crest factors ranging from 2.0 to 3.0, and higher values are possible.

The WattNode current transformer inputs will saturate and become inaccurate if the peak current is too high. This means you may want to be conservative in selecting the CT rated current. For example, if your load draws 10 amps RMS, but has a crest factor of 3.0, then the peak current is 30 amps. If you use a 15 amp CT, the WattNode will not be able to accurately measure the 30 amp peak current. Note: this is a limitation of the WattNode measurement circuitry, not the CT.

The following graph shows the maximum RMS current for accurate WattNode measurements as a function of the current waveform crest factor. The current is shown as a percentage of CT rated current. For example, if you have a 10 amp load with a crest factor of 2.0, the maximum CT current is approximately 85%. Eight-five percent of 15 amps is 12.75, which is higher than 10 amps, so your measurements should be accurate. On the other hand, if you have a 40 amp load with a crest factor of 4.0, the maximum CT current is 42%. Forty-two percent of a 100 amp CT is 42 amps, so you would need a 100 amp CT to accurately measure this 40 amp load.

You frequently won't know the crest factor for your load. In this case, it's generally safe to assume the crest factor will fall in the 1.4 to 2.5 range and select CTs with a rated current roughly 150% of the expected RMS current. So if you expect to be measuring currents up to 30 amps, select a 50 amp CT.

Voltage Balance, Energy Management Handbook, 1993

See image below.

STUDY QUESTIONS:

What are the two sources of voltage imbalance?

What is the impact of voltage imbalance on a motor?

NEMA recommends that voltage imbalance for a motor not exceed _____%?

T-frame motors will not hold up like U-frame motors (True or False)?

When served with balanced nameplate voltage, a T-frame motor will perform how?

How is PF metered?

Is there a PF charge on the utility bill for the building?

What does a PF study determine about PF charges on the utility bill?

When would it be appropriate to do a PF study?

Why would an electric utility implement voltage reduction?

What are impacts of voltage reduction on the performance of lighting systems and motors in the building?

Review discussion of voltage balance on this page.

ENERGY MANAGEMENT HANDBOOK

unless the motor maker so states, will not differentiate between a T-frame and an "energy-efficient" motor. NEMA requires that electric motors generally give satisfactory service with a supply voltage of plus or minus 10% of nameplate rating. A far better operating condition, however, will limit actual motor voltage to within 5% of nameplate rating. Design median voltage for single-phase motors remained at 115/230 V.

A T-frame motor is smaller in physical size and contains less copper and iron than a U-frame motor. It operates at a higher frame temperature with claims of an equal or longer insulation life than for U-frame motors. There was not much change for the better or worse with regard to efficiency and power factor. So, after 1965, new machines came with T-frame motors. Newly purchased motors were also T frame, and very shortly after operating experience began came the hue and cry of alarm. "T-frame motors will not hold up like U-frame motors." True: T-frame motors will not tolerate overload and other conditions compared with those a U-frame motor might withstand any more than a U-frame motor would withstand more exaggerated conditions than an A-frame motor might withstand. When served with *balanced nameplate voltage*, a T-frame motor will deliver rated horsepower for a normal life of 20 years, barring other damaging events, while operating at higher motor temperatures. A major part of the problem in preventing motor failure due to abuse has shifted to that of the mechanical engineer, who is usually concerned with the characteristics of the driven machine and how it operates in normal use.

If the writer seems to be covering a good amount of information which at first appearance has little bearing on electrical energy management, there is a good reason. Recall from Table 11.2 that almost two-thirds of all electrical energy used in the United States is used by motors. In a commercial building during hot weather, failure of an air-conditioner drive or a cooling-tower motor can cause people to be sent home. In industry a motor failure that stops production can produce losses of \$50 to \$3000 an hour, depending on the industry. A light bulb can go out and few will notice, but a critical motor vitally affects continued operation. I believe that a good understanding of what motors involve, and a better understanding of utility supply, is a very important part of electrical energy management.

A second problem in early motor failure can arise from the quality of utility electric supply. The quality of electric supply by the utility has been mentioned as well as balanced nameplate voltage for satisfactory operation of motors. As utility circuits serving customers have become

much longer, more service (both single- and three-phase) has been connected to the lines. The problem utilities have in providing voltage-balanced service for three-phase customers has become more pronounced. NEMA, in its guide for motors, changed the requirement for electric motor supply from "voltage balance to be as close as possible," to "voltage unbalance for a motor shall not exceed 1%."

Perfect voltage between electrical phases is difficult at any given customer location, and with a mixture for the utility of both single- and three-phase customers served by the same distribution line, balanced voltage supply by the utility may present an almost insurmountable problem for a utility in some locations. On the other hand, many studies have shown that the cause of voltage unbalance within a plant or commercial building is the result of an electrical condition within the plant or building rather than a lowering of the quality of power supplied by the utility.

Nevertheless, a voltage unbalance of 3% to a motor will cause the motor temperature to increase about 25% above normal. This indicates the strong need for energy management, since a decline in motor efficiency results. Even more important, such an abnormal temperature rise carries a great probability of early motor failure, with the attendant capital replacement costs and downtime loss. The decrease in motor efficiency is usually strongly overshadowed by replacement cost of the motor.

It should be noted that inexpensive voltmeters used to measure voltage are not sufficiently accurate for a voltage balance study. Good-quality voltmeters must be used for such a study. Even more important is that many studies have shown that voltage unbalance is caused within the facility rather than the quality of utility supply. (Should voltage balance be a problem, it is strongly suggested that the aid of the utility be requested before seeking legal or other remedies.)

The subject of "energy-efficient" motors must be discussed in some detail. Any designer/manufacture of electric motors can make a motor that is more efficient under a specific range of conditions compared with the efficiency of standard production motors.

Current information (1980) in the media indicates that the Department of Energy (DOE) is considering a requirement that all motor manufacturers design and make nothing but "energy-efficient" motors. This requirement is strongly opposed by motor manufacturers, as it should be. Requirements such as this can be compared with many other supposed energy-saving proposals which Congress did not contemplate when writing energy legislation.

The cost for making a motor more efficient is higher than for normal production-line motors. The comparison between the higher first cost and potential energy savings

Review discussion of Power Factor on this page.

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11.5.2 Power-Factor Calculations

By definition, power factor in ac circuits is determined by dividing real power in kilowatts by total power in kVA (Power factor = kW/kVA). Reactive power, either inductive or capacitive, always acts at right angles or 90° to real power. Thus power-factor calculations are only basic calculations to determine the length of sides of right triangles, which in scalar value represent electrical values, and the calculation of angles between the sides in degrees.

Sometimes two analogies are used to illustrate power factor. One analogy (Figure 11.1) is to use a stein of beer. The total capacity of the stein represents total power or kVA. The foam represents reactive power and the beer represents real power. With this analogy the ratio of beer to stein capacity is the power factor.

A second analogy (Figure 11.2) is to picture a horse pulling a car down a rail track, with the horse pulling at an angle to the direction of car travel. Thus the pull of the horse is total power, the tractive effort moving the car is real power, and the side pull, doing no real work, is the reactive power—both good analogies, but leaving us a bit short for actual power-factor calculations.



Fig. 11.1 Power factor analogy 1.

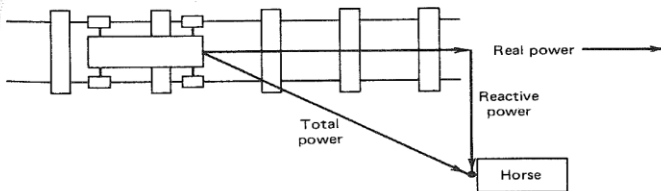


Fig. 11.2 Power factor analogy 2.

In the real world where power factor involves dollars, calculation must usually be made from the utility billing meter readings. A utility meter set will normally include three meters. A demand meter will record maximum power use for the billing period for the demand

interval of 5, 15, or 30 minutes. A watt-hour meter will record kilowatt-hours for the billing period. And a reactive meter will record kilovolt-ampere-hours reactive. Average power factor for the industrial plant or commercial building will then be calculated by dividing reactive KVA-hours by kilowatt-hours. (See Appendix III for a brief review of basic trigonometry.) This arithmetic calculates the tangent of the angle made by real power and total power. By a convenient table or computer, the tangent of the angle is converted to the cosine of the angle, which is the actual power factor average for the billing period. By moving the decimal point of the trigonometric cosine of the angle two places to the right, the power factor is converted to a percentage, the usual expression used with power factor. If we have the actual values, the cosine of the angle between total power kVA and real power kW can be calculated directly by simply dividing the real power by the total power. If the meter reading shows as many reactive kVA-hours as kilowatt-hours for the billing period, the cosine of the right triangle will be 0.7071, or 70.71% power factor. Thus in use there is as much reactive power required as there is kilowatt-hours or real power.

11.5.3 Making a Power-Factor Study

Many utilities will usually provide customers, at no expense, a power-factor study for a year's actual billing. This study will show power as actually billed and what the power billing would have been had the power factor over the annual period been raised to some value, usually 95%.

For the individual, making a power-factor study is a simple proposition. A table such as Table 11.7 is nothing more than convenient arrangement of trigonometric functions, and is included in most books or bulletins on power factor. Down the left column is the present power factor, usually obtained from the utility billing. This may vary from month to month, so an average should be chosen. Across the top is the desired power factor. Determining the addition of capacitors to raise the average power factor to the desired value is simple. Assume that the present power factor is 70%. From the left column go across to the value under the column headed by 95% (value found, 0.691) and to 100% column (value found, 1.020).

To raise the PF from 70 to 95%:

$$0.691 \times \text{actual demand} = \text{kVAR of capacitors needed}$$

Assume an actual demand of 100 kW:

$$0.691 \times 100 = 69.9 \text{ kVAR (70 to 95\%)}$$

$$1.020 \times 100 = 102 \text{ kVAR (70 to 100\%)}$$

Review discussion of Utility Voltage Reduction and Effects on Equipment on this page.

11.7 ELECTRIC UTILITY ENERGY CONSERVATION MEASURES

Both federal and state regulatory commissions are requiring utilities to institute power control measures in the name of energy reduction over which the consumer has no control. These measures include the ability of electric utilities to turn off certain loads during peak-load conditions. They include the requirement of rate design which will for financial reasons cause customers to consider changing their time of normal operations to some less costly off-electrical-peak condition for the utility. Also, seasonal rates with summer peak loads caused by residential and commercial air conditioning are higher than winter-month rates. It is probable that turn-off control by utilities of commercial air conditioning may be instituted. A further extension of this control is the requirement by some government, state, or federal agencies for an energy audit of electric energy users. As of this writing, the ultimate cost for control measures and their effect is yet to be determined.

11.7.1 Utility Voltage Reductions

Until recently, utilities resorted to distribution system voltage reduction as a measure of reducing the system load only during emergency losses of major generation capacity or transmission capability from storm or other causes. Utility voltage reduction is commonly termed "brownout." Tests have proved that voltage-reduction measures reduce utility load. Voltage reductions by utilities as a strategy to reduce peak load, to possibly defer construction of additional generation capacity, and as an energy conservation measure are becoming more common. The growth of this practice by utilities at times other than emergencies is as yet unknown. There is good reason to believe that the practice will grow as a normal operating procedure. An alternative, but far more drastic measure is the use of rotating blackouts, in which the power for whole circuits is switched off for short periods, usually 2 hours per circuit. In the event of rotating blackouts the economic effect on industry and commercial buildings, with production loss costs from \$100 to \$5000 per minute, will far exceed momentary savings of reduced consumption.

The effect of utility voltage reduction on user equipment should be of growing concern. Voltage reductions of 2-1/2, 5, and 7-1/2% are within the range a utility

might consider. The effect of voltage reduction on operating efficiency as well as equipment failure for a prolonged period of voltage reduction must be a factor of which users are aware.

