# Air Handling Unit Assessment Guidelines

**General Air Handling Unit Assessment Procedure**

1. Get copies of mechanical drawings (determine air handling unit [AHU] layout and site plan).
2. Determine type of AHUs throughout the building (constant volume, variable air volume, multi-deck, etc.).
3. Determine type of fan and fan engineering specification sheets (i.e., forward curved or backward curved and fan pressure versus flow performance).
   - ➢ Determine total fan system efficiency, mechanical efficiency, and part load performance.
4. Print a copy of the AHU mechanical schedules.
   - ➢ Analyze design flow rates for supply, outside, and return air versus as-found conditions.
5. Take screen shots of the AHU through the direct digital control (DDC) system.
6. Fill out AHU data collection forms.
7. Visually inspect coils to make sure they are clean.
8. Count all dampers, valves, and temperature sensors.

*Note: The following retro-commissioning information was taken directly from PECI's functional testing guide* ([www.peci.org/ftguide/](www.peci.org/ftguide/)) *and modified for this energy assessment training.*

**Analyze Operation and Control of the AHUs.**

- ➢ Count all outdoor air, return air, and exhaust air dampers.
  - – Record current position (% open).
  - – Record actuator type (electronic or pneumatic).
  - – Note condition of current actuator and damper bank.
- ➢ Verify proper stroke for outdoor, return, and exhaust dampers to ensure that they open, close, and modulate as intended. This can be accomplished by having a DDC operator command a damper to open, close, and modulate and visually observe the operation.
  - – Have one person stand next to the AHU with a walky-talky and have the DDC operator command the damper to open and close.
  - – Watch to make sure the actuator modulates and the dampers modulate.
  - – Check to make sure the dampers fully open and close.
  - – Make sure the control signal varies between 0–15 psi for pneumatic systems and 0–10 V or 4–20 mA for electronic actuators.
- ➢ Verify that the outdoor air ventilation is maintained at or above the minimum specified value (minimize outside air as much as possible, i.e., 17 CFM/person in office space).
  - – Use a handheld anemometer to measure outside airflow rates. Measurements should be taken across the damper bank and averaged.
  - – Calculate total exhaust airflow rate and make sure it is 10% greater than outside air when reducing outside air flow rates.
- ➢ Count all heating and cooling coils and valves.
  - – Record current valve position (% open).
  - – Record actuator type (electronic or pneumatic).
  - – Note condition of current valve.
  - – Make sure valve position hasn't been manually overridden.
- ➢ Verify proper stroke for control valves to ensure that they open, close, and modulate as intended. This can be accomplished by having a DDC operator command a valve to fully close.
  - – While sitting at the DDC screen, manually close a valve and record the mixed air temperature and discharge air temperature.
  - – If the valve fully closes, the system should reach an adiabatic state and the temperatures will be the same. (If the supply air fan is in the air stream the discharge air temperature might be a couple of degrees hotter since it is picking up the waste heat off of the motor.)
  - – If the temperatures don't reach an adiabatic state then the valve is leaking and needs to be repaired or replaced.

- For chilled water systems, check the supply and return water temperature at the coil to see how it compares with the temperatures in the secondary loop.
- Verify that the control valves close off completely through DDC overrides.
- Verify proper control of the heating coil, economizer, and cooling coil in each air handler through DDC overrides.
- Verify proper supply and return fan control per specified sequence of operations, including (but not limited to) morning warm-up, building pressure control, heating and cooling mode, economizer mode, and fire/life safety mode.
- Visually inspect the heating and cooling coils to make sure they are clean. Dirty coils can drastically reduce the overall heat transfer coefficient of the coil.
- Visually inspect the air filters to make sure they are clean.

**Setpoints and Reset Controls Assessment Procedure**

1. Verify the proper supply fan variable frequency drive (VFD) control static pressure setpoint in variable air volume systems. Oftentimes, the setpoint (whether specified by design engineer or estimated by controls contractor) is set artificially high, wasting fan energy for the life of the building if not corrected.
   - Record the current static pressure setpoint of all AHUs.
   - Determine if the static pressure is reset. If not, have the DDC operator analyze the applicability of reducing static pressure on one AHU. Trend supply air temperature, return air temperature, variable air volume (VAV) box position, supply fan VFD percent flow, and return fan VFD percent flow. The static pressure should be incrementally decreased until the VAV box in the worst case zone is 90% open.
   - Record outside air temperature and humidity when doing the test and help them develop reset guidelines (see energy assessment training presentations for more information).
2. Verify the static pressure reset control strategy in VAV systems. The supply fan static pressure setpoint may be reset downward based on dynamic load requirements to further reduce fan energy.
3. Verify that the maximum setpoint does not exceed the specified design pressure value.
4. Verify the discharge air temperature reset control strategy. Typically the discharge air temperature setpoint will be reset based on a parameter(s) that characterizes system load (such as outdoor air temperature, terminal unit valve, or damper position).
5. Verify proper coordination between individual setpoints and reset strategies.

**Airside Economizer Assessment Procedure**

The purpose of functionally testing an economizer cycle is to verify that the process and its related functions perform satisfactorily under all building operating conditions—providing free cooling using outdoor air quantities beyond ventilation requirements.

1. Verify that the control process provides reliable free cooling when conditions are appropriate under all building and system operating modes (including automatic and manual control modes) and under all climate conditions (including seasonal extremes outside the statistical design envelope).
2. Verify the cycle is integrated properly with other building processes and systems in both normal and emergency control modes.
3. Verify that interlocks return the economizer dampers to safe and efficient positions when the air handling system is shut down.
4. Verify that interlocks disable the economizer cycle when it no longer provides an energy savings benefit. The setpoints of these interlocks are appropriate for the loads served and the local environmental conditions.
5. Verify that interlocks protect the air handling system and building areas served by the economizer from damage in the event of a failure of the economizer control process or a component of the system. These interlocks include low temperature cut-outs, high and low static pressure cut-outs, pressure relief doors, and limit switches.

**AHU Morning Warm Up Assessment Procedure**
Because the heating elements used for warm-up usually perform other functions in the HVAC system they serve, the purpose of the test procedure for the warm-up process will verify that the warm-up function is properly integrated with the other heating functions and the overall operation of the system. Where dedicated warm-up elements are provided, additional testing to verify valve stroke, pressure, flushing, and capacity may also be required.

1. If warm-up uses the terminal unit reheat coils for warm-up, verify that the flow rate used by the terminal unit maximizes the heat available for warm-up and minimizes the cycle length without sacrificing energy efficiency. Higher flow rates at the terminal reheat coils do not necessarily translate into quicker warm-up times and more warm-up capacity. When ventilation loads cannot be eliminated, the terminal unit flow rate should be at a minimum.
2. Where appropriate, verify that makeup air, ventilation air, and exhaust systems are not operated during the warm-up cycle (typical sequence of operations). This will result in energy savings due to lower makeup air heating requirements and less fan energy.
3. Verify that the warm-up cycle length is not too long during extremely cold weather. This is best verified through trending. If the warm-up cycle is too long, the night setback control sequence and setpoints may need to be adjusted.
4. Verify that heat is available for warm-up during moderate weather (i.e., the heating plant is locked out based on atmospheric conditions). The lockout setpoint may need to be overridden during testing.

**AHU Instrumentation and Metering Assessment Procedure**
1. Use a hand-held anemometer to measure outside airflow rate and diffuser flow rate, temperature, and humidity.
2. Install HOBO data loggers in return air ducts to monitor $CO_2$, temperature, and humidity.
3. Use a handheld infrared (IR) gun to measure space temperatures versus DDC readings.

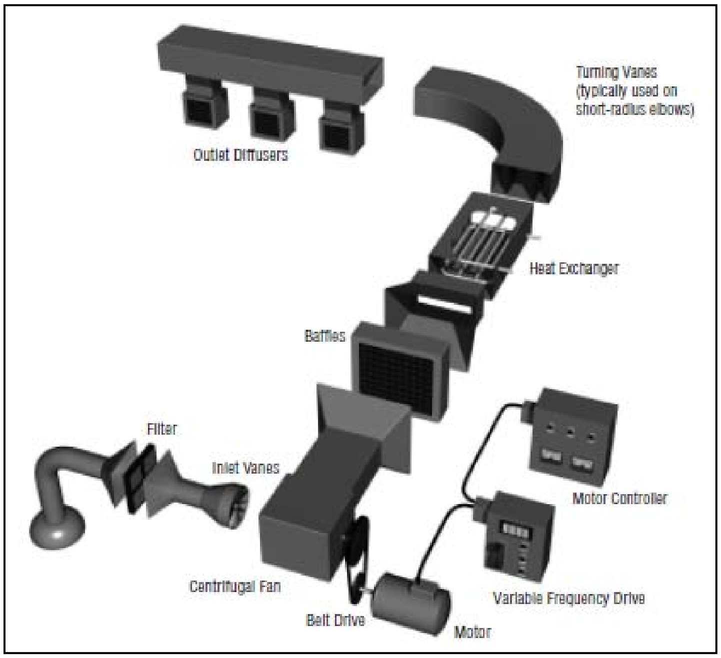



**Figure 1. Example of fan system components.**[1]
***Illustration from Lawrence Berkeley National Laboratory***

[1] *Improving Fan System Performance: A Sourcebook for Industry*. DOE/GO-102003-1294. Prepared by Lawrence Berkeley National Laboratory for U.S. Dept. of Energy. www.eere.energy.gov/industry/bestpractices/pdfs/fan_sourcebook.pdf. April 2003.

