U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Building Energy Asset Score: Building Upgrade Guide

This guide[1] complements the energy improvement recommendations listed in your building's Asset Score Report. A building's Asset Score Report provides a range of information, including the building's score and suggestions for how to improve the building's efficiency and score. Given that the Asset Scoring Tool uses limited building data to model the building, the Report's upgrade recommendations are somewhat general.

This guide can help building owners and operators take the next step toward identifying and evaluating the feasibility and applicability of more specific improvements. While the Asset Score Report provides high-level recommendations (e.g., "add roof insulation"), this guide provides specific technology options to consider and evaluate more thoroughly.

Before implementing any improvements, you will likely need to conduct additional analysis, consider local building codes and equipment standards, and get cost estimates. You may also need to consult with outside experts. This guide can help you get started.

Note -- the costs shown in this report:

- Are based on the Advanced Energy Retrofit Guide and RS Means;
- Refer to replacement costs, not incremental costs;
- Do not take into consideration replacing existing equipment that is at the end of its service life;
- Do not include local incentives
- Are shown as a range ($ = low cost, $$ = medium cost, $$$ = high cost).

[1] This guide is available for download from the Commercial Building Energy Asset Scoring Tool Log In page. Links to relevant portions of the guide are automatically available in the Upgrade Opportunities section of the Asset Score Report when recommended upgrades have been identified.

GLOSSARY

Ballast Factor (BF) – a measure of the actual lumen output for a specific lamp-ballast system relative to the rated lumen output measured with a reference ballast under test conditions.

Ballast Efficacy Factor (BEF) – the ratio of the ballast factor (BF) to input watts; it measures the efficiency of the lamp/ballast system relative to other systems using the same type and number of lamps.

Coefficient of Performance (COP) – the ratio of the rate of heat removed to the rate of energy input, in consistent units, for a complete refrigerating system or some specific portion of that system under designated operating conditions.

Color Rendering Index (CRI) – a measure of how accurately an artificial light source displays colors. CRI is determined by comparing the appearance of a colored object under an artificial light source to its appearance under incandescent light. The higher the CRI, the better the artificial light source is at rendering colors accurately.

Energy Efficiency Ratio (EER) – the ratio of net cooling capacity in Btu/h to total rate of electric input in watts under designated operating conditions.

Mean lumens - the reduced lumen output that occurs at 40% of the lamp's rated life.

Solar Heat Gain Coefficient (SHGC) – the ratio of the solar heat gain entering the space through the fenestration area to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation, which is then reradiated, conducted, or convected into the space.

U-factor – the thermal transmittance per unit time per unit area of the whole window and the boundary air films, induced by unit temperature difference between the environments on each side. U-factor (or U-value) is the inverse of R-value. U-factors are given in units of Btu/ft2*°F*h

Visible Transmittance (VT) – the solar radiation transmitted through a fenestration weighted with respect to the photopic response of the human eye. It physically represents the perceived clearness of the fenestration.

ENVELOPE

Roof Insulation

The applicability of roof insulation upgrades depends on roof construction type and presence of existing insulation. Basic recommendations based on type of roof and ceiling construction are given below. Detailed recommendations on the quantity of insulation suggested for different building types and climate zones are available in the ASHRAE Advanced Energy Design Guides: http://energy.gov/eere/buildings/advanced-energy-design-guides.

Asset Score Report Recommendation: Add Roof Insulation

Cost: $ to $$ based on whether it is possible to add blow-in insulation or if re-roofing is required.

Roof type: Pitched Roof/Shingles/Shakes

Attic Ceiling: Based on your current insulation level and space availability, add sufficient insulation to obtain the minimum insulation level for your climate location. A higher insulation R-value improves the thermal performance of your roof, keeping the interior space cooler in summer and warmer in winter. In addition, adding higher insulation levels beyond the minimum codes requirements may increase the cost-effectiveness of the upgrade; however, there will be diminishing returns, and therefore cost should be weighed carefully against performance. If there is no existing insulation, consider a high insulation level such as R-30 or R-38. Roof insulation should extend to the exterior of the walls to minimize edge effects.