Effects of voltage reduction on equipment vary quite widely. A general summary of voltages of various electrical equipment with a 10% voltage reduction is as follows:

1. **Incandescent Lights.** Light output drops off very rapidly. A 10% voltage reduction results in a 30% reduction in light output. There is no damage to incandescent lights; life is greatly increased. (Long-life lamps are usually 130-V lamps operated at 120 V.)
2. **Fluorescent Light.** At 10% reduction, light output drops 15%. Greater than 10% voltage reduction can result in shorter lamp life and possible ballast damage.
3. **Mercury, and High- and Low-Intensity Discharge Lamps.** Light output drops 30%. There may be problems in light restarting as well as ballast failure.
4. **Motors.** NEMA has a general requirement that motors will generally give satisfactory service when the motor supply is with $\pm 10\%$ of the motor nameplate voltage. Experience has shown, however, that when motors operate at extreme limits of voltage, motor failure increases rapidly. Motor load is determined by the requirements of the driven machine only. Electrical power in general is the product of voltage time amperage. Thus if voltage is less than the motor nameplate rating, the motor current must increase. The increased loss in the motor results in increased heating of the motor winding. (Often overlooked is the fact that a motor operating at nameplate rating is already overloaded.) Of particular concern is the fairly common use of motors rated 230 or 220 V on commercial building supply systems served with 120/208 V. These motors are already operating close to the lower range allowance of 10% less than motor nameplate rating. A further voltage reduction by the utility results in a motor voltage supply lower than any acceptable standard. (A comment by Austin Bonnett of U.S. Motors: With even a small and normally acceptable voltage unbalance, at reduced voltage almost any motor is very likely to fail.)
5. **Electronic Equipment.** Such electrical devices are greatly affected by voltage less than the nameplate rating. Computers, production control units, and medical and diagnostic instruments can be affected

Lighting

Correlated Color Temperature, CCT

<https://insights.regencysupply.com/what-is-correlated-color-temperature-cct-and-how-do-you-choose-it-for-your-lighting>

STUDY QUESTIONS:

What is CCT and how is it measured?

Why is CCT an important consideration during a lighting retrofit project?

IESNA Definition: the absolute temperature of a blackbody whose chromaticity most nearly resembles that of the light source.

The correlated color temperature (CCT) is a specification of the color appearance of the light emitted by a lamp, relating its color to the color of light from a reference source when heated to a particular temperature, measured in degrees Kelvin (K). The CCT rating for a lamp is a general "warmth" or "coolness" measure of its appearance. However, opposite to the temperature scale, lamps with a CCT rating below 3200 K are usually considered "warm" sources, while those with a CCT above 4000 K are usually considered "cool" in appearance. The correlated color temperature (CCT) designation for a light source gives a good indication of the lamp's general appearance, but does not give information on its specific spectral power distribution. Therefore, two lamps may appear to be the same color, but their effects on object colors can be quite different. Examples of the CCT of some common light sources are:

Source	CCT
Tungsten Halogen	3000 K
"Cool White" Linear Fluorescent	4200 K
High Pressure Sodium	1900 K
"Warm" Compact Fluorescent	2700 K

Light Levels

<https://www.archtoolbox.com/recommended-lighting-levels/>

STUDY QUESTIONS:

How are light levels measured – what location and what units?

Who establishes recommended light levels for indoor task?

Illuminance = Light Falling on a Surface

The amount of light falling on a surface is "illuminance", and is measured in lux (metric unit = lumen/m²) or foot-candles (English unit = lumen/ft²). 1 footcandle equals 10.8 lux. This is the measurement you'll work with the most for optimizing visual comfort because building regulations and standards use illuminance to specify the minimum light levels for specific tasks and environments.

This value does not depend on the material properties of the surface being illuminated. However, since the amount of light the surface "sees" depends on how much is being reflected from other surfaces around it, it does depend on the color and reflectance of the surfaces that surround it.

The brightness of the sky is often given using illuminance values measured on an unobstructed horizontal plane. Some common illumination levels are in the table below, from The Engineering Toolbox:

Outdoor Light Levels

Condition	Illumination	
	(ftcd)	(lux)
Sunlight	10000	107527
Full Daylight	1000	10752
Overcast Day	100	1075

Condition	Illumination	
	(ftcd)	(lux)
Very Dark Day	10	107
Twilight	1	10.8
Deep Twilight	0.1	1.08
Full Moon	0.01	0.108
Quarter Moon	0.001	0.0108
Starlight	0.0001	0.0011
Overcast Night	0.00001	0.0001

Indoor Light Levels

Comfortable Illumination Levels

The values above represent the total illumination available from the sky. As a designer, your job is to make sure that the occupants of your building have the right level of light for their activity, and try to get as much of that light as possible from natural light. These levels are usually measured on a working surface in the building.

Areas can be too dim or too bright, and these levels depend on the task. The brightness required to make jewelry or assemble electronic components is far greater than the brightness required to safely walk to a room's exit. The following is a table of commonly recommended light levels for different activities. To design for the activities in your program, see local codes or green building certification standards.

Maintained Illuminance (lux)	Foot-candles	Characteristics of Activity	Representative Activity
50	5	Interiors rarely used for visual tasks (<i>no perception of detail</i>)	Cable tunnels, nighttime sidewalk, parking lots
100 - 150	10-15	Interiors with minimal demand for visual acuity (<i>limited perception of detail</i>)	Corridors, changing rooms, loading bay
200	20	Interiors with low demand for visual acuity (<i>some perception of detail</i>)	Foyers and entrances, dining rooms, warehouses, restrooms
300	30	Interior with some demand for visual acuity (<i>frequently occupied spaces</i>)	Libraries, sports and assembly halls, teaching spaces, lecture theaters
500	50	Interior with moderate demand for visual acuity (<i>some low contrast, color judgment tasks</i>)	Computer work, reading & writing, general offices, retail shops, kitchens
750	75	Interior with demand for good visual acuity (<i>good color judgment, inviting interior</i>)	Drawing offices, chain stores, general electronics work

1000	100	Interior with demand for superior visual acuity <i>(accurate color judgment & low contrast)</i>	Detailed electronics assembly, drafting, cabinet making, supermarkets
1500 -2000+	150-200+	Interior with demand for maximum visual acuity <i>(low contrast, optical aids & local lighting will be of advantage)</i>	Hand tailoring, precision assembly, detailed drafting, assembly of minute mechanisms

Recommended illuminance levels for different tasks.

For more information on recommended levels from the Illuminating Engineering Society [see here](#).

LED Lighting Basics

http://www.energystar.gov/index.cfm?c=lighting.pr_what_are

STUDY QUESTIONS:

What are LED Bulbs?

How is LED lighting different than other light sources, such as incandescent and CFL?

What organization rates the energy consumption of LED lighting products?

Lighting Controls

<https://www.energy.gov/energysaver/lighting-controls>

STUDY QUESTIONS:

What is passive infrared technology?

Designed to detect motion from a heat-emitting source (such as a person entering a room) within its

field-of-view and automatically switch lights ON and OFF. Sensors have segmented lenses. For units to see motion, the person must cross between two segments or bands. The distance between the segments or bands increases the farther you are from the sensor, so motion has to be larger the farther you are from the unit. PIR sensors are considered line-of-sight sensors, meaning that the sensor must be able to have a direct line-of-sight to the person making the motion.

What is ultrasonic technology?

Ultrasonic sensors use the Doppler principle. These sensors produce low intensity, inaudible sound and detect changes in sound waves caused by motion, such as walking into the room, reaching for a telephone, or turning in a chair. They are volumetric in nature and therefore not line-of-sight dependent. Since they fill the space with these sound waves, they are excellent in bathrooms with stalls, enclosed hallways, or other oddly shaped rooms. In addition, they are much more sensitive to smaller motions.

What is dual technology?

Dual technology is the combination of PIR and Ultrasonic into one sensor and is the ultimate sensing solution available today. This pairing helps to eliminate false activations (both ON and OFF) thus saving additional energy use. Dual technology sensors ensure the greatest sensitivity and coverage for tough applications without the threat of false triggers. Cooper Controls sensors use PIR to turn the lights ON then one of two modes to turn the lights OFF. The first mode will accept either PIR or Ultrasonic to keep the lights ON and the second mode must see both technologies to hold the lighting ON.

What is major motion?

Major motion is defined as movement of a person walking into or through an area. Typical examples are a person walking into a room or through an open area. Major motion may be required to turn ON the lights, but transitions to minor motion once the occupant is in the room.

What is minor motion?

Minor motion is defined as movement of a person sitting at a desk reaching for a telephone, turning the pages of a book, opening a file cabinet, or picking up a cup of coffee.

What is NEMA?

NEMA provides a forum for the development of technical standards that are in the best interests of the industry and users, advocacy of industry policies on legislative and regulatory matters, and collection, analysis, and dissemination of industry data. More information about NEMA can be found at www.nema.org.

What is NEMA WD 7-2011 Occupancy Motion Sensors Standard?

The purpose of this standard is to promote uniformity for the definition and measurement of characteristics relevant to the use and application of occupancy motion sensors.

What is the difference between occupancy and vacancy sensing?

An occupancy sensor turn lights ON automatically upon the detection of motion then turns the lights OFF automatically soon after an area is vacated. A vacancy sensor requires manual activation of the lighting by the occupant then turns the lights OFF automatically soon after an area is vacated.

Occupancy Sensors

<https://www.energy.gov/femp/articles/wireless-occupancy-sensors-lighting-controls-applications-guide-federal-facility>

STUDY QUESTIONS:

What is the difference between PIR and dual technology sensors?

When might it be more effective to use a dual-technology sensor over a PIR?

What features are important to consider when installing occupancy sensors?

What is daylighting control?

Why is smooth and continuous dimming a preferred strategy for automated daylighting controls in offices or other work areas?

What is the energy savings potential for using daylighting control?

- **Passive infrared sensors (PIR)** respond to the infrared heat energy of occupants, detecting motion at the “human” wavelength. They operate on a line-of-sight basis and do not detect occupants behind partitions or around corners. They also are less likely to detect motion as the distance increases. Therefore, they are useful when a room is small or it is desirable to control only a portion of a space. PIR are more susceptible to false-off readings than false-ons, so tend to be more annoying to occupants than ultrasonic sensors.
- **Dual-technology sensors** combine two technologies to prevent both false-offs and false-ons. The most common one uses both ultrasonic and passive infrared sensing to detect occupancy.

The sensor usually requires that both US and PIR sense occupancy before turning on. The lights will remain on as long as either technology detects someone. High quality occupancy sensors use the dual technology, since it is more reliable than each of the separate technologies used independently. Dual-technology sensors cost more than sensors using either US or PIR alone.

Other occupancy sensor features to consider include:

- Mounting location – Ceiling, high-wall or corner, or wall box. Room size and layout are the major determinants. Ceiling-mounted sensors are the most versatile because their view is less obstructed. Wall box sensors take the place of the room's wall switch, and they are economical and easy to retrofit. Wall box sensors are appropriate for small, unobstructed spaces.
- On-Off settings – Occupancy sensors can automatically turn on (auto-on) and then automatically turn off (auto-off). Or, they can require the user to turn them on (manual-on) and then automatically turn off. Manual-on sensors save more energy because the lights do not turn on when the user does not need them. Auto-on sensors are useful in applications where the users are not familiar with the layout and switch locations, or where finding a switch would be inconvenient.
- Sensitivity – Most sensors can be adjusted for the desired degree of activity that will trigger a sensor response. The time-delay (i.e., the time elapsed between the moment a sensor stops sensing an occupant and the time it turns off) can also be selected. The setting can range from 30 seconds to 30 minutes, and the choice becomes a balance between energy conservation, user tolerance, and lamp life. We suggest no less than 15 minutes if controlling instant start ballasts.
- Multiple level control – Occupancy sensors are effective for multiple level switching in spaces where full off is not acceptable, but occupancy is not continuous. By using a two- or three-level ballast, or multi-lamp fixtures with lamps wired separately, the lowest level may be allowed to operate at most hours, but when occupancy is sensed, the light level increases. This is a useful energy saving strategy in areas where safety or security requires some light at all times, such as certain enclosed stairs, security corridors, restrooms, etc. Of the two strategies, multi-level ballasts have the advantage of keeping the lamp warm, reducing early burn-outs caused by frequent switching.

Daylight Controls. Daylight controls are photoelectric devices that turn off or dim the lights in response to the natural illumination available. Depending on the availability of daylight, the hours of operation and the space function, photoelectrically-controlled lighting can save 10% to 60% of a building's lighting energy. This can translate into even more savings since daylight availability coincides with the hours of the day when peak demand charges apply.



Figure 9.12.3. Photo-sensor and fluorescent dimming ballast for continuous daylight dimming.

Smooth and continuous dimming is the preferred strategy for automated daylighting controls in offices or other work areas, since it is not distracting to the workers. The photosensor adjusts the light level based on the amount of natural light sensed by sending a signal to the dimming ballast. The less expensive dimming ballasts with minimum settings of 20% of full output are appropriate for daylight dimming (EPRI 1997). The two strategies, “closed-loop” and “open loop,” are based on photo-sensor locations, and the correct sensor location is essential. In a “closed loop” system, the sensor is located above a horizontal surface to detect the light reflecting off that surface from both electric and daylight sources. Since the sensor is reading reflected light, the reflective characteristics of the surface should remain constant. Consequently, sensors are located over a circulation area, rather than a workstation where the reflectivity of the worker’s clothes or desktop contents might change. In an “open loop” system, the sensor is located near the window in such a way to only detect daylight. In both systems, the sensor must not pick up the direct illumination from the electric lights. Sensors can control more than one dimming ballast but the luminaires being controlled must all have a similar orientation to the natural light. For example, trees in front of several windows define a separate lighting “zone.” Time-delay settings are used to slow down the response to rapid changes in natural lighting conditions, providing more steady lighting.