# Boiler System Assessment Guidelines

**General Boiler System Assessment Procedure**

1. Acquire copies of mechanical drawings (determine boiler system layout).
2. Determine type of boilers: open draft, forced draft, water tube, fire tube, condensing, etc.
3. Collect boiler name plate data and sketch out the system configuration (including pumping system).
4. Acquire a copy of the boiler engineering specifications.
5. Take screen shots of the boiler system through the direct digital control (DDC) system.
6. Specifically record control sequences and setpoint temperatures.

*Note: The following retro-commissioning information was taken directly from PECI's functional testing guide* (www.peci.org/ftguide/) *and modified for this energy assessment training.*

The performance of a boiler and the hot water system is acceptable if it meets the design intent and specified operating sequence. Attention to the following actions during the commissioning process can result in significant improvements in system operation and energy efficiency:

- **Actuation and sequencing**
  - Verify that automatic isolation valves are installed and operate correctly, if applicable. Automatic isolation valves are typically installed when multiple boilers are connected to a common supply header. Boilers with dedicated pumps generally do not have automatic isolation valves. When an individual boiler is not operating, the isolation valve should be closed to prevent water from circulating through the unit. This configuration reduces pumping energy and prevents dilution of the hot water temperature by blending unheated water flowing through the non-operational boilers with hot water coming from the operating unit(s).
  - Verify proper boiler staging under normal operation, as well as under all failure and emergency operating modes, especially if multiple units are installed that are unequal in size. Close coordination between boiler staging and actual load minimizes energy usage. For example, it is beneficial to use a small boiler with good turn-down efficiency to meet low loads and to enable a larger boiler only when the load surpasses the heating capacity of the smaller boiler. When this occurs, the small boiler will be sequenced off until load exceeds the large boiler capacity, then both boilers would operate to meet the load.
  - Verify that the boilers and primary/feed water pumps stage up and down per the sequence of operations under all operating modes.
  - Verify that the time delay between boiler start/stop commands works as designed. To remove residual heat from the boiler, the primary/feed water pump operation time delay should operate as designed after the boiler is commanded OFF.
  - Verify that the automatic isolation valve(s) associated with the respective equipment opens fully upon start-up and closes fully upon shutdown after the specified time delay has expired.

- **Setpoints and reset controls**
  - Verify that the system operates and maintains its hot water supply temperature setpoint under all operating modes, including automatic, manual, and failure/emergency modes.
  - Verify proper coordination between individual setpoints and reset strategies. For example, the hot water temperature reset and air handling unit discharge air temperature rest control strategies should be compatible. Without coordination between hot water temperature reset and discharge air temperature reset, the air handler may be trying to make hotter air than is possible with the hot water supply temperature. This situation would result in boilers being staged ON even though there is no load on the system, wasting a significant amount of energy.
  - Verify that the control algorithms generate the proper water temperature setpoint based on the reset parameters specified in the sequence of operations.
  - Verify that the reset parameters are optimized for the system. In addition, ensure the reset control strategy does not result in a return water temperature from the building loads, which can cause the flue gasses to condense in noncondensing boiler systems.
  - Verify that the $O_2$ trim controls, if applicable for a specific project, operate to ensure that excess oxygen in flue gas is maintained at setpoint. If $O_2$ trim controls are not installed, review flue gas report and verify the boiler was tuned at high-fire and at least one intermediate part-load operating point.

**Control accuracy and stability**

- Verify that all control loops stabilize within a reasonable amount of time (typically 2 to 5 minutes) after a significant load change such as start-up or automatic/manual recovery from shutdown. Some projects may require full-load capacity and part-load turndown performance testing. Tests should be performed when the loads generated can be dissipated adequately. Verify the boiler meets the manufacturer's stated part load performance under actual operating conditions.

Final boiler system testing can be best achieved through trending under normal operation.

# Building Envelope Assessment Guidelines

**General Building Assessment Procedure**

1. Collect architectural and construction drawings to determine the layout of the internal zones and construction of all exterior surfaces; walls, floors, roof, ceiling, etc.
2. Sketch out the current building envelope layout and internal zone layout.
3. Walk around the building and look for noticeable infiltration.
    - Record temperatures in different locations and note the size of obvious infiltration points.
4. During the site assessment, record information on the following:
    - Roof:
        - Roof construction and insulation thickness
        - Roof age and warranty
        - Roof condition including signs of leaks, membrane holes, or damaged insulation
    - Walls:
        - Wall construction and insulation thickness
        - Wall condition and noticeable infiltration points that can be sealed
    - Windows:
        - Window to wall ratio on each façade
        - Window size and dimensions
        - Window framing and type of thermal break
        - Window type (double pained, single pained, etc.)
            - Record visible transmittance
            - Solar heat gain coefficient
            - Tinting and tint color
        - Center of glass U value
        - General window condition
        - Window operation
        - External window shades/overhangs
        - Interior window blinds
    - Floors and ceilings:
        - Floor construction
        - Wall construction
5. Light an incense stick and run it slowly along door jams, window frames, and vents to determine the level of air flow. Where there seem to be drafts or a lot of air movement, record this observation on the building sketch.
6. Use a thermal imaging camera to take pictures of building envelop elements and identify locations with insufficient insulation or excess heat loss or gain.
7. Compile a summary of the observations made, documenting all areas of concern with a digital camera.

**Site Assessment Tools**

1. Use a camera to document areas of concern and record window to wall ratios.
2. Use a thermometer or thermal imaging camera to record temperatures.
3. Use a flashlight and ladder for accessing roof insulation.
4. Use a tape measure to determine the amount of insulation that's been installed.
5. Use an incense stick to determine the direction of air flow.

| Building Toolkit | |
|---|---|
| Tape measure or ruler | Incense stick and lighter |
| Flashlight | Digital camera |
| Ladder | Thermometer |

Source: NREL

**Table 1. Final Energy Savings Recommendations* for Medium Office—Building Envelope[1]**

| Item | Component | | Climate Zone 1 (warmest) | Climate Zone 2 | Climate Zone 3 | Climate Zone 4 | Climate Zone 5 | Climate Zone 6 | Climate Zone 7 | Climate Zone 8 (coolest) |
|---|---|---|---|---|---|---|---|---|---|---|
| Roof | Insulation entirely above deck | R-value ft$^2$·F·h/Btu | R-20 c.i. | R-25 c.i. | R-25 c.i. | R-30 c.i. | R-30 c.i. | R-30 c.i. | R-35 c.i. | R-35 c.i. |
| | | *R-value K·m$^2$/W* | *R-3.5 c.i.* | *R-4.4 c.i.* | *R-4.4 c.i.* | *5.3 c.i.* | *5.3 c.i.* | *5.3 c.i.* | *6.2 c.i.* | *6.2 c.i.* |
| | Solar reflectance | | 0.69 | 0.69 | 0.69 | NR | NR | NR | NR | NR |
| | Emittance | | 0.87 | 0.87 | 0.87 | NR | NR | NR | NR | NR |
| Walls-exterior | Steel framed | R-value ft$^2$·F·h/Btu | R-13.0 + R-7.5 c.i. | R-13.0 + R-7.5 c.i. | R-13.0 + R-7.5 c.i. | R-13.0 + R-7.5 c.i. | R-13.0 + R-15.6 c.i. | R-13.0 + R-18.8 c.i. | R-13.0 + R-18.8 c.i. | R-13.0 + R-18.8 c.i. |
| | | *R-value K·m$^2$/W* | *R-2.3 + R-1.3 c.i.* | *R-2.3 + R-1.3 c.i.* | *R-2.3 + R-1.3 c.i.* | *R-2.3 + R-1.3 c.i.* | *R-2.3 + R-2.7 c.i.* | *R-2.3 + R-3.3 c.i.* | *R-2.3 + R-3.3 c.i.* | *R-2.3 + R-3.3 c.i.* |
| Slabs | Heated | R-value ft$^2$·F·h/Btu | NR | NR | NR | R-10.0 for 24 in. | R-10.0 for 24 in. | R-15.0 for 24 in. | R-15.0 for 24 in. | R-20.0 for 24 in. |
| | | *R-value K·m$^2$/W* | *NR* | *NR* | *NR* | *R-10.0 for 24 in.* | *R-10.0 for 24 in.* | *R-15.0 for 24 in.* | *R-15.0 for 24 in.* | *R-20.0 for 24 in.* |
| Vertical glazing | Thermal transmittance | U-factor Btu/h·ft$^2$·F | 0.51 | 0.51 | 0.51 | 0.44 | 0.44 | 0.42 | 0.31 | 0.31 |
| | | *U-factor W/m$^2$·K* | *2.89* | *2.89* | *2.89* | *2.5* | *2.5* | *2.38* | *1.76* | *1.76* |
| | Solar heat gain coeffi-cient (SHGC) | | 0.25 | 0.25 | 0.25 | 0.26 | 0.26 | 0.35 | 0.40 | 0.40 |
| | Exterior sun control (south only) | | PF>0.5 | PF>0.5 | PF>0.5 | PF>0.5 | PF>0.5 | NR | NR | NR |

Source: Pacific Northwest National Laboratory

* Implementation of these energy measures could allow a new midsize office building to achieve 50% energy savings relative to a building that just meets ANSI/ASHRAE/IESNA Standard 90.1-2004. Insulation requirements (R-value) increase and the corresponding thermal transmittance (U-factor) decreases as the climate gets colder. Recommendations are based on steel stud construction with curtain wall style windows.