Suspended Ceiling: If there is a suspended ceiling, add insulation on top of the suspended ceiling. When suspended ceilings with removable ceiling tiles are used, the insulation performance is best when installed at the roof line.

Roof type: Flat, Built-up Roof

Add at least 1 inch (e.g., at least R-5 or R-10) of roof insulation and re-roof. A higher insulation R-value improves the thermal performance of your roof, but the cost-effectiveness of additional insulation should be evaluated. Insulation above the deck should be continuous rigid boards because no framing members are present that would introduce thermal bridges or short circuits to bypass the insulation. If two layers are used, the board edges should be staggered to reduce the potential for convection losses or thermal bridging. If an inverted or protected membrane roof system is used, at least one layer of insulation should be placed above the membrane and a maximum of one layer placed beneath the membrane.

Roof type: Metal Surfacing

Add insulation to interior surface, such as 2 to 4 inches of fiberglass or 1 to 2 inches of foam. Thermal blocks cannot be used when through-fastened in a roof that is screwed directly to the purlins because the blocks diminish the structural load-carrying capacity by “softening” the connection and restraint provided to the purlin by the roof.

For Climate Zones 1-3, recommended construction is a filled cavity with the first insulation layer perpendicular to and over the top of the purlins and the second layer of insulation parallel to and between the purlins.

For Climate Zones 4-7, recommended construction is a linear system with the first layer of insulation parallel to and between the purlins and the second layer of insulation perpendicular to and over the top of the purlins.

For Climate Zone 8, recommended construction is a linear system with the first and second layers of insulation parallel to and between the purlins and the third layer of insulation perpendicular to and over the top of the purlins.

Asset Score Report Recommendation: Implement a Cool Roof

Cost: $ to $$ based on the ease of adding an additional reflecting layer to the existing roof.

Cool roofs are constructed with a material that reflects sunlight and emits thermal energy. In effect, the roof is “cooler” than conventional roofs, which reduces the amount of heat transferred into the building. Reducing the amount of heat transfer will also reduce the amount of mechanical cooling required in the building. This measure involves replacing the existing roof membrane with a cool roof membrane.

Wall Insulation

Asset Score Report Recommendation: Add Wall Insulation

Cost: $$ to $$$ (based on the difficulty of adding insulation to the existing wall)

The type and amount of wall insulation needed to improve performance can depend on several factors, including wall construction material, presence of existing insulation, and available space. Several insulation options are available and should be matched to the conditions of the existing walls. For walls with open and accessible cavities, such as wood or steel frame walls, consider blown-in insulation material to fill the available cavities. Otherwise, various methods of adding interior surface insulation (for example, for masonry or metal panel walls) or even exterior surface insulation might be options.

Options for interior surface insulation include varying thickness of fiberglass, reflective bubble pack, or foam. The optimal amount of wall insulation (from a cost-effective perspective) is heavily influenced by building location (i.e., climate zone) and energy prices. When upgrading wall insulation, it is important to consider methods to reduce infiltration through the wall and around windows to maximize energy savings.

Floor Insulation

Asset Score Report Recommendation: Add Floor Insulation

Cost: $$

The type and amount of insulation needed to improve performance depends on the type of the existing floor. Several insulation options are available and should be matched to the conditions of the existing floors. For floors types that include a crawlspace, add insulation between the floor joists at the top of the crawlspace. It is recommended that you add enough insulation to obtain the minimum insulation level for your climate location, in some cases perhaps as much as R-30 or R-38.

For slab-on-grade floor types, it is recommended that you insulate the perimeter of the slab by adding rigid insulation (typically at least 1 or 2 inches, but sometimes more can be cost-effective). In the case of unheated basements, use continuous rigid insulation should be used around the perimeter of the slab and should extend down to the depth listed in the current code or to the bottom of the footing, whichever is less. For heated basements, continuous rigid insulation should be used around the perimeter of the slab and should extend down to the depth listed in the current code or to the frost line, whichever is deeper.