Switching the lights off when sufficient natural lighting is present is a less expensive strategy, but not as acceptable to the occupants. This approach is most commonly found in outdoor applications – controlling parking lot lighting for example. In buildings, a stepped approach to daylight switching is sometimes employed, in which only some lamps are switched off in multi-lamp luminaires. Alternately, daylight switching is used in rooms where continuous occupancy is not common, such as corridors, cafeterias, atria, or copy rooms.

Pre-set Controls. Switching, dimming, or a combination of the two functions can be automatically preprogrammed so that the user can select an appropriate lighting environment (“scene”) at the touch of a button. Each scene uses a different combination of the luminaires in the room (sometimes dimmed) to provide the most appropriate light for one of several planned activities in that room. A “pre-set controller” and wiring plan organizes this. For example, the occupant of a conference room could select one pre-set scene from a five-button “scene selector” wall-mounted in the room, labeled “Conference,” “Presentation,” “Slide Viewing,” “Cleaning,” and “Off.” This allows multiple lighting systems to be installed to meet the varying needs of separate activities, but prevents them from all being used at full intensity for every activity. A pre-set scene should be included for the cleaning crew, which should use the most energy-efficient lights that will allow them to do their work.

Time Controls. Time clocks are devices that can be programmed to turn lights on or off at designated times. These are a useful alternative to photoelectric sensors in applications with very predictable usage, such as in parking lots. Simple timers are another option, turning the lights on for a specified period of time, although there are limited applications where this is appropriate, e.g., library stacks. A time-controlled “sweep” strategy is sometimes effective. After normal hours of occupancy, most of the lighting is turned off (swept off), but if any occupants remain, they can override the command in just their space. Override controls can be wall switches located within the space or be activated by telephone or computer. These systems typically flash the lights prior to turnoff, to give any remaining occupants ample time to take action. There is usually more than one sweep operation scheduled after hours until all lights are turned off.

Occupancy Sensors & Vacancy Sensors

<https://lightingcontrolsassociation.org/2017/08/21/all-about-occupancy-and-vacancy-sensors/>

STUDY QUESTIONS:

What this difference between an occupancy sensor and vacancy sensor?

What appropriate space use applications for vacancy sensors?

Ballast Factor

<https://bluefroglights.com/2017/06/30/ballast-factor-101/>

STUDY QUESTIONS:

TIP: Understand how to calculate ballast factor for a specified ballast.

IESNA Definition: the fractional flux of a fluorescent lamp operated on a ballast compared to the flux when operated on the standard (reference) ballast specified for rating lamp lumens.

Ballast factor (BF) is the measured ability of a particular ballast to produce light from the lamp(s) it powers. The ballast factor itself is derived by dividing the lumen output of a particular lamp-ballast combination by the lumen output of the same lamp(s) on a reference ballast. This factor, which usually results in a number less than one, accounts for the fact that some lumen loss results when operating lamps on commercially available ballasts.

Any single ballast may have several different ballast factors, depending upon the number and type of lamp(s) it operates. Go to URL to click on button to see results of different ballast factors:
<http://www.lrc.rpi.edu/education/learning/terminology/ballastfactor.asp>

If two 40-W fluorescent lamps rated at 3000 lumens each are operated on a two-lamp ballast, which has a ballast factor of 0.95, the actual lumens produced by the lamp-ballast combination will be:

$$3000 \text{ lumens} \times 2 \text{ lamps} \times 0.95 \text{ BF} = 5700 \text{ lumens}$$

Calculate Ballast Factor

<https://assets.lutron.com/a/documents/048-073.pdf>

STUDY QUESTIONS:

TIP: Understand how to calculate ballast factor for a specified ballast. See example below.

Let's work through an example. Let's determine what the ballast factor is for a QTP 1x32T8/UNV PSN ballast. Using the SYLVANIA Ballast Technology and Specification Guide, we can get the information we need. The following is a piece of that guide.

Item Number	Description	Input Voltage (VAC)	Input Current (AMPS)	Lamp Type	Rated Lumens (lm)	No. of Lamps	Ballast Factor (BF)	System Lumens	Input Wattage (W)	System Efficacy (lm/W)
51400	QTP 1x32T8/UNV PSN-TC	120-277	0.26/0.11	F032/XP(32W)	3000	1	0.88	2640	31/30	85/88
			0.24/0.10	F030/SS(30W)	2850	1	0.88	2510	29/28	87/90
			0.23/0.09	F028/SS(28W)	2725	1	0.88	2400	27/26	89/92

To find the ballast factor for this ballast, we need the system lumens and the rated lumens. The ballast factor is equal to the system lumens divided by the rated lumens. $BF = 2640 / 3000 = 0.88$ which matches the ballast factor column.

Currently, ballast factors range from 0.70 and 1.20. A low ballast factor has a value between 0.70 to 0.80. A normal or “standard” power factor is between 0.85 and 1.00. A high ballast factor is between 1.13 and 1.20. Ballast factor is used in lumen method lighting calculations and is a component of the light loss factors (LLF). Different ballast factors may be used to tailor different spaces in the same building with different light level while using the same lamp thus reducing the risk of using the wrong lamp in the wrong application.

Motors & Pumps

Hand, Off, and Automatic Operation of Motors

<https://www.bcx.org/blog/motor-starting-devices-components,-set-up-and-overload-protection.html>

STUDY QUESTIONS:

What happens to the motor in each of the three (HOA) settings?

Which is the most significant?

When to Use a True-RMS Multi-meter Current Clamp

<http://www.newark.com/pdfs/techarticles/fluke/whyTrueRMS.pdf>;

Why True RMS? Application, Fluke Digital Library, Fluke Corporation, 2002

STUDY QUESTIONS:

There are two types of current clamps: average responding and rms. What is the best one to use for measuring non-linear motor loads?

How would you determine which one to use in any given situation?



Figure 1. One current—two readings. Which do you trust? The branch circuit above feeds a non-linear load with distorted current. The true-rms clamp reads correctly but the average responding clamp reads low by 32 percent.

Basically, there are two types of current clamps commonly available: “average responding” and “true-rms.” The average responding units are widely used and are us lower cost. They give correct readings for linear loads such as standard induction motors, resistance heaters, and incandescent lights. But when loads are non-linear, containing semiconductors, the average responding meters typically read low. Worst case nonlinear loads include small adjustable speed drives (5 hp or less) connected line to line across two phases of a 480 V, three-phase system, solid state heater controls connected single phase to 240 V, or computers connected to 120 V.

When troubleshooting a branch circuit that suffers from circuit breaker tripping (or fuse blowing), the cause of the trouble can usually be separated into one of three categories:

1. Too much current.
2. Too much heat in the electrical enclosure.
3. Faulty circuit breaker (or fuse).

Your first instinct will probably be to measure the current with a current clamp while the load is on. If the current is within the circuit rating, you may be tempted to replace the circuit breaker. Before you do that, make two other observations: First, analyze the load. If the load contains power

semiconductors, rectifiers, SCRs, etc., be suspicious of the current clamp reading. Second, look at the front panel of your current clamp—does it say true-rms? If you can't find the words true rms on the front panel, then you probably have an average responding current clamp.

If you are trying to measure current drawn by a non-linear load containing semiconductors, without a true rms meter, you are likely to make the wrong conclusion; that the problem is a faulty circuit breaker. Replacing the breaker won't help. You'll get a call-back with some unpleasant words from your customer. To avoid this, see PDF: [Fluke Application Note: Why True RMS?](#)

Variable Frequency Questions? The Best Applications For VFDs

<http://www.facilitiesnet.com/hvac/article/Variable-Frequency-Questions-The-Best-Applications-For-VFDs-Facilities-Management-HVAC-Feature--11279>

STUDY QUESTIONS:

What are good candidates for VFD applications? What are poor candidates?

What are two precautions to consider before installing a VFD?

The most commonly used motor in building HVAC applications is the three-phase, induction motor, although some smaller applications may use a single-phase induction motor. VFDs can be applied to both.

While VFD controllers can be used with a range of applications, the ones that will produce the most significant benefits are those that require variable speed operation. For example, the flow rate produced by pumps serving building HVAC systems can be matched to the building load by using a VFD to vary the flow rate. Similarly, in systems that require a constant pressure be maintained regardless of the flow rate, such as in domestic hot and cold water systems, a VFD controlled by a pressure setpoint can maintain the pressure over most demand levels.

The majority of commercial and institutional HVAC systems use variable volume fan systems to distribute conditioned air. Most are controlled by a system of variable inlet vanes in the fan system and variable air volume boxes. As the load on the system decreases, the variable air volume boxes close down, increasing the static pressure in the system. The fan's controller senses this increase and closes down its inlet vanes. While using this type of control system will reduce system fan energy requirements, it is not as efficient or as accurate as a VFD-based system.

Another candidate for VFD use is a variable refrigerant flow systems. Variable refrigerant flow systems connect one or more compressors to a common refrigerant supply system that feeds multiple

evaporators. By piping refrigerant instead of using air ducts, the distribution energy requirements are greatly reduced. Because the load on the compressor is constantly changing based on the demand from the evaporators, a VFD can be used to control the operating speed of the compressor to match the load, reducing energy requirements under part-load conditions.

Additional VFD Applications

While the primary benefit of both of these VFD applications is energy savings, VFDs are well suited for use in other applications where energy conservation is of secondary importance. For example, VFDs can provide precise speed or torque control in some commercial applications.

Some specialized applications use dual fans or pumps. VFDs, with their precise speed control, can ensure that the two units are operated at the desired speed and do not end up fighting each other or having one unit carry more than its design load level.

Advances in technology have increased the number of loads that can be driven by the units. Today, units are available with voltage and current ratings that can match the majority of three-phase induction motors found in buildings. With 500 horsepower units or higher available, facility executives have installed them on large capacity centrifugal chillers where very large energy savings can be achieved.

One of the most significant changes that has taken place recently is that with the widespread acceptance of the units and the recognition of the energy and maintenance benefits, manufacturers are including VFD controls as part of their system in a number of applications. For example, manufacturers of centrifugal chillers offer VFD controls as an option on a number of their units. Similarly, manufacturers of domestic water booster pump systems also offer the controls as part of their system, providing users with better control strategies while reducing energy and maintenance costs.

A Few Cautions

When evaluating the installation of a VFD, facility executives should take into consideration a number of factors related to the specifics of the application. For example, most VFDs emit a series of pulses that are rapidly switched. These pulses can be reflected back from the motor terminals into the cable that connects the VFD to the motor. In applications where there is a long run between the motor and the VFD, these reflected pulses can produce voltages that exceed the line voltage, causing stresses in the cable and motor windings that could lead to insulation failure. While this effect is not very significant in motors that operate at 230 volts or less, it is a concern for those that operate at 480 volts or higher. For those applications, minimize the distance between the VFD and the motor, use cabling specifically designed for use with VFDs, and consider installing a filter specifically designed to reduce the impact of the reflected pulses.

Another factor to consider is the impact the VFD may have on the motor's bearings. The pulses produced by the VFD can generate a voltage differential between the motor shaft and its casing. If this voltage is high enough, it can generate sparks in the bearings that erode their surfaces. This condition can also be avoided by using a cable designed specifically for use with VFDs.

SOURCE: James Piper, PhD, PE, is a writer and consultant who has more than 25 years of experience in facilities management. He is a contributing editor for Building Operating Management.

Pump Operation & Control

<https://www.energy.gov/femp/equipment-operations-and-maintenance-summaries>

STUDY QUESTIONS:

What are the three affinity laws that govern pump systems?

Of the 4 ways to control flow through pump speed variation, which one is the most efficient?

Why is flow control by speed regulation is always more energy efficient than by a control valve?

In addition to energy savings, what other benefits does flow control offer?