[1] Thornton, B.; Wang, W.; Lane, M.; Rosenburg, M.; Liu, B. *Technical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings*. PNNL-18774. Prepared by Pacific Northwest National Laboratory for U.S. Dept. of Energy. www.pnl.gov/main/publications/external/technical_reports/PNNL-19004.pdf. September 2009.

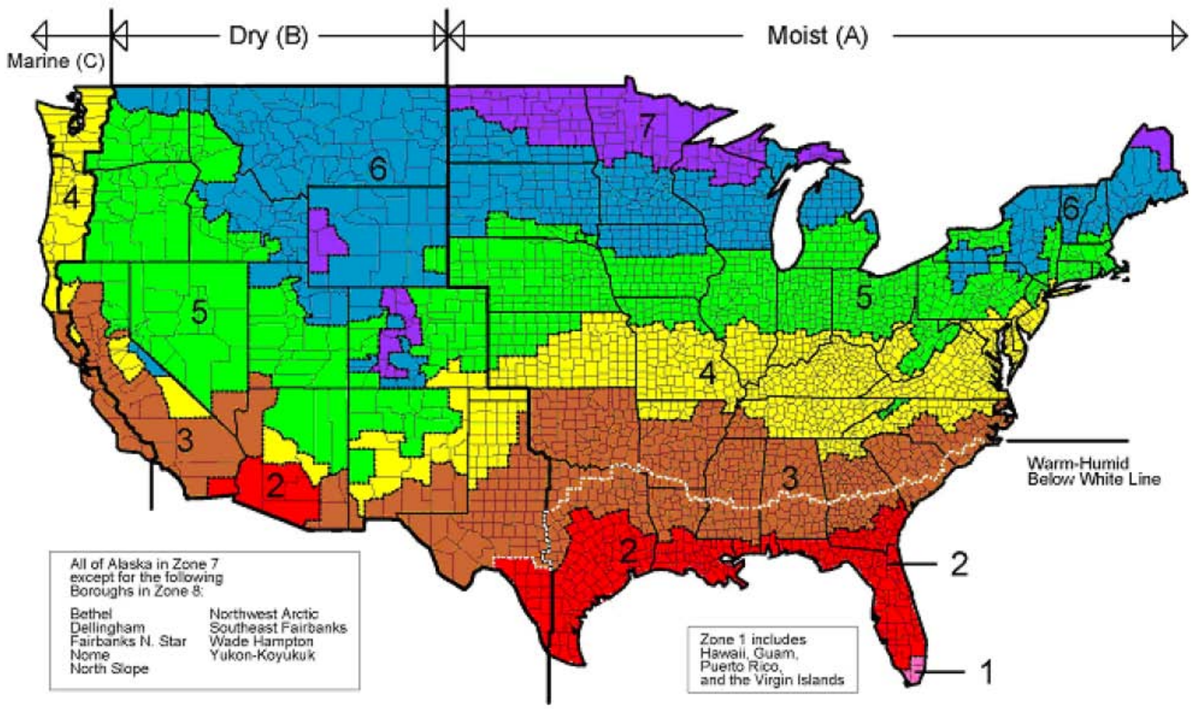



**Figure 1. DOE-developed climate zone map.**[2] ***Illustration from Pacific Northwest National Laboratory***

The sixteen cities representing the climate zones are:

1A: Miami, Florida (hot, humid)
2A: Houston, Texas (hot, humid)
2B: Phoenix, Arizona (hot, dry)
3A: Atlanta, Georgia (hot, humid)
3B-CA: Los Angeles, California (hot, dry)
3B-other: Las Vegas, Nevada (hot, dry)
3C: San Francisco, California (marine)
4A: Baltimore, Maryland (mild, humid)
4B: Albuquerque, New Mexico (mild, dry)
4C: Seattle, Washington (marine)
5A: Chicago, Illinois (cold, humid)
5B: Denver, Colorado (cold, dry)
6A: Minneapolis, Minnesota (cold, humid)
6B: Helena, Montana (cold, dry)
7: Duluth, Minnesota (very cold)
8: Fairbanks, Alaska (extreme cold)

[2] Thornton, B.; Wang, W.; Lane, M.; Rosenburg, M.; Liu, B. *Technical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings*. PNNL-18774. Prepared by Pacific Northwest National Laboratory for U.S. Dept. of Energy. www.pnl.gov/main/publications/external/technical_reports/PNNL-19004.pdf. September 2009.

# Chilled Water System Assessment Guidelines

**General Chilled Water System Assessment Procedure**

1. Get copies of mechanical drawings (determine chiller layout).
2. Determine type of chillers (centrifugal, reciprocating, screw, etc.).
3. Fill out chilled water system data collection forms and sketch out the system configuration.
4. Get a copy of the chiller engineering specifications.
5. After the assessment, send the chiller manufacturer the worksheet to develop part load and leaving chilled water temperature (LCHWT), entering condenser water temperature (ECWT) performance curves.
6. Take screen shots of the chilled water system through the direct digital control (DDC) system.
7. Go through the list of potential DDC points and determine the points that are currently available and the points that would be needed to implement sub-metering and continuous commissioning of the chilled water system. Note: If a trend log hasn't been started prior to the assessment, start trending the following points every 30 minutes:
   - Chiller On/Off Status
   - Chiller kilowatts (kW)
   - Chiller entering water temperature (EWT)
   - Chiller leaving water temperature (LWT)
   - Chilled Water Supply Temperature to Loads
   - Chilled Water Temperature Setpoint
   - Primary Chilled Water Flow Rate
   - Secondary Chilled Water Flow Rate to Loads
   - Chilled Water Return Temp from Loads
   - Pump Status On/Off
   - Pump Speed
   - Distribution Static Pressure
   - Static Pressure Setpoint
   - Tower Fan On/Off Status
   - Tower Fan Speed
   - Tower EWT
   - Tower LWT
8. Chiller energy use is primarily a function of evaporator load (part load), ECWT and LCHWT, although the energy use of the unit is primarily driven by part load performance. Because most chilled water plants are designed with constant volume primary chilled water loops and condenser water loops, in-field measurements of entering and leaving chilled water and condenser water temperature can be analyzed to develop actual chiller performance curves. In addition, chilled water supply temperature and entering condenser water temperature are usually fixed, making it easier to measure part load performance.
   - Chilled water and condenser water temperatures should be trended and current transformers should be installed to the chillers to measure power output.
   - Chilled water and condenser water flow rates can be taken from pump curves, as described in the pumping section.
   - Induced loads should be programmed into the control sequence during off-peak hours to develop an in-situ performance curve (i.e., set the space temperatures to 55°F during unoccupied hours to simulate full chiller load).

*Note: The following retro-commissioning information was taken directly from PECI's functional testing guide* (www.peci.org/ftguide/) *and modified for this energy assessment training.*

This section highlights key functional testing issues for chillers, including system integration with pumps and condensers.

- Verify that the chiller meets the specified performance requirements for temperature or part-load operation, as well as specified energy efficiency requirements.
  - In some instances, verifying chiller capacity and/or efficiency at peak load may be required. However, creating a peak load operating condition and testing the system at ARI (American Refrigeration Institute) atmospheric conditions may be difficult, especially if the system is tested during off-peak months. Verifying part load performance can be an easier and more cost-effective solution than attempting to test peak load performance since most systems operate at part load a majority of the time.

**Staging**

- Verify that isolation valves are installed and operating correctly.
  - When an individual chiller is not operating, the isolation valve should be closed to prevent water from circulating through the unit. This configuration reduces pumping energy and prevents dilution of the chilled water temperature due to blending of warm return water flowing through the non-operational chillers with chilled water coming from the operating unit(s).
- Verify that the chillers and primary CHW pumps stage up and down appropriately, per the sequence of operations.
  - This is especially important if multiple units are installed and they are unequal in size. Close coordination between chiller staging and actual load will minimize energy usage. For example, it is beneficial to use a small chiller with good turn-down efficiency to meet low loads and to enable a larger chiller only when the load surpasses the cooling capacity of the smaller chiller. When this occurs, the small chiller should be turned off until load exceeds the large chiller capacity, then both chillers operate to meet the load.