Windows

Asset Score Report Recommendations:

- **Install Double Pane Windows (Cost: $$)**
- **Install High Performance Double Pane Windows (Cost: $$)**
- **Install High Performance Triple Pane Windows (Cost: $$ - $$$, based on the type of frame)**
- **Add Retrofit Film (Cost: $)**

Window upgrades can include a variety of measures such as replacing single pane windows with double pane windows as well as replacing existing windows double pane windows with those with higher thermal performance, or adding shading, storm windows, or additional film to the glass to reduce heat gain due to solar radiation. Compared to regular double pane windows, high-performance double pane windows can incorporate combinations of low- emissivity film, higher performance frames, and gas fill.

For north- and south-facing windows, consider windows with low solar heat gain coefficient (SHGC) and an appropriate visible transmittance (VT). Certain window coatings, called selective low-e, transmit the visible portions of the solar spectrum selectively, rejecting the nonvisible infrared sections. These glass and coating selections can provide a balance between VT and solar heat gain. Higher SHGCs are allowed in colder regions, but installing continuous horizontal overhangs is still advantageous in that it blocks the high summer sun angles. Table 1 provides general guidelines for upgrading windows in different climate zones. Note that Table 1 only shows examples of combinations of glass, frame, and fill characteristics; other options are available and should be evaluated when considering a window upgrade.

For buildings with operable windows, the mechanical systems should use interlocks to ensure that the HVAC system shuts down in the affected zone while the windows are open. A high level of integration between envelope and HVAC system design helps to maximize energy efficiency.

Table 1: Examples of High Performance Windows by Most Applicable Climate Zone

Climate Zone	U-Factor	SHGC	VT	Glass and Coating	Gas-Fill	Spacer	Frame
1-3	0.46	0.23	0.51	Double clear, highly selective low-e coating	Air	Standard	Thermally broken aluminum
1-3	0.47	0.24	0.32	Double clear, low-e reflective coating	Air	Standard	Thermally broken aluminum
1-3	0.32	0.20	0.29	Double clear, low-e reflective coating	Air	Standard	Foam-filled vinyl or pultruded fiberglass
4-5	0.34	0.25	0.51	Double clear, highly selective low-e coating	Argon	Insulated	Thermally broken aluminum
4-5	0.35	0.22	0.32	Double clear, low-e reflective coating	Argon	Insulated	Thermally broken aluminum
4-5	0.32	0.20	0.29	Double clear, low-e reflective coating	Air	Standard	Foam-filled vinyl or pultruded fiberglass
6-7	0.31	0.39	0.50	Triple clear, low-e coating for outer light only	Argon	Insulated	Thermally broken aluminum
6-7	0.26	0.31	0.54	Double clear, low-e reflective coating	Argon	Insulated	Foam-filled vinyl or pultruded fiberglass
8	0.25	0.39	0.53	Triple clear, low-e coating for outer	Argon	Insulated	Aluminum thermally isolated frame
8	0.22	0.36	0.53	Triple clear, low-e coating for outer	Argon	Insulated	Foam-filled vinyl or pultruded fiberglass

Source: ASHRAE (2011), Advanced Energy Design Guide for Small to Medium Office Buildings, Page 121. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. https://www.ashrae.org/standards-research--technology/advanced-energy-design-guides

LIGHTING SYSTEMS

Lighting upgrade considerations should include existing lighting levels (e.g., daylighting, other lighting that will stay in place) plus the lamp wattage, light output, and ballast factor of the replacement lighting. When changing lamp types, it is important to choose the appropriate ballasts. One-for-one lamp replacement can cause areas to be over lit if higher output lamps are selected; in this event, consider delamping, removing unnecessary light bulbs or fixtures, or choosing a lower ballast factor while ensuring that light levels meet applicable standards for occupancy use.

Asset Score Report Recommendations:

Upgrade to Compact Fluorescent Lighting

Cost: $

Compact fluorescent lighting is often recommended as a replacement for incandescent lighting; a variety of sizes and lamp styles are available to fit many applications.