9.9.9 Relevant Operational/Energy Efficiency Measures

There are a number of operational/energy efficiency measures that could be presented for proper pump operation and control. This section focuses on the most prevalent O&M recommendations having the greatest energy impacts at Federal facilities and includes (DOE 2001, DOE 2004, BEE 2004):

- Pump Selection
- Controlling the flow rate by speed variation
- Eliminating flow control valve
- Eliminating by-pass control
- Impeller trimming

Pump Selection

In selecting a pump, facility managers try to match the system curve supplied by the user with a pump curve that satisfies these needs as closely as possible. The pump operating point is the point where the pump curve and the system resistance curve intersect. However, it is impossible for one operating point to meet all desired operating conditions. For example, when the discharge valve is throttled to control flow, the system resistance curve shifts so does the operating point – this to a less-than efficient point of operation.

The efficiency of a pump is affected when the selected pump is oversized. This is because flow of oversized pumps must be controlled with different methods, such as a throttle valve or a by-pass line. These devices provide additional resistance by increasing the friction. As a result the system curve shifts and intersects the pump curve at a different point, a point of lower efficiency. In other words, the pump efficiency is reduced because the output flow is reduced but power consumption is not. Inefficiencies of oversized pumps can be overcome by, for example, the installation of variable speed drives, two-speed drives, operating the pump at a lower rpm, or installing a smaller impeller or trimmed impeller (BEE 2004).

Controlling flow rate by speed variation

A centrifugal pump's rotating impeller generates head. The impeller's peripheral velocity is directly related to shaft rotational speed. Therefore varying the rotational speed has a direct effect on the performance of the pump. The pump performance parameters (flow rate, head, power) will change with varying rotating speeds. To safely control a pump at different speeds it is therefore important to understand the relationships between the two. The equations that explain these relationships are known as the "Affinity Laws" these are:

- Flow rate (Q) is directly proportional to the rotating speed
- Head (H) is proportional to the square of the rotating speed
- Power (P) is proportional to the cube of the rotating speed

As can be seen from the above laws, doubling the rotating speed of the centrifugal pump will increase the power consumption by 8 times. Conversely a small reduction in speed will result in a very large reduction in power consumption. This forms the basis for energy conservation in centrifugal pumps with varying flow requirements. It is relevant to note that flow control by speed regulation is always more efficient than by a control valve. This is because valves reduce the flow, but not the energy consumed by pumps. In addition to energy savings, other benefits could include:

- Increased bearing life – this is because bearings carry the hydraulic forces on the impeller (created by the pressure profile inside the pump casing), which are reduced approximately with the square of speed. For a pump, bearing life is proportional to the seventh power of speed.

- Vibration and noise are reduced and seal life is increased, provided that the duty point remains within the allowable operating range.

Using variable speed drive (VSD)

Controlling the pump speed is the most efficient way to control the flow, because when the pump's speed is reduced, the power consumption is also reduced. The most commonly used method to reduce pump speed is Variable Speed Drive (VSD). VSDs allow pump speed adjustments over a continuous range, avoiding the need to jump from speed to speed as with multiple-speed pumps. VSDs control pump speeds use two types of systems:

- Mechanical VSDs include hydraulic clutches, fluid couplings, and adjustable belts and pulleys.
- Electrical VSDs include eddy current clutches, wound-rotor motor controllers, and variable frequency drives (VFDs). VFDs are the most popular and adjust the electrical frequency of the power supplied to a motor to change the motor's rotational speed.

For many systems, VFDs offer a means to improve the pump operating efficiency under different operating conditions. When a VFD reduced the RPM of a pump, the head/flow and power curves move down and to the left, and the efficiency curve also shifts to the left. The major advantages of VSD application in addition to energy saving are (DOE, 2004):

- Improved process control because VSDs can correct small variations in flow more quickly.
- Improved system reliability because wear of pumps, bearings and seals is reduced.
- Reduction of capital & maintenance cost because control valves, by-pass lines, and conventional starters are no longer needed.
- Soft starter capability: VSDs allow the motor the motor to have a lower startup current.

Eliminating flow control valve

Another method to control the flow by closing or opening the discharge valve (this is also known as "throttling" the valves). While this method reduces the flow, it does not reduce the power consumed, as the total head (static head) increases. This method increases vibration and corrosion and thereby increases maintenance costs of pumps and potentially reduces their lifetimes. VSDs are always a better solution from an energy efficiency perspective.

Eliminating by-pass control

The flow can also be reduced by installing a by-pass control system, in which the discharge of the pump is divided into two flows going into two separate pipelines. One of the pipelines delivers the fluid to the delivery point, while the second pipeline returns the fluid to the source. In other words, part of the fluid is pumped around for no reason, and thus is energy inefficient. Because of this inefficiency, this option should therefore be avoided.

Impeller trimming

Changing the impeller diameter gives a proportional change in the impeller's peripheral velocity. Similar to the affinity laws, the following equations apply to the impeller diameter:

- Flow rate (Q) is proportional to the diameter
- Head (H) is proportional to the square of the diameter
- Power (P) is proportional to the cube of the diameter

Changing the impeller diameter is an energy efficient way to control the pump flow rate. However, for this option, the following should be considered:

- This option cannot be used where varying flow patterns exist.
- The impeller should not be trimmed more than 25% of the original impeller size, otherwise it leads to vibration due to cavitation and therefore decrease the pump efficiency.
- The balance of the pump has to been maintained, i.e. the impeller trimming should be the same on all sides.

Changing the impeller itself is a better option than trimming the impeller, but is also more expensive and sometimes the next smaller impeller is too small.

Flow Meter Installation Requirements

https://scceh.com/Portals/6/Env_Health/water_resources/DrinkingH2O/Flow%20Meter%20Installation%20Guidelines.pdf

STUDY QUESTIONS:

What are the requirements for a flow meter to take accurate measurements of water flow through the system?

What does a pitot tube measure?

2.0 INTRODUCTION

Installation of flow meters in accordance with the manufacturer's written specifications is necessary for a flow-meter to be accurate as it claims. Every design has a certain tolerance to non-stable velocity conditions in the pipe, but all units require proper piping configurations to operate efficiently. Proper piping provides a normal flow pattern for the device, ensuring specified accuracy and performance.

For Water meters to operate correctly the flow upstream and downstream of the flow-meter must

be as free as possible from obstructions, such as butter-fly valves, flow switches, elbows etc, as they can cause incorrect measurement of flow and induce errors ranging +/- 50%, to allow for errors created by the pipe run HBRC specify a minimum distance that must be free of any obstructions that could induce these errors. The flow of water into flow-meters can also be disturbed by partially open valves or poorly mounted flange gaskets.

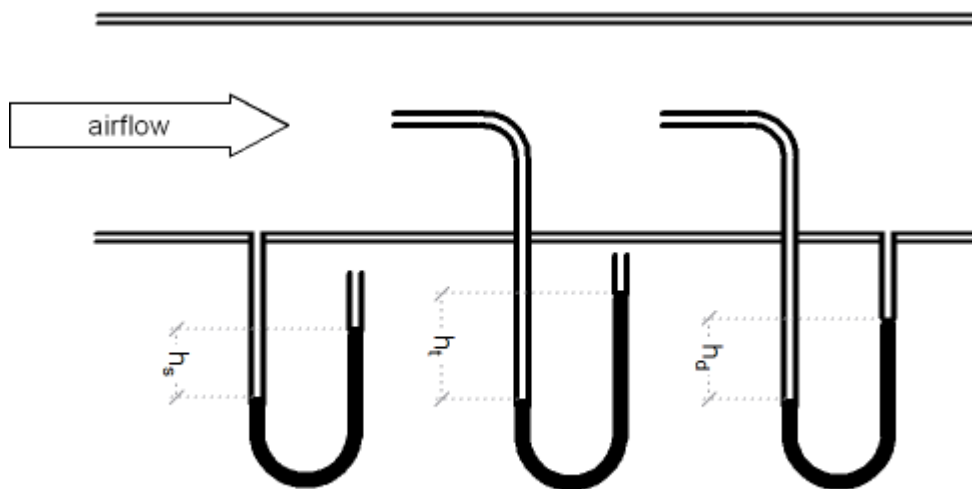
Meters are to be located as close as practical to the point of extraction and preferably on the discharge side of the pump. There must only be permitted off-takes of water between the point of extraction and the meter. (examples domestic, stock water and fire fighting outlets)

LOCATION OF METER

The measuring mechanism of the meter must be located in straight clean pipe of uniform, circular cross section and without any fittings or obstructions. In all cases the meter must be installed so that at all flow rates there is a “full pipe of water” on both the intake and discharge sides of the meter. No meter with flow totalizers attached shall be installed deeper than 1.5 meters below ground level. Where a meter with flow totalizers attached is installed underground, sufficient space must be provided to facilitate easy access for maintenance and reading of totalizers at all times. Meters with flow totalizers attached located down to 0.5 meters below ground will require a suitable meter box to house the meter. When meters with flow totalizers attached are located between 0.5 meters and 1.5 meters, an access pit must be provided.

Pitot Tube

The pitot tube is a simple and convenient instrument to measure the difference between static, total and dynamic pressure (or head).



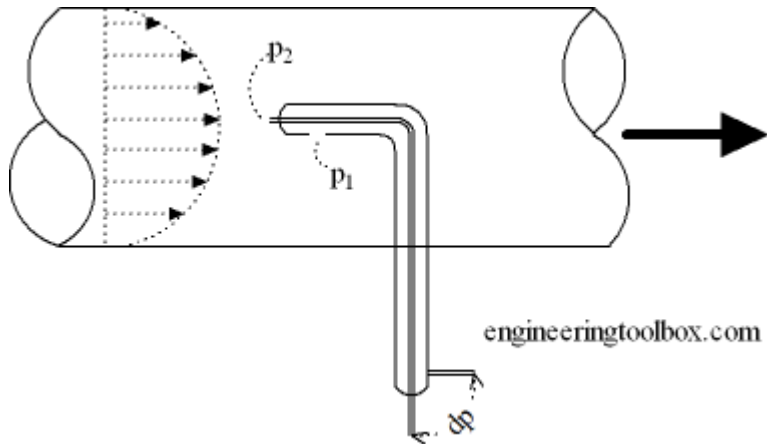
engineeringtoolbox.com

The head - h - (or pressure difference - dp) can be measured and calculated with u-tube manometers, electronic pressure transmitters or similar instrumentation.

Pitot Tubes

http://www.engineeringtoolbox.com/pitot-tubes-d_612.html, The Engineering ToolBox

A pitot tube can be used to measure fluid flow velocity by converting the kinetic energy in a fluid flow to potential energy.



The principle is based on [the Bernoulli Equation](#) where each term of the equation can be interpreted as pressure

$$p + \frac{1}{2} \rho v^2 + \gamma h = \text{constant along a streamline} \quad (1)$$

where

p = [static pressure](#) (relative to the moving fluid) (Pa)

ρ = [density](#) (kg/m^3)

v = [flow velocity](#) (m/s)

$\gamma = \rho g$ = [specific weight](#) (N/m^3)

g = [acceleration of gravity](#) (m/s^2)

h = [elevation height](#) (m)

Each term of the equation has the dimension force per unit area N/m^2 (Pa) - or in imperial units lb/ft^2 (psi).

Static Pressure

The first term - p - is the static pressure. It is static relative to the moving fluid and can be measured through a flat opening in parallel to the flow.

Dynamic Pressure

The second term - $\frac{1}{2} \rho v^2$ - is called the dynamic pressure.

Hydrostatic Pressure

The third term - γh - is called the hydrostatic pressure. It represents the pressure due to change in elevation.

Stagnation Pressure

Since the Bernoulli Equation states that the energy along a streamline is constant, (1) can be modified to

$$\begin{aligned} p_1 + 1/2 \rho v_1^2 + \gamma h_1 \\ &= p_2 + 1/2 \rho v_2^2 + \gamma h_2 \\ &= \text{constant along the streamline} \end{aligned} \quad (2)$$

where

suffix₁ is a point in the free flow upstream

suffix₂ is the stagnation point where the velocity in the flow is zero

Motor V-belt Maintenance

<http://www.grainger.com/content/supplylink-v-belt-maintenance-key-to-electric-motor-efficiency>

STUDY QUESTIONS:

What are three benefits of V-belt maintenance?

What is the most common operating problem for belt-driven electric motors?

What is the best way to correct the problem?

What causes V-belt failure?

What factors should be considered when replacing V-belts?

What are the benefits of using synchronous belts over V-belts?

What safety factors should be considered when installing and maintaining V-belts?

Plant managers' to-do lists can get long pretty quickly, and making sure V-belts on electric motors are properly installed and maintained might tend to slip a few notches down the list. But that would be a mistake. Improperly maintained V-belts wear out faster and make motors work harder to produce the same power output, therefore wasting energy.

If you keep the innumerable V-belts in your plant working efficiently, it can pay big dividends—in the form of lower power usage, longer belt life and improved machine uptime.