**Reset Controls**

- Verify proper reset parameters, which are verified per the design sequence of operations.
  - The sequence may be revised to optimize system operation relative to atmospheric conditions and system load. Since resetting the chilled water supply temperature is a fairly common control strategy, it warrants close attention. Reset strategies can impact chiller capacity controls and staging. Typically, the chilled water supply temperature setpoint will be reset based on some parameter(s) that characterize(s) system load, such as valve position, outside air temperature, and damper position.
- Verify proper coordination between individual setpoints and reset strategies.
  - The chilled water temperature reset strategy should be coordinated with the discharge air temperature (DAT) reset for each air handling unit (AHU). Without this coordination, excess equipment may be operated and energy will be wasted. To illustrate this point, assume the chilled water setpoint is reset based on outside air temperature but the AHU discharge air temperature setpoint is reset based on the variable air flow box damper position. Without close coordination between the two reset strategies, it is possible that the chilled water temperature could exceed the discharge air temperature setpoint. Additional chillers and pumps may be staged ON due to the increased flow, wasting significant pumping and chiller energy.
- Verify that the chilled water supply temperature reset does not adversely impact supply air dehumidification.
  - Resetting the chilled water supply temperature upward will save chiller energy but may prevent proper dehumidification of the supply air. This can result in discomfort and indoor air quality issues within the space(s) served.

### Cooling Towers

Regardless of whether the system is an open-circuit or closed-circuit cooling tower, heat rejection is based on both convective and evaporative heat transfer principles. Condenser water temperature is controlled primarily by the modulation of air flow through the tower. The purpose of the tests is to ensure that individual components are installed and integrated to operate on a system level per the design intent and sequence of operations.

#### Actuation and Sequencing

- Verify proper stroke for control valves to ensure that they open and close completely (for example, isolation valves and coil valves).
  - Control valve leakage testing should reveal no detectable leakage when the valve is commanded closed under normal operating conditions.
- Verify proper cooling tower staging, water control, and fan control (including water distribution across the fill and fan modulation) to maintain design condenser water temperature setpoint per the specific sequence of operations.
  - When an individual cooling tower is not operating, the isolation valve should be closed to prevent condenser water from circulating through the unit. Depending on the control sequence, this configuration should reduce pumping energy and prevent control problems.
- Verify proper control of both the spray pump and tower fan for evaporative and "fluid" coolers to maintain the fluid temperature setpoint per the specific sequence of operations.
  - Typically, the first stage of heat rejection in a closed-circuit system is to spray water over the coils and then modulate the tower fan to achieve the condenser water temperature setpoint. This control strategy may be altered during winter months to prevent operational problems or tower freezing: Some portion of the condenser water may flow through a bypass valve, rather than over the tower fill. Testing will ensure proper system performance throughout all operating conditions.
- ***Note: A control strategy with potential to reduce cooling tower fan energy*** *is to distribute condenser water across the entire fill (in multiple cooling tower applications) before modulating the fans to maintain water temperature. Care must be exercised to ensure that the expected performance is achieved.*
- Verify proper cooling tower fan control and staging, especially if multiple units are installed.
  - Regardless of the type of tower, optimizing the control strategy used to maintain the condenser water at setpoint is important. For example, every tower system will vary the amount of air flowing across the heat transfer elements as part of the control strategy. Commissioning the system and making sure that the particular control strategy (fan cycling, two-speed motor, or variable frequency drive [VFD]) is optimized will reduce system energy usage.
- Verify proper condenser water pump staging and VFD control (if applicable).
  - Many condenser systems are designed to provide a constant flow of water through the chiller condenser bundle, and the condenser water pumps should stage on and off per the design sequence. However, variable condenser water flow is becoming increasingly accepted as a way to further reduce energy consumption and improve chiller performance. For example, the flow rate may be modulated based on maintaining a constant temperature differential across the chiller condenser. Another example of variable flow would be a heat pump loop: As individual heat pumps cycle on and off, two-way valves open and close to vary the flow of condenser water through the entire loop. Testing will ensure that the control strategy operates as designed.

**Setpoints and Reset Controls**

- Verify the optimum condenser water temperature setpoint. The condenser water temperature setpoint is sometimes held constant based on the performance characteristics of the chiller being served.
  - Some chillers use less energy with lower condenser water temperature, but the cooling tower will expend additional energy to achieve the lower temperature setpoint. Testing will help determine the optimum setpoint to minimize overall system energy usage.
- Verify the condenser water temperature setpoint reset strategy per the sequence of operations.
  - The sequence may be revised to optimize system operation relative to atmospheric conditions, chiller energy, and tower fan (energy). For example, if the current atmospheric conditions will not allow the condenser system to achieve setpoint, then the setpoint may be raised to reduce condenser energy in exchange for a slight increase in chiller energy usage. A condenser water reset control strategy can be complicated and must be tested in order to achieve design intent and proper system operation.

# Domestic Hot Water Assessment Guidelines

**General Hot Water Assessment Tasks**

1. Identify domestic hot water (DHW) tanks and write down the following:
   - Fuel source
   - Tank size (gallons)
   - Heat input (Btu/hr or kW)
   - Efficiency (%)
   - Estimated usage (gallons/day)

2. Determine size, capacity, and fuel source of proposed on demand/heat pump DHW tank.

3. Natural gas DHW water heaters typically cost less to operate than electric water heaters.
   - Cost depends on electric and natural gas rates

4. Typical equipment costs are as follows:
   - On demand water heaters = $120 to $1,300
   - Heat pump water heaters = $800 to $2,000

5. Federal gas water heater performance requirements:
   - Energy factor of 0.67 or higher
   - Annual energy use of 242 therms/year or less for a 50-gallon tank
   - Tankless energy factor of 0.82 or higher

6. Federal electric water heater performance requirements:
   - Energy factor of 0.93 or higher
   - Annual energy use of 4,721 kWh/yr or less for a 60+-gallon tank

**Table 1. Hot Water Use By Building Type**

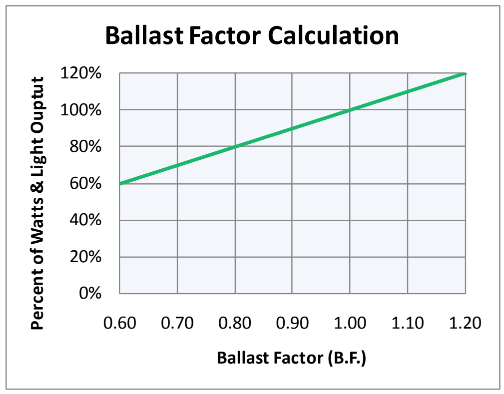
| Building Type | Estimated Hot Water Use Gallon/Person/Day |
|---|---|
| House | 15.8 |
| Hotel/Motel | 20.0 |
| Hospital | 52.0 |
| Office | 1.1 |
| Restaurant | 2.4 |
| School | 0.5 |
| School with Showers | 1.9 |

Source: NREL

# Lighting System Assessment Guidelines

**General Lighting Assessment Procedure:**

1. Record illuminance levels (foot-candles or lux) in various spaces using a handheld light meter:
   - Office light levels should be taken at desk level (standard is 30 inch above the finished floor [AFF]).
   - Hallway measurements should be taken at the floor level and restroom measurements should be taken at counter height.
   - Develop a grid of points; 2 ft on center for small offices and 10 ft on center for large open spaces, and record light levels at each point on the grid (note minimum, maximum, and average light level for each space).
   - Record nighttime and daytime light levels within each space. Take nighttime and daytime measurements at the same location to determine daylight contribution and note sky condition (clear, partly cloudy, cloudy). This can give a rough sense for expected annual daylight to see if fixture rezoning or other daylight measures are appropriate. Note: Make sure the lighting design can meet nighttime illuminance requirements when reducing lighting power density (LPD) and light levels.
2. Count lamps/ballasts in each room:
   - Count fixtures, lamps, and ballasts—Fixture counts can also be approximated from electrical drawings.
   - Calculate space area and LPD (W/ft$^2$) for each space type. Fixture wattage = lamp wattage x number of lamps x ballast factor (B.F.).
   - Record fixture type (i.e., recessed, recessed vented, indirect/direct, etc.). If pendant mounted, note the pendant length.
   - Record ceiling height and type.
3. Write down lamp data and ballast data:
   - Look up ballast specifications on the Internet.
   - Record lamp type, lamp color temperature (Kelvin), and lamp wattage.
   - Record ballast type, ballast factor and program, instant, or rapid start.
4. Write down operational hours per day:
   - Calculate operational hours per year.
5. Write down control system and wiring layout:
   - Look for existing occupancy sensors, dimming ballasts, and lighting control systems.
   - Sketch out the configuration of lighting zones within the space.
   - Use the following graph to determine acceptable reduction in ballast factor if the space is over-lit. Ballast factor is proportional to light output and percentage of lamp wattage.