Upgrade to T5 Fluorescent Lighting

Cost: $

T5 and high output T5 fluorescent lighting can replace a variety of lighting types (e.g., incandescent, T12 fluorescent, high-pressure sodium, mercury vapor, and metal halide lighting) depending on application and fixture type. A 28W T5 lamp produces about the same light output as a 32W T8 when operated with a similar ballast type. T5 lamps appear brighter compared with T8 or T12 lamps with the same light output because T5 lamps produce same amount of light from a smaller area; therefore, T5 is more suitable for compact indirect fixtures. T5 lamps cannot be used in existing T8 and T12 fixtures because T5 lamps are a little shorter. All fluorescent lamps are temperature-sensitive and produce lower light levels in both exceedingly cold and hot environments.

Ballasts. When upgrading T5 fluorescent lamps, consider upgrading the ballast as well. The ballast factor (BF) is a measure that influences the relative light output of the fixture and should be selected in order to achieve the required light output at minimum power consumption. A BF of 1.0 would indicate that the ballast is driving the lamp to produce 100% of the rated lamp lumens. Light output and wattage are related—the lower the BF, the lower that wattage and the lower the light output. Normal BF ballasts range from 0.85 to 1.0, with many at 0.87 or 0.88. Low-BF ballasts, with BFs below 0.85, can be used to reduce the light output and wattage of the system when the layout of the fixtures will provide more light than is required for the space. High-BF ballasts, with BFs above 1.0, can increase the light output of the lamp in areas where the fixture layout would otherwise under-light the space—lighting energy use will go up proportionally to the BF.

Upgrade T8 Fluorescent Lighting or to High Efficacy T8 Fluorescent Lighting

Cost: $

T8 and high efficiency T8 fluorescent lighting can replace a variety of lighting types (e.g., T12 fluorescent, high- or low-pressure sodium, mercury vapor, and metal halide lighting) depending on application. Standard T8 lamps have a nominal power usage of 34W, whereas, high-efficacy T8 lamps use less than 34W. High-efficacy T8 lamps are defined as having a lamp efficacy of 90+ nominal lumens per watt, based on mean lumens[2] divided by the cataloged lamp input watts. High-performance T8 lamps are also defined as having a color rendering index (CRI) of 81 or higher and 94% lumen maintenance. The high-performance lamp is available in 32W paired with rapid start ballasts and in 30, 28, and 25W paired with instant start ballasts.

Replacing the ballast of an existing fluorescent lamp may improve lighting efficiency. Below are some specific types of ballasts that could be installed:

Instant start T8 ballasts provide light output at the lowest wattages, increasing energy savings and reducing costs. However, instant start ballasts may reduce lamp life when switched on and off frequently, such as when controlled by occupancy sensors or daylight switching systems. Yet, even if the rated lamp life is reduced by 25% because of the occupancy sensor, the socket life (the length of time before the lamps are replaced) will still be greater than a standard T8 lamp with a standard ballast. In applications where reduced socket life is a concern, consider program rapid start ballasts.

High-performance electronic program rapid start ballasts are defined, for the purpose of this guide, as having a ballast efficacy factor-prime (BEF-P) of 3.00 or greater. Ballast efficacy factor (BEF), sometimes called the ballast efficiency factor, is the ratio of ballast factor (as a percentage) to power (in watts). BEF is a relative measurement of the system efficacy to the fluorescent lamp-ballast combination.

While program rapid start ballasts are normally recommended on occupancy-sensor controlled lamps due to increased lamp life, program rapid start ballasts use approximately 5% more power than instant start ballasts. Using program rapid start ballasts will result in slightly higher power consumption with the same light level. For energy-saving T8 lamps, the BEF-P is 3.3 or greater for 30W systems, 3.6 or greater for 28W systems, and 3.9 or greater for 25W systems.

High-performance dimming ballasts are defined as having a BEF-P of 3.00 or greater. Dimming ballasts are commonly used where daylight controls are present to modulate lighting output based on available daylight.

[2] Mean lumens are published in lamp catalogs as the reduced lumen output that occurs at 40% of the lamp's rated life.

Upgrade to High-Pressure Sodium Lighting
Upgrade to Metal Halide Lighting
Cost: $

High-intensity discharge (HID) lamps, such as high-pressure sodium and metal halide lighting, have higher efficacy (lumen per watt) than fluorescent and incandescent lamps. High-pressure sodium (HPS) lighting has the highest efficacy level but low color quality (low CRI). HPS is suited for street and area lighting applications where high efficiency and long life are desired but color rendering is not critical. High efficiency options for these lighting types are available.