Volumes of V-Belts

There are more than a few belt-driven electric motors in use today: Approximately one-third of the electric motors in the industrial and commercial sectors use belt drives. And V-belts are powerful tools. Belt drives provide flexibility in the positioning of the motor relative to the load. Pulleys, or sheaves, of different diameters allow driven-equipment speeds to be increased or decreased relative to the motor speed. Belt power-transmission systems are relatively quiet and offer high efficiency. They require no lubrication and don't need a lot of maintenance.²

That's why smart maintenance managers understand how V-belts and the sheaves they run on affect the performance of their electric motors. They ask the right questions, like: are the right V-belts installed; are they at optimal tightness; or have they worn prematurely? They understand when belts need to be replaced and how to do it properly.

They also know that improper V-belt tension is the most common operating problem for belt-driven electric motors, followed by alignment, and that worn sheaves greatly reduce system efficiency while adding to maintenance costs. V-belt drives can have a peak efficiency of 95 percent or higher when installed properly, but efficiency can deteriorate by as much as 5 percent due to slippage if the belt is not periodically retensioned.²

Tension City

As mentioned above, proper belt alignment and tensioning are critical to maintaining motor efficiency. Belt tension that is too loose or too tight leads to inefficient power transmission, belt wear, belt failure and possible premature motor failure. In fact, a V-belt that is over-tensioned by 10 percent can produce a 10 percent reduction in bearing life of the motor, and over-tensioning is also the leading cause of V-belt failure.³

To combat tensioning problems, maintenance professionals should have a strong arsenal of tools that they are well trained to use. These include:

- A tension meter to measure V-belt deflection and tension;
- Infrared tools that identify over-tension;
- Vibration analyzers that identify loose or damaged belts; and

- Strobe lights or tachometers. These tools can be used to make a tension check on newly installed V-belts after they have been run-in for 24 to 48 hours. After the break-in period, belt tension should be checked every 3 to 6 months.

Belt Failure Beat-Down

Premature wear is not the only operating problem with V-belts. Outright V-belt drive failures can be caused by tension loss, tensile breaks or belt cracking:

- Tension loss is typically caused by a weak support structure on the motor; lubricants being sprayed or spilled on belts; excessive sheave wear; or excessive belt load.
- Tensile breaks are typically produced by excessive shock load; operating belts in less-than-optimal sheave groove diameters; extreme sheave runout; and storing belt inventory in excessively hot or dry locations (higher than 85° F and 70 percent relative humidity).
- Belt cracking is typically caused by operating belts in less-than-optimal sheave groove diameters; running them at extremely low temperatures during start-up; and exposing the belts to chemicals or lubricants.

The Replacements

When replacing V-belts, maintenance professionals must verify that the replacements are the correct size. The belt should ride in the groove with its top flat surface level with the outer edge of the sheave. Belts should always be installed in matched sets, and never install belts from different manufacturers on the same motor. Otherwise, the belts may have different stretch characteristics and coefficients of friction and may not have the same load-carrying ability. Overloading will cause rapid wear and reduced belt life.

Sheave wear is also a crucial issue. Misalignment and improper belt tensioning can cause sheaves to wear prematurely, and when that happens, a formerly flat groove sidewall can take on a concave shape and the surface that interacts with the belt can be damaged. Eroded sheave sidewalls can reduce V-belt drive efficiency up to 12 percent, and operating sheaves with rough, worn sidewalls can cut V-belt life by as much as 50 percent.

Sheave gauges are available to assess the condition of the sheave wall. There are also laser alignment tools to ensure proper alignment of parallel and angular sheaves.

Drive Home Safely

Safety must be the number one concern when installing and maintaining V-belts on electric motor drives. Maintenance professionals should be aware of the potential for injuries from sharp objects, extreme temperatures, high-speed abrasions, pinch points, confined spaces, unexpected movement and blunt-force injuries from excessive force or uncontrolled release of belt tension. Other hazards include

unbalanced loads, airborne objects, inadequately secured pulleys and loose bushings and screws. Maintenance professionals should maintain a well-organized and well-lit work area with little clutter. Also, they should consult with machinery OEMs and belt suppliers for advice on parts such as V-belts, sheaves and conveyors and how they should be maintained.⁶

Trying on Different Belts

There are several different types of V-belts for use on electric motors:

- **Standard V-belts**, used in the majority of belt drives, have a trapezoidal cross section that fits tightly into a sheave to increase friction and power transfer capability. V-belt drives can have a peak power efficiency of 95 percent or more at the time of installation. The efficiency rating depends on pulley size, pulley wear, V-belt alignment, transmitted torque, and if belts are under- or over-sized for specific load requirements. If the belt is not periodically retensioned, power efficiency can deteriorate by as much as 5 percent over time due to slippage.²
- **Notched belts** have grooves, or notches, that run perpendicular to the belt's length, which reduces the bending resistance of the belt. Notched belts can use the same sheaves as most standard V-belts. Notched belts run cooler, last longer and are about 2 percent more efficient than standard V-belts.² They should be considered as replacements for V-belts wherever possible.
- **Synchronous belts**, which have teeth, are about 98 percent efficient and maintain that efficiency over a wide range of loads. Synchronous belts typically require less maintenance and retensioning than V-belts and notched belts and can operate in wet and oily environments. However as stated, they require the installation of matching tooth-sized drive sprockets, requiring motors running standard V-belts to be retrofitted before synchronous belts can be used.⁵ Synchronous belts are also called cogged, timing, positive-drive and high-torque drive belts.

The Big Switcheroo

There are several reasons to switch to synchronous belts. Standard V-belts typically experience a sharp drop in efficiency when operated at high torque due to increased slippage. By contrast, synchronous belts do not slip. However, synchronous belts are noisier than V-belts, less suited for use on shock-loaded applications and transfer more vibration due to their stiffness.²

In spite of these concerns, the main reason to use synchronous belts is their outstanding energy efficiency. For example, a continuously operating, 100-hp, supply-air fan operating at an average motor load of 75 percent will consume 527,000 kWh of electricity annually. If a 95 percent efficient standard V-belt is replaced with a 98 percent efficient synchronous one, annual power cost savings would be \$1,290 (with electricity priced at \$0.08 per kWh).²

As a result, plant managers should:

- Use synchronous belts for all new installations. The price premium is minimal since standard sheaves do not need to be replaced if all the equipment is new;
- Have a power-transmission specialist determine the energy and cost savings potential from retrofitting all V-belt drives (including sheaves) for synchronous belts; and
- Install notched belts where the retrofit of a synchronous belt is not cost effective.²

V-belts are just one part of a plant maintenance program, but they are an important part. By making sure they cover the basics of proper tensioning, belt and sheave maintenance, and by doing proper monitoring, plant managers can go a long way toward getting the most efficiency and service life out of their V-belts.

Electrical Motor - Power

https://www.engineeringtoolbox.com/electrical-motor-calculator-d_832.html

STUDY QUESTIONS:

TIP: Prepare to use the formula for “Electrical Motor – Power”

Electric Power

$$P = U I$$

$$P = R I^2$$

$$P = U^2 / R$$

where

P = power (watts, W, J/s)

U = [voltage](#) (volts, V)

I = current (amperes, A)

R = resistance (ohms, Ω)

Electrical Motor - Power

$$P_{3-phase} = (U I PF 1.732) / 1,000$$

where

$P_{3-phase}$ = electrical power 3-phase motor (kW)

PF = [power factor electrical motor](#)

Thermal energy storage (TES)

http://en.wikipedia.org/wiki/Thermal_energy_storage

STUDY QUESTIONS:

What is TES and what is the benefit of TES systems?

What are the sources of thermal energy storage?

Will a building owner who does not incur peak rates for electricity use benefit from TES?

Thermal energy storage (TES) is achieved with greatly differing technologies that collectively accommodate a wide range of needs. It allows excess [thermal energy](#) to be collected for later use, hours, days or many months later, at individual building, multiuser building, district, town, or even regional scale depending on the specific technology. As examples: energy demand can be balanced between daytime and nighttime; summer heat from [solar collectors](#) can be [stored inter-seasonally](#) for use in winter; and cold obtained from winter air can be provided for summer air conditioning. Storage media include: water or ice-slush tanks ranging from small to massive, masses of native earth or bedrock accessed with heat exchangers in clusters of small-diameter boreholes (sometimes quite deep); deep aquifers contained between impermeable strata; shallow, lined pits filled with gravel and water and top-insulated; and [eutectic](#), [phase-change materials](#).

Other sources of thermal energy for storage include heat or cold produced with [heat pumps](#) from off-peak, lower cost electric power, a practice called [peak shaving](#); heat from combined heat and power (CHP) power plants; heat produced by renewable electrical energy that exceeds grid demand and [waste heat](#) from industrial processes. Heat storage, both seasonal and short term, is considered an important means for cheaply balancing high shares of variable [renewable electricity](#) production and integration of electricity and heating sectors in energy systems almost or [completely fed](#) by renewable energy.

2. Building Envelope

What “R-Value” Means?

<https://www.archtoolbox.com/r-values/>

STUDY QUESTIONS:

What are the four ways heat moves in and out of a building?

What factors contribute to heat transfer in buildings?

What is R-value a measure of?

What constitutes a quality insulation system for a commercial building?

THE FACTS ABOUT INSULATION & R-VALUE

One of the most important and misunderstood aspects of insulation is R Value. Unfortunately, R-Value has taken hold in the consumer's mind as a universal method for comparing insulations - the higher the R-Value, the better the insulation, end of story. But all R-Values are not created equal, because they measure only one of the factors that determine how insulation will perform in the real world.

What *R-Value*

$$R\text{-Value} = \frac{\text{Temp Difference} \times \text{Area} \times \text{Time}}{\text{Heat Loss}}$$

Really *Means*:

It's just 1 of 4 factors in selecting insulation!

Insulation is, first and foremost, meant to stop the movement of heat. The problem with using R-Value as the sole yardstick of an insulation's effectiveness is that heat moves in and out of your home (or about any other structure) in four ways: by [conduction](#) (which R-Value measures), and by [convection](#), [radiation](#) and [air infiltration](#) (none of which R-Value measures). But let's stick with the concept of R-Value for the moment.

The R-Values of insulation materials are measured in a lab. That would work great - if your home were inside a lab! But your home was built outdoors, and that means there are other factors like wind, humidity, and temperature changes in play. These factors create pressure differences between the interior and the exterior of the building due to things like hot air rising, wind, and mechanical systems forcing air through every tiny little opening and making its way to the interior or exterior, or to unconditioned areas of the building like attics, basements and crawl spaces.

Your home or commercial building may look solid, but there are thousands of tiny gaps, cracks and penetrations between building materials. For example, if you apply the air pressure of a 20 MPH wind on a 20 degree (F) day to a building, the typical R-19, batt insulated wall often performs no better than the wood studs (R-6) because of air infiltration, with heat being transported around (bypassing) the batts through convection. In very low density materials like loose blown fiberglass, heat will actually

radiate right through the insulation, and this, along with convection, significantly reduces fiberglass' installed performance and your comfort.

A superior insulation system will have good R-Value (prevent heat loss via conduction), will be pneumatically or spray applied, fully filling the building cavity (prevent heat loss via convection), and will be densely packed (prevent heat loss via air infiltration and radiation). Cellulose meets all four of these critical performance criteria!

In addition, you want your insulation to do more than just insulate. Besides insulating, cellulose can help prevent the [spread of flames](#) in the event of a fire and blocks the transmission of [sound](#). The insulation in your walls, ceilings, attic, etc., has a lot of jobs to do besides insulating - and cellulose is up to task!

Find more R-Value and other technical information on the U.S. Department of Energy's [energy.gov website](#). Click on this map to find insulation R-Value recommendations from the U.S. Department of Energy for your region. http://www.cellulose.org/userdocs/DOE_Insulation_map.pdf

Low-E Window Coatings

<https://efficientwindows.org/low-e-coating/>

STUDY QUESTIONS:

What are the benefits of low-E coatings on window glass?

What buildings would benefit most from applications of low-E coatings?

What unit of measure is used to rate low-E glass compared to clear glass?

When heat or light energy is absorbed by glass, it is either convected away by moving air or reradiated by the glass surface. The ability of a material to radiate energy is called its emissivity. All materials, including windows, emit (or radiate) heat in the form of long-wave, far-infrared energy depending on their temperature. This emission of radiant heat is one of the important components of heat transfer for a window. Thus reducing the window's emittance can greatly improve its insulating properties.