Source: Illuminating Engineering Society of North America

**Figure 1. Ballast factor calculation[1]**

**Retrofit and Redesign Issues:**

1. A redesign should be considered when:
   - The space is undergoing a major renovation and the current fixtures are recessed direct fixtures
   - Existing luminaries provide nonuniform light distribution and/or can't meet illumination requirements
2. Look for opportunities to re-zone the space for occupancy and daylighting control.
3. For retrofit or redesign projects, the new design should produce acceptable light quality by:
   - Maintaining uniformity
   - Providing for glare control
   - Improving color rendering.

[1] Calculation based on information from the Illuminating Engineering Society of North America, Fundamentals of Lighting Course, 2009.

**Table 1. Recommended Illuminance (IES) and Lighting Power Density (ASHRAE 90.1 version) by Space Type[2]**

| IESNA Recommended Horizontal Illuminances and ASHRAE/IESNA 90.1 LPD Recommendations | | |
|---|---|---|
| **Space Type** | **Illuminance (fc)** | **LPD (W/ft²)** |
| Open Offices | 30 to 50 (5 to 10 with task lighting) | 1.1 |
| Private Offices | 50 | 1.1 |
| Conference Rooms | 30 | 1.3 |
| Corridors | 5 | 0.5 |
| Restrooms | 10 | 0.9 |
| Lobby | 10 | 1.3 |
| Copy Rooms | 10 | |
| Classrooms | 30 | 1.4 |
| Gymnasiums | 100 | 1.1 |
| Dining Areas | 10 | 0.9 |
| Kitchen | 50 | 1.2 |
| Labs | 50 | 1.4 |
| Libraries | 30 | 1.2 (reading area), 1.7 (stacks) |
| VDT Areas | 3 | |
| Museums (display areas) | 30 | 1 |
| General Warehousing/Storage | 10 | 0.8 |
| Inactive Storage | 5 | 0.3 |
| General Manufacturing | 30 | 1.2 (low bay), 1.7 (high bay) |
| Residences (General) | 5 | |
| Parking Areas (uncovered) | 0.2 | 0.15 |

Source: ASHRAE and Illuminating Engineering Society of North America

**Occupancy Sensor Assessment Tasks:**

1. To start, follow the general procedures listed above. Then take the following steps:
   - Determine appropriate mounting configuration (wall or ceiling mounted).
   - Determine appropriate sensor type (ultrasonic, infrared or combination).
   - Determine the number of occupancy sensors per space:
     - Typical coverage range for a wall-mounted sensor is 300–400 ft²
     - Typical coverage range for a ceiling-mounted sensor is 1,000–2,000 ft²
   - Determine installation time.
   - Look for opportunities to rewire the space into multiple smaller zones with one occupancy sensor per zone.
   - Determine reduction in operational hours.
   - Note commissioning settings (e.g., manual on and auto off).

**Table 2. Recommended Lighting Reduction by Space Type[3]**

| Space Type | Percent Reduction (%) |
|---|---|
| Private Office | 15-55 |
| Open Office | 15-30 |
| Classroom | 10-45 |
| Conference Room | 25-65 |
| Restroom | 30-75 |
| Warehouse | 50-75 |
| Storage | 45-65 |

Source: TIAX LLC

[2] Created based on information from *Energy Standard for Buildings Except Low-Rise Residential Buildings*, ASHRAE/IESNA Standard 90.1 (2004); and the *IESNA Lighting Handbook Reference and Application*, Ninth Edition, Illuminating Engineering Society of North America.

[3] Created based on data from *Energy Impact of Commercial Building Controls and Performance Diagnostics: Market Characterization, Energy Impact of Building Faults and Energy Savings Potential, Final Report*; prepared by TIAX LLC for the U.S. Department of Energy; November 2005.

**Daylighting Side-Lighting Analysis:**

1. Calculate floor to window height (ft).
   - Assume that daylight from side lighting can go 1.5 to 2 times the height of the window into space.

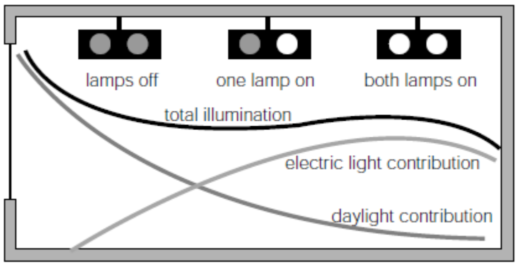



**Figure 2. Lighting schematic in a room with stepped lighting controls.**[4] ©1997 by Ernest Orlando Lawrence Berkeley National Laboratory; reprinted with permission.

**Central Lighting Control System Assessment Tasks:**

1. Determine if a central lighting control system is applicable (usually for larger commercial buildings):
   - Count the number of lighting panels and lighting breakers per panel.
   - Determine the number of different lighting schedules that will be needed.

**Site Assessment Tools:**

1. Use an illuminance meter to record light levels, a roller wheel or ultrasonic range finder to measure space dimensions, and a tape measure to measure floor to window height.
   - Count the number of fixtures located within this area.
   - Record light levels next to windows and make sure glare prevention (e.g., blinds) are blocking any direct sun.
   - Determine rough zoning recommendations (model energy savings in eQUEST).

**Daylighting Top-Lighting Analysis:**

1. Calculate top floor area.
2. Analyze the roof construction to determine applicability for top lighting.
3. Skylight to floor area ratio should be 3%–5%

[4] O'Connor, J., Lee, E., Rubinstein, F. Selkowitz, S. *Tips for Daylighting with Windows, The Integrated Approach*. Ernest Orlando Lawrence Berkeley National Laboratory. LBNL-39945 1997. http://windows.lbl.gov/daylighting/designguide/dlg.pdf. 1997.

**Table 3. Final Energy Savings Recommendations*—Lighting[5]**

| Item | Component | All Climate Zone Locations | | | | | |
|---|---|---|---|---|---|---|---|
| | | | W/ft² | *W/m²* | | W/ft² | *W/m²* |
| Interior Lighting | Lighting power density | Office, open plan | 0.68 | *7.3* | Office, enclosed | 0.8 | *8.6* |
| | | Conference/meeting | 0.77 | *8.3* | Active storage | 0.64 | *6.9* |
| | | Corridor/transition | 0.50 | *5.4* | Restrooms | 0.82 | *8.8* |
| | | Lounge/recreation | 0.73 | *7.9* | Stairs | 0.6 | *6.5* |
| | | Electrical/mechanical | 1.24 | *13.3* | Lobby | 1.09 | *11.7* |
| | | Other | 0.82 | *8.8* | OVERALL | 0.75 | *8.1* |
| | Fluorescent lamps | T5HO or T8 high-performance with high-performance electronic ballast and compact fluorescent (CFL) with electronic ballast, | | | | | |
| | Occupancy controls | Added for open-office task lights, enclosed office ambient lighting, active storage, restrooms and electrical/mechanical spaces. | | | | | |
| | Plug load lighting | Compact fluorescent (CFL) with electronic ballast | | | | | |
| Exterior Lighting Power Density | Base allowance | | 750 W | | | | |
| | | | W/ft² | *W/m²* | | | |
| | Parking areas and drives | | 0.100 | *1.08* | | | |
| | Walkways | | 0.160 | *1.72* | | | |
| | Entry canopies | | 0.400 | *4.31* | | | |
| | Façade (use wattage only for façade) | | 0.075 | *0.81* | | | |

Source: Pacific Northwest National Laboratory

* Implementation of these energy measures could allow a new midsize office building to achieve 50% energy savings relative to a building that just meets ANSI/ASHRAE/IESNA Standard 90.1-2004.

[5] Thornton, B.; Wang, W.; Lane, M.; Rosenburg, M.; Liu, B. *Technical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings*. PNNL-18774. Prepared by Pacific Northwest National Laboratory for U.S. Dept. of Energy. www.pnl.gov/main/publications/external/technical_reports/PNNL-19004.pdf. September 2009.

# Metering System Assessment Guidelines

**General Automated Metering Assessment Procedure**

1. Conduct a site assessment to determine the current number of standard electric, natural gas, fuel oil, steam, and water meters.
2. If the facility has standard (mechanical meters with no automated meter reading capabilities) electric, natural gas, fuel oil, steam, or water meters, calculate the cost effectiveness of installing an advanced meter using the following steps:
   - As a first order of approximation, assume that the meter will reduce the electric, natural gas, or water utility costs by 2% (see Table 1).

**Table 1. Metering Savings Ranges**[1]

| Action | Observed Savings |
|---|---|
| Installation of meters | 0% to 2% (the Hawthorne effect)* |
| Bill allocation only | 2.5% to 5% (improved awareness) |
| Building tune-up | 5% to 15% (improved awareness, and identification of simple O&M improvements) |
| Continuous commissioning | 15% to 45% (improved awareness, identification of simple O&M improvements, project accomplishment, and continuing management attention) |

Source: FEMP
*Improvements in productivity or process resulting from the awareness of extra attention or observation of that process.

   - Use Table 2 to approximate the installed cost of the metering system.

**Table 2. Approximate Installed Costs of a Metering System**[2]

| Advanced Electric System Costs per Meter | | |
|---|---|---|
| **Installation Cost** | **Low ($)** | **High ($)** |
| Meter | 1,000 | 1,500 |
| Ancillary device | 300 | 600 |
| Communications (modem) | 100 | 200 |
| Software | 0 | 100 |
| Installation | 500 | 1,000 |
| Install phone line or LAN | 0 | 2,000 |
| Total | 1,900 | 5,400 |
| **Metering System Ongoing Costs per Meter** | | |
| **Recurring Costs per Month** | **Low ($)** | **High ($)** |
| Phone/LAN | 05.00 | 40.00 |
| Data collection | 00.00 | 01.70 |
| Data analysis/billing | 04.50 | 04.50 |
| Total | 09.50 | 46.20 |

Source: Pacific Northwest National Laboratory

   - Use the following calculation to determine the cost effectiveness of installing an advanced meter:

**Formula and sample calculation:**

$$\frac{\left[\left(\frac{\text{Installed Cost}}{\text{Desired Simple Payback}}\right) + \text{Annual Cost}\right]}{\%\ \text{Annual Savings}} = \text{Minimum Annual Electric Bill}$$

Source: FEMP

**Figure 1. Advanced meter calculation**[3]

[1, 3] *Guidance for Electric Metering in Federal Buildings*. DOE/EE-0312. U.S. Dept. of Energy, Federal Energy Management Program. www.femp.energy.gov/pdfs/adv_metering.pdf. February 3, 2006.
[2] Sullivan, G.; Pugh, R.; Hunt, W. *Metering Best Practices: A Guide to Achieving Utility Resource Efficiency*. Prepared by Pacific Northwest National Laboratory for U.S. Dept. of Energy, Federal Energy Management Program. www.femp.energy.gov/pdfs/mbpg.pdf. October 2007.

# Motor Assessment Guidelines

### General Motor Assessment Tasks

1. Write down motor name plate data (using NREL input forms).
2. Write down operational hours per day, week, and month.

### Constant Volume Fans and Pumps

1. Write down motor name plate data (using NREL input forms).
2. Measure voltage (volt) and operating current (amp)
3. Calculate motor load using a hand-held amp/voltage meter with the following equation:
   - For long-term load calculations, a current transformer can be installed to calculate amp load over time (for constant volume fan and pump systems a calculation at one point in time is all that is needed, as the load will not change over time).
   - Record amperage on each phase (A, B, C) and phase to phase voltage (A-B, B-C, A-C) (take an average of the measured amps and voltage).

$$\text{Motor load} = \frac{\text{Amps measured}}{\text{Amps full load nameplate}} x \left( \frac{\text{Volts measured}}{\text{Volts nameplate}} \right)$$

Source: Washington State University Cooperative Extension Energy Program

**Figure 1. Voltage compensated amperage ratio technique**[1]

4. For fan systems record belt type (cogged or V-belt) and the number of belts per drive.
   - Record pulley dimensions and distance between pulleys.

### Variable Frequency Drives

1. Write down variable frequency drive (VFD) name plate data (manufacturer, model number, and specifications).
2. Record frequency and percent flow rate at time of assessment.
3. Make sure the drive isn't in "hand" or "manual" mode.
4. Make sure the VFD display matches the direct digital control (DDC) signal.
   - Command the VFD to ramp up and down through the DDC system and make sure it is controlling properly.

**National Electrical Manufacturers Association (NEMA) Premium Open Drip Proof (ODP) Motors**[2]

| *HP* | Speed | Full Load RPM | Encl | *Eff* | PF |
|---|---|---|---|---|---|
| ***1*** | 1,800 | 1740 | ODP | ***86.0%*** | 78.0% |
| ***3*** | 1,800 | 1770 | ODP | ***90.2%*** | 78.9% |
| ***5*** | 1,800 | 1750 | ODP | ***90.0%*** | 80.0% |
| ***7.5*** | 1,800 | 1760 | ODP | ***92.0%*** | 79.0% |
| ***10*** | 1,800 | 1773 | ODP | ***93.0%*** | 83.4% |
| ***20*** | 1,800 | 1775 | ODP | ***93.6%*** | 82.7% |
| ***40*** | 1,800 | 1775 | ODP | ***95.0%*** | 86.0% |
| ***60*** | 1,800 | 1785 | ODP | ***95.4%*** | 85.3% |
| ***75*** | 1,800 | 1785 | ODP | ***95.0%*** | 86.3% |
| ***200*** | 1,800 | 1780 | ODP | ***96.0%*** | 87.0% |

Source: NREL

[1] *MotorMaster 4.0 User Guide*. WSUCEEP03_13. Developed by Washington State University Cooperative Extension Energy Program for U.S. Dept. of Energy. http://www1.eere.energy.gov/industry/bestpractices/pdfs/motormaster_user_manual.pdf. 2003.
[2] Generated using data from MotorMaster+, a free online NEMA motor selection and management tool, available at www.eere.energy.gov/industry/bestpractices/software_motormaster.html.

### NEMA Premium ODP Motors[3]

| HP | Speed | Full Load RPM | Encl | Eff | PF |
|---|---|---|---|---|---|
| 1 | 3,600 | 3492 | ODP | 84.0% | 84.0% |
| 3 | 3,600 | 3450 | ODP | 88.0% | 89.0% |
| 5 | 3,600 | 3515 | ODP | 91.0% | 89.0% |
| 7.5 | 3,600 | 3500 | ODP | 91.0% | 95.0% |
| 10 | 3,600 | 3500 | ODP | 92.0% | 90.0% |
| 20 | 3,600 | 3540 | ODP | 93.0% | 85.0% |
| 40 | 3,600 | 3550 | ODP | 94.5% | 83.0% |
| 60 | 3,600 | 3540 | ODP | 95.0% | 92.0% |
| 75 | 3,600 | 3560 | ODP | 95.4% | 89.0% |
| 200 | 3,600 | 3570 | ODP | 96.2% | 91.0% |

Source: NREL

### NEMA Premium Totally Enclosed Fan Cooled (TEFC) Motors[4]

| HP | Speed | Full Load RPM | Encl | Eff | PF |
|---|---|---|---|---|---|
| 1 | 1,800 | 1775 | TEFC | 88.5% | 76.3% |
| 3 | 1,800 | 1775 | TEFC | 91.7% | 81.3% |
| 5 | 1,800 | 1760 | TEFC | 90.2% | 84.1% |
| 7.5 | 1,800 | 1770 | TEFC | 92.4% | 80.5% |
| 10 | 1,800 | 1770 | TEFC | 92.4% | 80.5% |
| 20 | 1,800 | 1780 | TEFC | 93.6% | 81.0% |
| 40 | 1,800 | 1775 | TEFC | 95.0% | 84.0% |
| 60 | 1,800 | 1780 | TEFC | 95.0% | 87.0% |
| 75 | 1,800 | 1775 | TEFC | 95.4% | 88.0% |
| 200 | 1,800 | 1790 | TEFC | 96.5% | 86.5% |

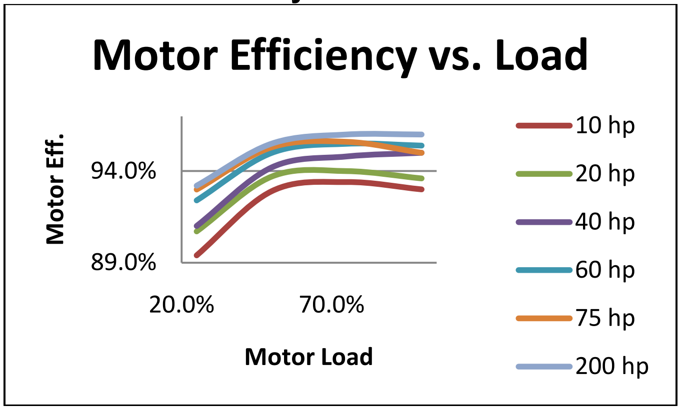
Source: NREL

### NEMA Premium TEFC Motors[5]

| HP | Speed | Full Load RPM | Encl | Eff | PF |
|---|---|---|---|---|---|
| 1 | 3,600 | 3550 | TEFC | 88.5% | 85.0% |
| 3 | 3,600 | 3500 | TEFC | 90.0% | 92.0% |
| 5 | 3,600 | 3550 | TEFC | 90.2% | 84.0% |
| 7.5 | 3,600 | 3535 | TEFC | 91.7% | 86.0% |
| 10 | 3,600 | 3500 | TEFC | 92.0% | 92.0% |
| 20 | 3,600 | 3530 | TEFC | 92.4% | 89.0% |
| 40 | 3,600 | 3540 | TEFC | 94.1% | 91.5% |
| 60 | 3,600 | 3565 | TEFC | 95.0% | 89.5% |
| 75 | 3,600 | 3575 | TEFC | 95.4% | 82.5% |
| 200 | 3,600 | 3575 | TEFC | 96.2% | 87.7% |