Standard clear glass has an emittance of 0.84 over the long-wave portion of the spectrum, meaning that it emits 84% of the energy possible for an object at its temperature. It also means that 84% of the long-wave radiation striking the surface of the glass is absorbed and only 16% is reflected. By comparison, low-E glass coatings can have an emittance as low as 0.04. Such glazing would emit only 4% of the

energy possible at its temperature, and thus reflect 96% of the incident long-wave, infrared radiation. Window manufacturers' product information may not list emittance ratings. Rather, the effect of the low-E coating is incorporated into the U-factor for the unit or glazing assembly.

The solar reflectance of low-E coatings can be manipulated to include specific parts of the visible and infrared spectrum. This is the origin of the term spectrally selective coatings, which selects specific portions of the energy spectrum, so that desirable wavelengths of energy are transmitted and others specifically reflected. A glazing material can then be designed to optimize energy flows for solar heating, daylighting, and cooling.

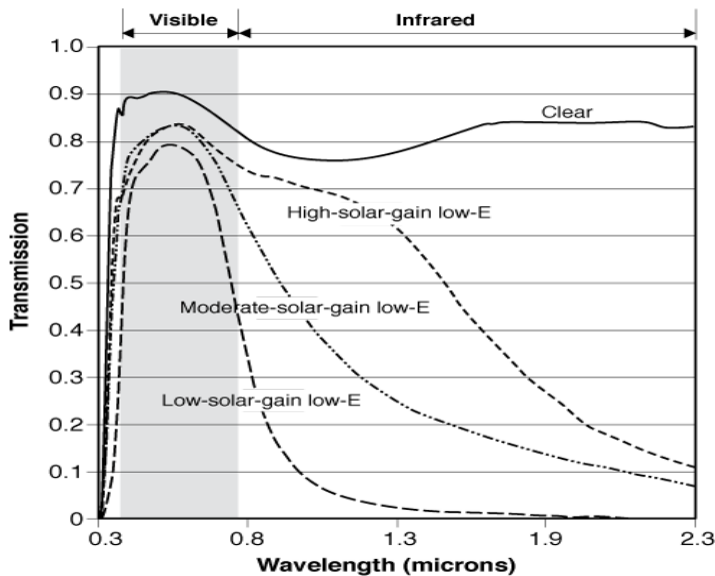


Figure: Spectral transmittance curves for glazings with low-emittance coatings (Source: Lawrence Berkeley National Laboratory).

With conventional clear glazing, a significant amount of solar radiation passes through the window, and heat from objects within the space is reradiated back into the glass, then from the glass to the outside of the window. A glazing design for maximizing energy efficiency during underheated periods would ideally allow all of the solar spectrum to pass through, but would block the reradiation of heat from the inside of the space. The first low-E coatings, intended mainly for residential applications, were designed to have a high solar heat gain coefficient and a high visible transmittance to allow the maximum amount of sunlight into the interior while reducing the U-factor significantly. A glazing designed to minimize summer heat gains, but allow for some daylighting, would allow most visible light through, but would block all other portions of the solar spectrum, including ultraviolet and near-infrared radiation, as well as long-wave heat radiated from outside objects, such as pavement and adjacent buildings. These second-generation low-E coatings still maintain a low U-factor, but are

designed to reflect the solar near-infrared radiation, thus reducing the total SHGC while providing high levels of daylight transmission (see figure to the right).

Low-solar-gain coatings reduce the beneficial solar gain that could be used to offset heating loads, but in most commercial buildings this is significantly outweighed by the solar control benefits. In commercial buildings, it is common to apply low-E coatings to both tinted and clear glass. While the tint lowers the visible transmittance somewhat, it contributes to solar heat gain reduction and glare control. Low-E coatings can be formulated to have a broad range of solar control characteristics while maintaining a low U-factor.

There are two basic processes for making low-E coatings—sputtered and pyrolytic. Sputtered coatings are multilayered coatings that are typically comprised of metals, metal oxides, and metal nitrides. These materials are deposited on glass or plastic film in a vacuum chamber in a process called physical vapor deposition. Although these coatings range from three to possibly more than thirteen layers, the total thickness of a sputtered coating is only one ten thousandth the thickness of a human hair. Sputtered coatings often use one or more layers of silver to achieve their heat reflecting properties. Since silver is an inherently soft material that is susceptible to corrosion, the silver layer(s) must be surrounded by other materials that act as barrier layers to minimize the effects of humidity and physical contact. Historically, sputtered coatings were described as soft-coat low-E? because they offered little resistance to chemical or mechanical attack. While advances in material science have significantly improved the chemical and mechanical durability of some sputtered coatings, the glass industry continues to generically refer to sputter coat products as "soft-coat low-E."

Most sputtered coatings are not sufficiently durable to be used in monolithic applications; however, when the coated surface is positioned facing the air space of a sealed insulating glass unit, the coating should last as long as the sealed glass unit. Sputtered coatings have emittance as low as 0.02 which are substantially lower than those for pyrolytic coatings.

A typical pyrolytic coating is a metallic oxide, most commonly tin oxide with some additives, which is bonded to the glass while it is in a semi-molten state. The process by which the coating is applied to the glass is called chemical vapor deposition. The result is a baked-on surface layer that is quite hard and thus very durable, which is why pyrolytic low-E is sometimes referred to as "hard-coat low-E." A pyrolytic coating can be ten to twenty times thicker than a sputtered coating but is still extremely thin. Pyrolytic coatings can be exposed to air and cleaned with traditional glass cleaning products and techniques without damaging the coating.

Because of their inherent chemical and mechanical durability, pyrolytic coatings may be used in monolithic applications, subject to manufacturer approval. They are also used in multi-layer window systems where there is air flow between the glazings as well as with non-sealed glazed units. In general, though, pyrolytic low-E is most commonly used in sealed insulating glass units with the low-E surface facing the sealed air space.

Low-solar-gain low-E coatings on plastic films can also be applied to existing glass as a retrofit measure, thus reducing the SHGC of an existing clear glass considerably while maintaining a high visible transmittance and lower U-factor. Other conventional tinted and reflective films will also reduce the SHGC but at the cost of lower visible transmittance. Reflective mirror-like metallic films can also decrease the U-factor, since the surface facing the room has a lower emittance than uncoated glass.

Adding an additional room side (also known as the 4th surface) low-E coating to the low-E coating in an insulating glazing unit allows for increased thermal performance without having to add another layer of glass. Infrared heat is generated inside a room. Adding this roomside low-E coating reflects the heat back into the space which reduces the amount of radiant heat loss through the glass.

3. Retro-Commissioning

<https://www.energystar.gov/sites/default/files/buildings/tools/EPA BUM CH5 RetroComm.pdf>

STUDY QUESTIONS:

What is the difference between retro-commissioning and retrofits?

Operator Training

http://aceee.org/files/proceedings/2004/data/papers/SS04_Panel3_Paper07.pdf

A well designed and executed training plan supported by the operations and maintenance manuals, systems documentation, and videotapes of the training sessions will help ensure that the building is operated efficiently and that performance benefits persist for the life of the building. There are many real-life situations where better training for building operators could have prevented problems. In one office building that was a part of the persistence study, the operator was never taught how to service the carefully designed daylighting control system. As a result, the system was in need of calibration and the louvers rarely operated to vary lighting level. In another building that was a part of the persistence study, the operator disabled the evaporative cooling system because he was not trained on how to maintain it, and it became a nuisance to operate. As a result, the building owner's investment in energy efficiency was wasted. Perhaps the most needed area for improvement in training lies in the trending functions of the DDC system. The wide gap between the capabilities of DDC systems and the ability of building operators to fully utilize them leads to missed opportunities every day, in both the early identification of building problems and significant energy savings. A Chief Engineer from a Portland, Oregon property management firm stated, "There is a real shortage of well-trained people who can effectively operate and maintain buildings. Where are we going to find them? It's scary. My management is beginning to understand trained building operators are crucial to risk management." The following summarizes three critical areas of training, which are

emphasized in the Persistence Guide.

Training during commissioning. Involving operating staff in the commissioning process during construction observation, start-up, and functional testing can provide training that is difficult to duplicate in a classroom setting. Early involvement allows the operating staff to observe the fabrication of the systems – and reveals the exact configuration of components that will be concealed when the building is complete. Participating during start-up and testing provides first-hand insight into the operating fundamentals of the systems. In retro-commissioning, building operating staff should be involved in development and implementation of improvements and should received training to maintain the improvements.

4. Energy Management

Energy Accounting

<https://facilio.com/blog/energy-accounting/>

STUDY QUESTIONS:

What is energy accounting?

What causes variations in energy use?

What are the units of measure and billing for electricity and natural gas?

What are demand charges on the electric bill?

Energy Management Planning – *see image below.*

Setting Goals

Once a baseline of a building's energy consumption has been established, the next step is to set an energy performance improvement goal. Setting clear and measurable goals is critical for the energy team to understand and pursue intended results, develop effective strategies, and reap financial gains.

There are many tools and calculators, free and proprietary, available to help the energy team set energy performance goals at one building or across a property portfolio. One example of a free tool is the EPA's FVC (financial value calculator). The financial value of a portfolio is directly linked to its energy consumption because increases or decreases in energy consumption affect net operating income. The calculator allows the user to set energy reduction goals and using the company's annual energy expenditure and prevailing price to earnings ratio, the tool estimates the market value that can result from increased energy efficiency.

Information

To download the Financial Value Calculator, visit www.energystar.gov/index.cfm?c=assess_value.bus_financial_value_calculator.

Creating and Implementing an Action Plan

Once goals have been set, an action plan should be put into place to serve as a road map for how to reach a building's energy performance goals. A detailed action plan ensures a systematic process to implement changes in energy use. The action plan should be updated regularly, often annually, to reflect recent achievements, changes in performance, and shifting priorities.

Key Concept

While the scope and scale of an action plan depends on the building, the plan should, at minimum, define technical steps and targets, determine roles, and identify usable resources.

Defining Technical Steps and Targets

The energy team should define the technical steps that can be taken to improve energy performance, set targets based on them, and ensure that action items are appropriately tracked. To this end, the team should:

- ▷ Identify gaps between current performance and goals by reviewing the results of the technical assessments and audits or progress evaluations.
- ▷ Identify the steps necessary for upgrading and moving facilities from current performance to the desired level of performance as defined by the goals.
- ▷ Create performance targets with timelines for each facility, department, and operation within the building to track progress toward achieving goals.

Energy Audits

<https://www.energy.ca.gov/programs-and-topics/programs/building-energy-benchmarking-program/benchmarking-building-owner-0>

STUDY QUESTIONS:

What organization establishes guidelines for energy audits?

What are the differences between Level I, II and III audits?

If an organization is interested in implementing major capital measures, which level of audit would be most appropriate?

According to the American Society of Heating, Refrigeration and Air Conditioning Engineers ([ASHRAE](#)), there are three levels of energy audits that serve as general categories for identifying the level of information provided and the types of results expected.

3 Levels of a Commercial Building Energy Audit

Level I Energy Audit

The ASHRAE Level I Energy audit is the first step in developing a priority list for buildings that may qualify for a Level II or Level III Energy audit, or for cases where a large portfolio of buildings exists. A Level I audit involves assessing a building's energy cost and efficiency by analyzing energy bills and briefly surveying the building. Level I analysis identifies and provides a savings and cost estimate of low-cost/no-cost measures. The Level I audit is most useful when there is some doubt about the energy savings potential of a building, or when an owner wishes to establish which buildings have the greatest potential for energy savings. Generally, a Level I audit will only uncover significant energy deficiencies and major problem areas.

Level II Energy Audit

The second stage in a commercial building Energy audit is Level II. A Level II audit (Energy Survey and Analysis) includes a more detailed building survey and energy analysis. In a case where sub-metering is not present, energy usage for individual building systems or components can be estimated using installed equipment efficiencies and general rules. This breakdown helps the auditor determine which efficiency improvements are most favorable in terms of return on investment (ROI). It also

gives auditors the data they need to make simple payback calculations for the system's owner. Level II analysis identifies and provides practical measures that meet the owner's constraints and economic criteria, along with a discussion of any effects on operation and maintenance procedures. It also lists potential capital-intensive improvements that require more thorough data collection and analysis, along with an initial judgment of potential costs and savings. As the ASHRAE handbook states, the level of detail associated with this type of audit suits most cases, and it is therefore the most common.