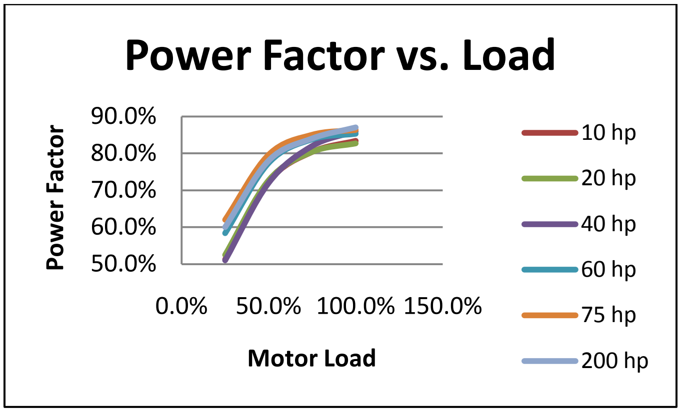
Source: NREL

### Motor Efficiency versus Load[6]




Source: NREL

### Motor Power Factor versus Load[7]




Source: NREL

[3, 4, 5, 6, 7] Generated using data from MotorMaster+, a free online NEMA motor selection and management tool, available at www.eere.energy.gov/industry/bestpractices/software_motormaster.html.

# Plug Load Assessment Guidelines

**General Plug Load Assessment Procedure:**

1. Inventory plug load equipment within the building:
   - Use the NREL data collection forms to develop an inventory of the plug load equipment.
   - Calculate active/on, suspended, and off power draws—using a kill-o-watt or similar device—for all computers and monitors within the building.
   - Install a modified surge protector and current transformer to establish the 24-hour load profile of a typical computer/monitor combination by recording an average amp draw every minute.
   - Write down plug load nameplate data.
2. Check computer power settings:
   - Determine the power settings of a series of desktop computers.
   - Check to see if the monitor turns off and the computer goes into standby mode after a predefined period of inactivity.

**General Information:**

- A typical desktop computer uses 80 W to 100 W when acitve.
- A typical laptop computer uses 20 W to 40 W when active.

**Table 1. Average Monitor Power Consumption by Monitor Type and Size[1]**

| Monitor Type | Size (Inches) | Count | Off (Watts) | Deep Sleep (Watts) | On (Watts) |
|---|---|---|---|---|---|
| All Monitors | All | 35 | 1 | 5 | 55 |
| CRT | 15 | 4 | 1 | 2 | 58 |
| | 17 | 5 | 1 | 2 | 61 |
| | 19 | 5 | 2 | 14 | 85 |
| | 21 | 5 | 1 | 7 | 95 |
| LCD | 15 | 9 | 2 | 2 | 20 |
| | 17 | 4 | 2 | 2 | 35 |
| | 18 | 3 | 2 | 3 | 54 |

Source: Lawrence Berkeley National Laboratory

[1] Roberson, J.; Brown, R.; Nordman, B.; Webber, C.; Homan, G.; Mahajan, A.; McWhinney, M.; Koomey, J. *Power Levels in Office Equipment: Measurements of New Monitors and Personal Computers.* LBNL-50508. Lawrence Berkeley National Laboratory. www.osti.gov/bridge/product.biblio.jsp?osti_id=799608. May 14, 2002.

**Site Assessment Tools:**

1. Use a kill-o-watt or similar device to measure plug load wattages of standard equipment.
2. Use a modified surge protector and current transformer to develop a 24-hour load profile.

**Table 2. Final Energy Savings Recommendations*—Plug Loads[2]**

| Component | Recommendations (for climate zones 1–8) |
|---|---|
| Computers—mix of desktop and laptop computers | Increase proportion of laptop computers to desktop computers for primary computer workstations to at least 67% of computers |
| Computers—servers, desktops, laptops, monitors, laser printers, copy machines, fax machines, water coolers, refrigerators | Use ENERGY STAR equipment |
| Computers—desktops, laptops | Apply power management software and activation across all computers |
| Computer monitors, portable HVAC (heaters, fans), other small appliances and chargers | Use occupancy sensor plug strips, or selected outlet occupancy sensor controls in conjunction with lighting control |
| Water coolers, coffee makers | Use timer switches set to turn off equipment during off-hours |
| **Overall plug loads power density** | **0.55 W/ft$^2$ (5.92 W/m$^2$)** |

Source: Pacific Northwest National Laboratory

* Implementation of these energy measures could allow a new midsize office building to achieve 50% energy savings relative to a building that just meets ANSI/ASHRAE/IESNA Standard 90.1-2004.

Visit the University of British Columbia Department of Physics and Astronomy Web site to learn more about the power consumption of items commonly found in an office: www.physics.ubc.ca/sustain/Energy_Info.pdf

[2] Thornton, B.; Wang, W.; Lane, M.; Rosenburg, M.; Liu, B. *Technical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings*. PNNL-18774. Prepared by Pacific Northwest National Laboratory for U.S. Dept. of Energy. www.pnl.gov/main/publications/external/technical_reports/PNNL-19004.pdf. September 2009.

# Pump System Assessment Guidelines

**General Pumping System Assessment Procedure**

1. Get copies of mechanical drawings (determine pumping system specifications).
2. Get copies of pump engineering specification sheets (head versus flow rate for various impeller sizes).
3. Fill out pumping system data collection forms and sketch out the pump system configuration.

*Note: The following retro-commissioning information was taken directly from PECI's functional testing guide* (www.peci.org/ftguide/) *and modified for this energy assessment training.*

**Constant Volume Systems**

The performance of a constant flow water system is acceptable if it meets the design intent and specified operating sequence. In some instances, witnessing the flushing and pressure testing of individual coils and/or distribution piping may be required.

**Actuation and Sequencing**

- Verify proper stroke for control valves to ensure that they open and close completely (coil valves, isolation valves, etc.).
  - Control valve leakage testing reveals no detectable leakage when valve is commanded closed.
- Verify proper distribution pump staging per the sequence of operations.
  - Frequently, water and air temperature reset strategies are not coordinated; this can result in the unnecessary staging of distribution pumps in the on position. Optimizing various reset strategies, during both initial system set up and commissioning, will improve system control and minimize pumping energy.
- Verify that three-way control valves modulate correctly.
  - This will help to ensure that simultaneous heating and cooling does not occur. For example, a leaky hot water valve on a pre-heat or heating coil will add unwanted heat to the air stream, which can cause the chilled water valve to modulate open. This wastes heating and cooling energy.

Review the TAB report, including flow, impeller size, and motor volt/amp measurements.

**Control Accuracy and Stability**

- Verify proper control sequence and integration over all components (such as setpoints, start-up/shut-down procedures, and time delays).
  - This includes verification of proper stand-by pump operation in the case of a lead pump failure. Temperature control strategies impact water flow through the system and pump staging, which can cause system instability. Typically, testing entails verifying that the proportional integral derivative (PID) control loop generates the proper control signal based on the setpoint. Testing should also verify the setpoints are optimized for the system or recommend modifications, if necessary.

Valve leakage tests and tests that are targeted at verifying valve stroke, spring range, and sequencing should be conducted with the pumping system operating at its peak differential pressure. The differential pressure across the valve plug can have a significant impact on the close-off rating and shift the operating spring range of the valve. These tests should be performed prior to temporary system operation to ensure that equipment will not be damaged during functional testing.

**Test Conditions, Considerations, and Cautions**

The following points should be noted to avoid testing complications:

- Rapid stroking of valves during a test process can cause water hammer problems in the piping systems.
- Consider stroking each valve in stages to prevent slamming valves open or closed, giving the system time to respond appropriately.

**Functional Testing Field Tips—Variable Flow Actuation and Sequencing**

- Verify two-position control valves associated with the respective equipment open fully upon start-up and close fully upon shutdown. This is typical for water-source heat pumps and water-cooled process equipment.
- Verify proper distribution pump staging and variable frequency drive (VFD) control, if applicable, per the sequence of operations.
  - Typically, distribution pumps in variable flow systems utilize a VFD to modulate pump speed in order to deliver water flow that matches system loads. VFD staging and modulation control is normally based on maintaining a constant differential pressure either across the distribution pumps themselves or out in the loop. The differential pressure setpoint is based on the pressure required to provide adequate flow through the worst case load (for example, the load with the highest overall pressure drop piping losses and device requirements) at full load. Often, the setpoint (either specified by the design engineer or estimated by the controls contractor, if not provided) is set artificially high, wasting pumping energy for the life of the building. The actual system pressure setpoint should be determined during the initial system setup and commissioning to improve system control and minimize pumping energy.

**Setpoints and Reset Controls**

- Verify the system operates and maintains chilled and hot water supply temperature setpoints and discharge air temperature setpoints in all modes including morning warm-up, occupied mode, and night low-limit mode.
- Verify VFD control loops generate the proper setpoint based on the reset parameters, if applicable. Reset parameters are optimized for the system.
- Verify the differential pressure reset control strategy.
  - Frequently, the discharge pressure setpoint is reset based on dynamic load requirements to reduce pump energy even further. Various indicators can be used to signify reduced load on the system, one example being valve position. In this control strategy, the system pressure setpoint is reset higher or lower in order to maintain one chilled water valve at a preset position (95% open, for example).
- Verify proper coordination between individual setpoints and reset strategies.
  - Resetting the chilled water supply temperature warrants close attention. Without coordination between chilled water temperature reset and discharge air temperature reset, the air handler may be trying to make colder air than is possible with the chilled water supply temperature. This situation will result in distribution pumps operating at full flow even though there is no load on the system, wasting significant pumping energy.

# Renewable Energy Site Assessment Guidelines

**Solar PV Site Assessment Procedure**

Preview site using NREL In My Backyard (IMBY) or Google Earth to identify possible land or roof areas for solar PV systems.

- Identify roof areas with flat or south-facing surfaces with little or no equipment on the roof.
- Identify large, open land areas.
- Print off an overhead map of the site and mark these potential land and roof areas on the map for ease of location during site visit.
- Access the roof or land area being considered for PV systems. Note the tilt angle and orientation of the south-facing or flat roof area. Also note the type, condition, and age of the roof. If it is a land area, note the approximate grade and orientation of the land area.
- Identify the shade-free roof or land area. If there are no objects that could cause shading on the roof or land (such as trees, parapet walls, mechanical equipment, or buildings), measure the entire area and record the dimensions on the overhead map or image or draw the area.
- If there are likely shading issues, pick a large contiguous area and begin taking shade analysis measurements. If the measurement is less than 90% annual solar access for a particular location, move away from the shading object and take another measurement. Refine the location until you are able to achieve a measurement of 90% or better. Do this for the four potential "corners" of the system location. When four corners are identified with measurements of 90% or better, measure and note the location of these corners and the dimensions of the contained area.
- Identify the nearest location for housing the inverter bank. This must be shaded and in most instances is enclosed. Note the distance from the proposed PV system location to the inverter bank.
- Identify the nearest electrical panel and record the location and distance from the inverter bank to the electrical panel, the voltage (V) at interconnect, number of phases (one or three), capacity of main breaker (amps) and the capacity of the panel (amps).

**Solar Hot Water Site Assessment Procedure**

Work with site contact to identify buildings and applications with high solar hot water loads, including dormitories, cafeterias, laundry facilities, and swimming pools.

- Preview site using IMBY or Google Earth to identify which of these buildings have roof areas with flat or south-facing surfaces with little or no equipment on the roof or nearby open land areas.
- Print off an overhead map of the site and mark these potential land and roof areas on the map for ease of location during the site visit.
- Access the roof or land area being considered for solar hot water systems. Note the tilt angle and orientation of the south-facing or flat roof area. Also note the type, condition, and age of the roof. If it is a land area, note the approximate grade and orientation of the land area.
- Identify the shade-free roof or land area. If there are no objects that could cause shading on the roof or land (such as trees, parapet walls, mechanical equipment, or buildings), measure the entire area and record the dimensions on the overhead map or image or draw the area. If there are objects that will cause

shading, pick a large contiguous area and begin taking shade analysis measurements. If the measurement is less than 90% annual solar access for a particular location, move away from the shading object and take another measurement. Refine the location until you are able to achieve a measurement of 90% or better. Do this for the four potential "corners" of the system location. When four corners are identified with measurements of 90% or better, measure and note the location of these corners and the dimensions of the contained area. Also note locations of roof vents, drains, etc. on the map or drawing.

- Identify the location of the current hot water heating system. Note the nameplate data, fuel used, capacity, and efficiency, if possible. Also note the distance from the potential solar hot water location to the current hot water heating system location. Note the temperature of the incoming unheated water as well as the heated supply water temperature.
- Gather data to help quantify the hot water load. Note what types of applications or operations use hot water and the operational schedule of those applications or operations (i.e., hours per day, days per week, weeks per year). The following table can be used as a general estimate of hot water load for different applications.

**Table 1. Hot Water Load Estimates Per Building Application[1]**

| Application | Hot Water Load | Unit |
|---|---|---|
| Dormitory | 13 | gal/day/person |
| Motel | 20 | gal/day/unit |
| Hospital | 52 | gal/day/bed |
| Office | 1 | gal/day/person |
| Food Service | 2.4 | gal/meal |
| Fast Food | 1 | gal/meal |
| Residence | 40 | gal/day/person |
| School | 1.8 | gal/day/student |
| Apartment | 45 | gal/day/unit |
| Laundry | 46 | gal/day/machine |
| Car Wash | 9 | gal/car |

Source: RETScreen

[1] Hot water load estimates come from the RETScreen Solar Hot Water Module, available at www.retscreen.net/.

# Water Site Assessment Guidelines

**General Water Assessment Procedure:**

1. Does the organization have a water management plan and a staff awareness campaign?
   - If yes, how often are the plan and campaign reviewed and renewed?

2. Record water usage from bills (delivered and wastewater).

3. Check the billing rate ($/unit of water).

4. Locate the water meter and record the meter reading, verifying that the meter reading matches the billing amount.

5. Compile a list of buildings, floor plans, plumbing drawings (where available), operational schedules of employees and number of employees (to predict consumption), an inventory of all water-using equipment, outdoor water usage, and watering schedule.

6. Check all toilets, faucets, showerheads, and urinals for condition and leaks.
   - Toilets should not continue running after the tank has filled.
   - Urinals should shut off after a complete flush cycle.
   - Showerheads and faucets should not drip or leak.
   - Are any low-flow or aerating faucets and showerheads installed?
   - Are there waterless urinals?
   - Are water displacement devices installed in toilet cisterns?

7. Check water-using equipment within processing, cooling towers, boilers, kitchen equipment, etc.
   - Note the manufacturer's flow rate information, along with hours of operation for each piece of equipment to estimate consumption rates.

8. Measure flow rate by using a container (e.g., a gallon bucket) and a stopwatch to determine gallons per minute, or attach a strap-on flowmeter to measure flow rate where equipment information is not available.

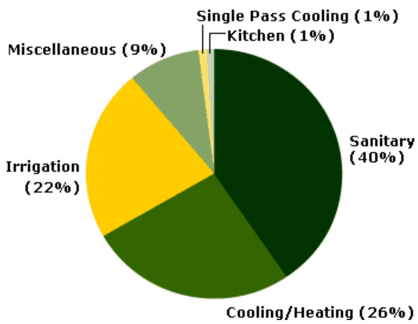
9. Determine how much water is used annually per employee or per total floor area of a building in order to create a benchmark across facilities.
   - This will allow a benchmarking exercise to determine whether certain buildings have a higher rate of consumption than other buildings and will assist with prioritizing areas for conservation measures.

| Commonly Used Water Units |
|---|
| 1 cubic foot (ccf) = 7.48 gallons |
| 1 acre foot = 325,851 gallons |
| 1 million gallons per day = 3.07 acre feet per day |

Source: NREL

**Retrofit and Redesign Issues:**

1. A redesign should be considered when:
   - ➢ The space is undergoing a major renovation.
   - ➢ Existing water-using equipment requires replacement.




Source: EPA

**Figure 1. Typical office water use[1]**

2. Look for opportunities to incorporate low-water design in landscaping, renovation, and new-building projects (including grayscale systems and water-wise planting).

3. Consider porous pavement when resurfacing parking lots and landscaping as this helps prevent flashpoint flooding and allows more dispersed infiltration into groundwater.

4. Consider using rainwater harvesting to water landscaping, but check with state and local regulations to determine whether this is allowed.

5. For retrofit or redesign projects the new design should meet lower levels of water consumption, below traditional usage, while maintaining acceptable performance levels.
   - ➢ Reduce losses by fixing leaky faucets and pipes.
   - ➢ Reduce use through installation of low-flush toilets, auto faucets, etc.
   - ➢ Reuse water that is being discarded to irrigate landscaping.

6. Look for the EPA's WaterSense Label on equipment. The WaterSense program was designed by the EPA, water utilities, manufacturers, and retailers to set water conservation criteria for equipment and water products. Look for the label and find out more information about product specification at www.epa.gov/watersense or www.epa.gov/watersense/products

Source: EPA

[1] "Laboratory Water Use vs. Office Water Use." *U.S. Environmental Protection Agency*, www.epa.gov/oaintrnt/water/lab_vs_office.htm. Accessed December 13, 2010.

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