Level III Energy Audit

The ASHRAE Level III audit is by far the most comprehensive. The main difference between a Level II and Level III audit is that the Level III includes detailed analysis of capital-intensive modifications with a level of confidence high enough for major capital expenditures. Again, it is difficult to estimate the cost of an energy audit based on square footage alone. Coming up with a ballpark cost for an energy audit typically requires knowledge about the building's lighting, HVAC, domestic hot water, metering and other systems. A very rough figure for a Level II Audit is somewhere in the range of \$8,000 to 12,000, including energy usage benchmarking with [ENERGY STAR Portfolio Manager](#). Differences for Level I and Level III Audits vary, but would likely be something around ± 20 percent. These numbers are a very general estimation, since every project is different and fees vary pretty widely. For more information about energy audits, check out the [ASHRAE website](#) and consider learning more about energy audits and LEED green certification.

Load Shedding

Source: BOMI Energy Management and Controls 10-11, 10-22

STUDY QUESTIONS:

What is load shedding?

What organizations can benefit from it?

How are load shedding control points organized and ranked?

Load Shedding

Source: BOMI Energy Management and Controls 10-11, 10-22

Computers, and Microprocessors 10-11

Daily Scheduling

Daily scheduling allows you to program equipment so that it operates only when needed. This application can monitor the rate of heat loss or gain and then use this data to decide when equipment should be turned on in order to regain desired space conditions.

Holiday Programming

Holiday programming allows you to completely or partially shut down equipment. Holiday programs can be scheduled for a single day or for a range of days.

Load Shedding

Load shedding allows you to reduce peak demand and lower energy costs. In general, loads are assigned to meters in the specific order in which they will be shed. Control points that are allowed to be shed are usually given a status: a "round-robin" demand point (first off-first on); a "priority" demand point (first off-last on); or a "temperature" demand shed point (load closest to the setpoint is shed first).

Night Setback

Night setback allows you to lower temperature limits for nighttime, weekends, and holiday hours based on outdoor air temperatures. It also enables you to choose parameters and limits for normal, occupied operation.

Minimum On–Minimum Off

Some mechanical equipment is designed to run for a minimum amount of time once started and/or remain off for a minimum amount of time once shut down. A minimum on–minimum off program allows you to enter these times.

Service Hot Water Systems

Hot water reset decreases the temperature of hot water as a building's heating requirements decrease. Typically, this function is accomplished by controlling a three-way valve in the hot water loop or by floating the water temperature setpoint.

Heating Systems

Boiler optimization allows you to operate multiple boilers efficiently. Multiple boilers are staged so that preference is given to the most efficient boiler.

Lighting Systems

Much of the light used in office buildings is wasted. Lights in an average office are on approximately 14 hours a day even though the office is only occupied for about 8 hours each day.

Key Concept

With load shedding, equipment is turned off when the input kilowatts to a building reach a certain value. This occurs because utilities often bill on a bulk rate and have a demand charge that penalizes the owner when the input kilowatts reach a certain value.

An FMS operates fire and security systems and will sense fire. This system will also automatically alert fire authorities should a fire occur in the facility.

A management system keeps track of preventive maintenance such as oiling, greasing, and fan-belt adjustment by providing information for maintenance schedules as well as alerting you if a scheduled procedure has been overlooked.

Performance Contracting

Source: IFMA Operations & Maintenance, 2005

STUDY QUESTIONS:

What is energy performance contracting?

Operational Efficiency - Used in the calculation of Overall Equipment Effectiveness. The actual output produced from an asset in a given time period divided by the output that would have been produced from that asset in that period, had it produced at its rated capacity. Normally expressed as a percentage.

Operations - Work to keep the facility performing the function for which it is currently classified. Typically includes the provision of utilities, heating, ventilation, and air conditioning. Activities include work reception and coordination, operation and repair of building systems and other building-related equipment.

Outage - A term used in some industries (notably power generation) which is equivalent to a shutdown.

Overhaul - A comprehensive examination and restoration of an asset to an acceptable condition.

Part - One piece, or two or more pieces joined together, which cannot be disassembled without destruction or loss of design use.

Paved - Means surfaced with a hard, smooth surface, usually consisting of portland cement concrete or asphalt concrete underlain by a subgrade of crushed rock.

PdM - see *Predictive Maintenance*

Pending Work - Work that has been issued to a mechanic or contractor that is unfinished. It is important to complete all pending work.

Performance - A measure of how well a system or item functions in the expected environments.

Performance-Based Contracting - The method of contracting which entails structuring all aspects of an acquisition process around the purpose of work to be performed as opposed to how the work is to be performed. It emphasizes objective, measurable performance requirements and quality standards in developing statements of work, selecting contractors, determining contract incentives, and performance of contract administration.

P-F Interval - A term used in Reliability Centered Maintenance. The time from when a Potential Failure can first be detected on an asset or component using a selected Predictive Maintenance task, until the asset or component has failed. Reliability Centered Maintenance principles state that the frequency with which a Predictive Maintenance task should be performed is determined solely by the P-F Interval.

Piping (and vents) – Provides means of transporting liquids/gases.

Energy Efficient Operation of Commercial Buildings, Peter Herzog, 1997

building, copies of these plans are useful for recording information about the location of key energy-consuming equipment. The plans can be produced quickly by tracing the outline of a reduced architectural plan and may already exist in the form of plans that show the location of building exits and fire safety equipment. A single plan may be sufficient in a multi-story building where all of the floors are nearly identical.

A building elevation or section is useful to describe the number and relationship of levels in complex multi-floor buildings. The collected drawings should be filed in Section A—Tab 2 of the energy management file.

Mechanical Drawings and Specifications

Mechanical floor plans will show how heating, ventilating and air conditioning (HVAC) is distributed in the building, and the location of the equipment that provides it. A list of all the building's air-handling units will be found in the *Schedules* section of the mechanical drawings or specifications. A copy of this schedule should be made for Section B—Tab 2 of the energy management file (Figure 3-10).

In the case of buildings with water-to-air heat pumps, the mechanical plan will show the number and location of heat pumps. A chart listing all heat pumps, along with their sizes and capacities, will usually be found in the *Schedules* of the drawings or specifications and should also be copied for the energy management file.

The *Schedules* section of the mechanical drawings or specifications should be studied for lists of additional energy-consuming equipment, such as boilers, chillers, cooling towers, water heaters, pumps and exhaust fans. The location of this equipment will be shown on the enlarged plans of mechanical equipment rooms. This information should be reviewed and filed for future reference in the front of Section B if the equipment consumes electrical energy, or in Section C if it primarily consumes fuel energy (Figure 3-11). When the energy-efficient operation process is set up, much of this information will be distributed to the appropriate subtabs in the electrical or fuels sections of the filing system.

Section B: Electrical equipment

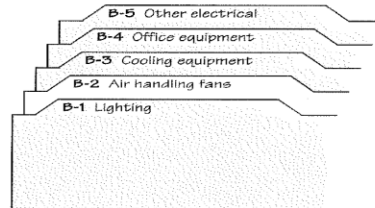


Figure 3-10. Place schedules for air handling units into Section B—Tab 2 of the filing system.

Section C: Fuel consuming equipment

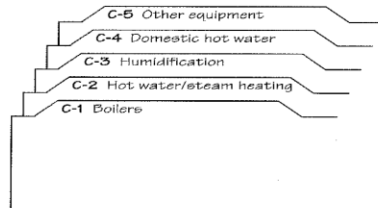


Figure 3-11. Place schedules for fuel consuming equipment into the appropriate tabs in Section C of the filing system.

Compressed Air Systems

<https://betterbuildingssolutioncenter.energy.gov/better-plants/compressed-air>

STUDY QUESTIONS:

What is the primary cause of excessive compressed air consumption in most buildings?

What unit of measure is used to rate leakage?

What factors determine the leakage rate?

A fact of operating cost for compressed air systems shows that 76% of the costs for compressed air are for electrical energy and maintenance, it becomes apparent that the cost of pneumatics is not the investment accounting for only 12% but the operation. Therefore, it makes sense to pay special attention to the proper usage of compressed air. Assuming that the compressors, the distribution system, and the pneumatic drives are all properly sized, steps must be taken to avoid the inefficient use of compressed air and/or air losses caused by leaks.

A little air lost here and there doesn't seem like a big deal. This may be the reason why air leaks are often not taken seriously. In existing installations, leaks are the primary cause of excessive compressed air consumption, as high as even 30% of the total air used. Wasted compressed air may be harmless to the environment, but it is not harmless to the bottom line. When cost is an issue, it is absolutely essential to recognize when compressed air is exhausting into the atmosphere. Very often, the cost of generation is not known; however, some companies use a value of \$ 18-30 per 1,000 cubic feet of compressed air. Leakage rates are a function of the supply pressure in an uncontrolled system and increase with higher system pressures. Leakage rates identified in cubic feet per minute (cfm) are also proportional to the square of the orifice diameter [6]. For various leakage diameter sizes and working pressure, the annual costs of compressed air are listed in Figure 1.2. Figure 1.2: Leakage rate for different supply pressures and approximately equivalent orifice size.(For well-rounded orifices, values should be multiplied by 0.97 and by 0.61 for sharp ones.)

Pressure (psig)	Orifice diameter (inches)					
	1/64	1/32	1/16	1/8	1/4	3/8
	Leakage flow rate (cfm)					
70	0.29	1.16	4.66	18.62	74.4	167.8
80	0.32	1.26	5.24	20.76	83.1	187.2
90	0.36	1.46	5.72	23.1	92	206.6
100	0.4	1.55	6.31	25.22	100.9	227
125	0.48	1.94	7.66	30.65	122.2	275.5

Figure 1.2: Leakage rate for different supply pressures and approximately equivalent orifice size.(For well-rounded orifices, values should be multiplied by 0.97 and by 0.61 for sharp ones.)

How to Get Rid of Water in Your Compressed Air System

<http://www.fluidairedynamics.com/get-rid-water-compressed-air-system/>

STUDY QUESTIONS:

What causes moisture in a compressed air system?

How is it detrimental?

What are solutions for reducing water in the system?

Air includes water, so moisture is always present in your compressed air to varying degrees depending on humidity and temperature. An accumulation of water can cause moisture to get pulled back into the compressed air stream. This can be especially problematic when you are using a compressor to spray paint because water can cause negative visual and texture effects on the finish sheen. Other uses where moisture is a real nuisance include sand and other material blasting, pneumatic tools, CNC machining centers, robotics, air cylinders, valves, and many other applications.

When a compressor draws in air, the air is compressed about 12 times normal atmospheric pressure. Moisture that is present as a vapor in air begins to condense. More condensation occurs as the compressed air moves through the system and cools. The effect is more pronounced in summer because of higher humidity.

While it's impossible to prevent moisture from entering your compressor, you can get rid of most of it. This is done in stages using different components throughout your system.

The first place of attack is in the tank. When compressed air emerges from the pump, it's hot which temporarily keeps the water in its vapor state. But when it gets to the tank it will become liquid again and collects.

So dependable draining of the tank is crucial to getting rid of moisture in your compressor system. This can be accomplished most simply with a manual drain but timer-based drains and pneumatic drains are other very useful options.

Another solution is a mechanical separator, which looks like an in-line air filter. This filter, also known as a filtration water separator, removes large amounts of moisture from the air supply with centrifugal force. It can get rid of 40 to 60 percent of the water, and the air may be dry enough for your application at this point.

If further moisture removal is needed, look next to refrigerated air dryers. Temperature, pressure and moisture content are correlated, and by chilling the air this step take out more water. Refrigerated air

dryers typically get you between a 34 and 40 degree dew-point which is sufficient for most applications.

Desiccant dryers can be another step that gets air very dry and are helpful in painting, printing and instrument applications, or when compressed air meets ambient temperatures of less than 34 degrees. Desiccant dryers range from -40 degrees to -100 degrees in dewpoint based off of the selected model.

5. Measurement Tools & Devices

Airflow Measurement & TAB

Alnor, Testo, Fluke, Extech and TSI Capture Hoods, Flow Hoods, Anemometers, Hot Wires, Pitot Tubes and Static Pressure Tips for Measuring Airflow and Static Pressures

<https://trutechtools.com/tab-tools-airflow-measurement.html> Airflow measurement, subcategories - Anemometers (vane & hot-wire), posted to TrutechTools

STUDY QUESTIONS:

What tools measure air flow?

When is a pitot tube preferred for a velocity measurement?

What is the best tool for air balancing and quick measurement?

Measuring airflow is easy, measuring airflow accurately however is a challenge! Using the right tools and the right process can simplify otherwise what might seem a daunting process.

When selecting an airflow measurement instrument, it is important to consider your application. Vane anemometers are often ideal because they do not require air density correction. When considering hand held instrumentation, typically hot wires are suited for very low velocity measurements, vane anemometer for mid level and Pitot tubes for high velocity measurements. While all of these have some overlap, we have found the vane to be one of the most useful tools when trying to select a single instrument for multiple applications typical to residential and light commercial applications. For air

balancing and quick measurement consider a capture hood. While they are initially more expensive, if you do a lot of air-side work, there could be considerable labor savings.

An **anemometer** is an instrument used to measure the speed or velocity of air (gases) either in a contained flow, such as airflow in a duct, or in unconfined flows, such as atmospheric wind. To determine the air velocity, anemometers detect change in some physical property of the fluid or the effect of the fluid on a mechanical device inserted into the flow.

The hot wire anemometer is the most popular kind of constant-temperature devices. It consists of an electrically heated, fine-wire element (0.00016 inch in diameter and 0.05 inch long) supported by needles at its ends. While hot wire are best suited for clean gases at low velocities, venturi meters can also be considered for some liquid (including slurry) flow applications.

Types of anemometers

There is a wide range of anemometers models for directly measuring wind and air velocity. The four most popular models are: Vane Anemometers, Thermal Anemometers, Thermal Anemometers with Velocity / Temperature Profiling and Cup Anemometers. This type of air velocity indicator is usually classified as either constant-temperature, or constant-power anemometers.

6. Miscellaneous

EvapoTranspiration and ET Controllers

<https://extension.okstate.edu/fact-sheets/smart-irrigation-technology-controllers-and-sensors.html>

STUDY QUESTIONS:

How do ET controllers differ from standard irrigation controllers?

What three factors contribute to ET?

The words of "evaporation" and "transpiration" are combined into "**EvapoTranspiration**" or **ET**. Water "evaporates" from the dirt. Plants use "transpiration" of soil moisture to cool themselves like humans use "perspiration". Plants also use water in photosynthesis. ET measures all these water losses from the landscape.

It is not practical to directly measure ET. So various state agencies have researched the correlation between weather data and ET. The picture below shows a weather station specifically designed to collect weather data for the purpose of estimating ET. This ET weather instrument is part of the California Irrigation Management Information Service (CIMIS).

ET weather stations measure

- solar radiation
- wind speed
- temperature
- humidity

On average, 85% of ET is solar radiation and 10% is wind. When there is no wind, then solar radiation is 90-95% of ET.

ET controllers are irrigation controllers which use some method of weather based adjustment of irrigation. These adjusting methods include:

- use of historical monthly averages of ET;
- broadcasting of ET measurements; and
- use of on-site sensors to track ET.

Rupture Disc

https://en.wikipedia.org/wiki/Rupture_disc

STUDY QUESTIONS:

How does a rupture disc differ from a conventional safety valve?

What is the benefit of using a rupture disc in combination with a safety valve?

A **rupture disc**, also known as a pressure safety disc, burst disc, bursting disc, or burst diaphragm, is a non-reclosing [pressure relief](#) device that, in most uses, protects a [pressure vessel](#), equipment or system from over-pressurization or potentially damaging [vacuum](#) conditions. A rupture disc is a type of [sacrificial part](#) because it has a one-time-use membrane that fails at a predetermined differential pressure, either positive or vacuum. The membrane is usually made out of metal, but nearly any material (or different materials in layers) can be used to suit a particular application. Rupture discs provide instant response (within milliseconds) to an increase or decrease in system pressure, but once

the disc has ruptured it will not reseal. Major advantages of the application of rupture discs compared to using pressure relief valves include leak-tightness and cost.

Rupture discs can be used as single protection devices or as a backup device for a conventional [safety valve](#); if the pressure increases and the safety valve fails to operate (or can't relieve enough pressure fast enough), the rupture disc will burst. Rupture discs are very often used in combination with safety relief valves, isolating the valves from the process, thereby saving on valve maintenance and creating a leak-tight pressure relief solution.

Check Valve

https://en.wikipedia.org/wiki/Check_valve

STUDY QUESTIONS:

What is the function of a check valve?

What is cracking pressure and why is it important to consider in selecting and maintaining check valves?

A check valve, clack valve, non-return valve or one-way valve is a [valve](#) that normally allows [fluid](#) ([liquid](#) or [gas](#)) to flow through it in only one direction.

Check valves are two-port valves, meaning they have two openings in the body, one for fluid to enter and the other for [fluid](#) to leave. There are various types of check valves used in a wide variety of applications. Check valves are often part of common household items. Although they are available in a wide range of sizes and costs, check valves generally are very small, simple, or inexpensive. Check valves work automatically and most are not controlled by a person or any external control; accordingly, most do not have any valve handle or stem. The bodies (external shells) of most check valves are made of plastic or metal.

An important concept in check valves is the cracking [pressure](#) which is the minimum upstream pressure at which the valve will operate. Typically the check valve is designed for and can therefore be specified for a specific cracking pressure.

Cold Storage Facility

http://aceee.org/files/proceedings/2002/data/papers/SS02_Panel3_Paper09.pdf, pages 1-12,
Commercial Buildings: Technologies, Design, Performance Analysis & Building Industry Trends,

Showcasing Energy Efficiency Solutions in a Cold Storage Facility, authors Ramin Faramarizi, Bruce A. Coburn & Rafik Sarhadian of Southern California Edison

STUDY QUESTIONS:

How does the energy use of refrigerated warehouses compare to other building types?

What measures have been shown to reduce the energy intensity of refrigerated warehouses?

Refrigerated warehouses have one of the highest electric *energy usage intensities* in the commercial building sector (Leue and Eilert 2000). Their electric usage, often ranges from 40 to 60 kilowatt-hours per square foot per year, with refrigeration accounting for more than 70 percent of overall electric usage. Although refrigeration equipment performance in cold storage facilities is not governed by any efficiency standards, these facilities can benefit significantly from commercially available energy efficiency solutions, which can reduce energy consumption and improve food safety by providing desirable temperatures. This paper presents the findings of an energy efficiency showcase of a 24,600 square foot cold storage facility in Ontario, Calif. A short-term end-use monitoring plan was deployed to capture the impact of the following energy efficiency solutions:

- Enclose an open loading dock area and add energy efficient cooling and dehumidification to reduce cooling load.
- Design and implement a new state-of-the-art refrigeration system, with advanced controls; sub-cooling; floating head pressure; high efficiency evaporators, condensers, and motors; and variable speed drives.

At a mild ambient temperature of 65°F, the new system reduced daily refrigeration energy use by approximately five percent, and reduced the facility's peak electric demand by five percent. (The site is, however, exposed to temperatures higher than 65°F during summer.) Additionally, the north and west freezers' storage temperatures dropped by 2.6°F and 5.6°F, respectively. These improvements were achieved despite a 17 percent increase in refrigerated floor space.

See PDF

Thermal Comfort

Comfort Factors

<https://www.hse.gov.uk/temperature/thermal/>

<https://www.simscale.com/blog/what-is-ashrae-55-thermal-comfort/>

STUDY QUESTIONS:

What factors influence occupant thermal comfort?

The most commonly used indicator of thermal comfort is air temperature – it is easy to use and most people can relate to it. However, air temperature alone is not a valid or accurate indicator of thermal comfort or thermal stress. It should always be considered in relation to other environmental and personal factors.

The six factors affecting thermal comfort are both environmental and personal. These factors may be independent of each other, but together contribute to an employee’s thermal comfort.

Environmental factors:

- Air temperature
- Radiant temperature
- Air velocity
- Humidity

Personal factors:

- Clothing Insulation
- Metabolic heat

7. Practice Questions and Answers

The practice questions below are retired exam questions from early versions of the certification exam. Candidates should review the questions and answers, and be prepared to answer questions of similar content.

1. In typical office settings to avoid complaints of “drafts”, which of the following factors is not a concern about the air moving past the building occupants?

- a. The temperature of the air
- b. The turbulence of the air
- c. The CO₂ content of the air
- d. The velocity of the air

2. Because not all electrical loads are running at the same time and at the full capacity, overall power capacity requirements are lowered. This is called:

- a. Diversity
- b. Power factor
- c. Redundancy
- d. Load shedding

3. In 60-hertz, alternating-current (AC) circuits the electrical flow is switching direction every 1/120th of a second and requires two conductors to complete the electrical loop. One conductor is moving electrons from the source (utility) to the load while the other conductor is moving electrons from the load to the source. Three-phase systems can have 3- or 4-wire configurations for transmitting the electricity from the source to the load. Current transducers (CTs) are used to quantify the amperage through a circuit by measuring the electrical flow through the CT opening or donut. When installing CTs on 3-phase AC systems, which guideline described below is true?

- a. The current transducer should be looped around all conductors connecting the AC load to the power source.
- b. The direction the CT is facing (toward the source or toward the load) does not impact the measurement of current.
- c. The CT must be sized to the expected amperage draw of the load being measured.
- d. The output signal of the CT will provide you with a power reading in watts or kilowatts

Current Transducer image for Q3.



4. Determine the annual energy savings for the following exit sign retrofit project: 6-watt single-lamp CFL exit signs with magnetic ballasts are to be replaced by 3-watt LED exit signs. The facility has 100 exit signs. Use the table of lamp wattages provided below to calculate the fixture wattages.
- a. 1 kW
 - b. 2628 kWh
 - c. 8760 kWh
 - d. 11388 kWh
5. What happens to the cooling efficiency of refrigerant systems as you lower the discharge pressure and raise the suction pressure across the compressor?
- a. The efficiency improves
 - b. The efficiency stays the same
 - c. The efficiency degrades
 - d. None of the above, refrigerant systems do not have efficiencies
6. You are to install an ultrasonic flow meter on a chilled water system. Which of the following installation strategies is appropriate?
- a. Place the flow-meter in a straight run of pipe with the water flow going down
 - b. Place the flow-meter 20 pipe diameters downstream and 10 pipe diameters upstream from any pipe angles or insertions
 - c. Place the flow-meter as close as possible to the downstream side of the chilled water pump
 - d. Place the flow-meter at the highest location possible in the piping system

7. A pitot tube is shown in the provided image. This device is used by test and balance contractors to measure which of the following variables in a building:

- a. Air velocity
- b. Air temperature
- c. Relative humidity of air
- d. Air turbulence

Pitot Tube image for Q7.



Table of Lamp Wattages for Q4.

SORTED by FIXTURE CODE					nameplate	Actual
	LAMP		BALLAST	LAMP/	WATT/	WATT/
	CODE	CODE	DESCRIPTION	TYPE	FIXTURE	LAMP
ECF		EXIT Sign Fixtures				
ECF5/1	CFT5W	EXIT Compact Fluorescent, (1) 5W lamp	Magnetic	1	5	9
ECF5/2	CFT5W	EXIT Compact Fluorescent, (2) 5W lamps	Magnetic	2	5	20
ECF6/1	CFT6W	EXIT Compact Fluorescent, (1) 6W lamp	Magnetic	1	6	13
ECF6/2	CFT6W	EXIT Compact Fluorescent, (2) 6W lamps, (2) ballasts	Magnetic	2	6	26
ECF6/1-E	CFT6W-E	EXIT Compact Fluorescent, (1) 6W lamp	Electronic	1	6	8
ECF6/2-E	CFT6W-E	EXIT Compact Fluorescent, (2) 6W lamps, (2) ballasts	Electronic	2	6	15
ECF7/1	CFT7W	EXIT Compact Fluorescent, (1) 7W lamp	Magnetic	1	7	10
ECF7/2	CFT7W	EXIT Compact Fluorescent, (2) 7W lamps	Magnetic	2	7	21
EF8/1	F8T5	EXIT T5 Fluorescent, (1) 6W lamp	Magnetic	1	6	10
EF8/2	F8T5	EXIT T5 Fluorescent, (2) 6W lamps	Magnetic	2	6	20
EI5/1	I5	EXIT Incandescent, (1) 5W lamp		1	5	5
EI5/2	I5	EXIT Incandescent, (2) 5W lamps		2	5	10
EI6/1	6S6	EXIT Incandescent, (1) 6 W lamp		1	6	6
EI6/2	6S6	EXIT Incandescent, (2) 6 W lamps		2	6	12
EI7.5/1	I7.5	EXIT Tungsten, (1) 7.5 W lamp		1	7.5	8
EI7.5/2	I7.5	EXIT Tungsten, (2) 7.5 W lamps		2	7.5	15
ELED2/1	LED2W	EXIT Light Emitting Diode, (1) 2W lamp, Single Sided		1	2	6
ELED2/2	LED2W	EXIT Light Emitting Diode, (2) 2W lamps, Dual Sided		2	2	9
ELED3	LED3W	EXIT Light Emitting Diode, (1) 3W lamp, Single Sided		1	3	3

Practice Question Answers:

1. C 2. A 3. C 4. C 5. A 6. B 7. A

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