Upgrade to LED Lighting
Cost: $$

Light-emitting diode (LED) lamps continue to emerge and evolve as a promising energy-saving lighting option. More information on choosing appropriate LED lamps for your application is available from the DOE Commercially Available LED Product Evaluation and Reporting (CALiPER) Program at http://www1.eere.energy.gov/buildings/ssl/caliper.html.

LIGHTING CONTROL SYSTEMS

With proper controls, simply relying on natural light can decrease energy consumption by dimming or turning off lights that are not needed.

Asset Score Report Recommendations:

Add Daylighting Sensors for Perimeter Spaces

Cost: $$

Daylighting sensors reduce artificial lighting in response to the amount of daylight entering the building. There are different types of dimming controls: continuous and stepped. Dimming systems continuously adjust the light output by signaling dimming ballasts. ON/OFF switching turns lighting on or off respectively when the daylight contribution becomes sufficient or diminishes. Use of continuous dimming controls will maintain a more constant light level and reduce distraction of the occupants, when compared with simple on-off or bi-level switching controls. However, dimming ballasts are more expensive and less efficient than the most efficient non-dimming ballasts, using approximately 20% more energy than constant output ballast to produce equivalent light level.

Add Toplighting Controls

Cost: $$

Toplighting is an effective source of daylight recommended for use in occupied spaces that have no access to sidelight. Toplighting is best used in circulation areas and contiguous spaces that are used for reception areas or lobbies.

The design of such a daylight harvesting system should account for sensor location, sensor orientation, and number of sensors. During installation, the light sensitivity settings should be adjusted so that the desired lighting level is maintained in the space. Also, the system should be tested for proper functionality. Dimmable ballasts are typically also required as part of a daylighting strategy.

Install Occupancy Sensors for Interior Lighting Control

Cost $$

Occupancy or motion sensors are devices that turn lights and other equipment on or off in response to the presence (or absence) of people in a defined area. A complete sensor unit consists of a motion sensor, an electronic control unit, and a controllable switch/relay.

Source: http://www.doi.gov/greening/energy/occupancy-sensors.cfm

HVAC SYSTEMS

A variety of HVAC system upgrades can be considered, depending on the existing configuration. Both equipment replacements and add-on technologies can improve the efficiency of HVAC systems. Some equipment recommendations may suggest implementing the same type of equipment or technology. This implies installing a newer high efficiency version of the current technology. When a "High Efficiency" unit is not specified in an AS report, that unit may not be cost effective. However, it is recommended to consider installing the highest efficiency level when economically feasible.

Heating

Asset Score Report Recommendations:

- **Upgrade to High-Efficiency Natural Gas Furnace / Boiler**
- **Upgrade to New Conventional Natural Gas Furnace / Boiler**
- **Upgrade to High-Efficiency Fossil Fuel Furnace / Boiler**
- **Upgrade to New Conventional Fossil Fuel Furnace / Boiler**
- **Upgrade to New Electric Furnace**

Cost: $$$

When upgrading to new conventional fossil fuel or natural gas furnaces (in buildings with air-based heating systems) or boilers (in buildings with water-based heating systems), consider installing the highest efficiency level that is economically feasible. High-efficiency fossil fuel or natural gas furnaces and boilers refer to condensing type units. Table 2 displays the Federal Energy Management Program (FEMP) designated minimum efficiency requirements for commercial boilers.

Table 2: Examples of Minimum Thermal Efficiency (required for federal buildings) for Commercial Fossil Fuel Boilers (300,000-10,000,000 Btu/hour Rated Capacity.

Boiler Type (Fuel)	Thermal Efficiency
Hot Water, Condensing (Oil or Gas)	94% or greater
Hot Water, Non-Condensing (Oil)	85% or greater
Hot Water, Non-Condensing (Gas)	84% or greater
Steam (Oil)	83% or greater
Steam (Gas)	80% or greater

Source: Federal Energy Management Program (FEMP) (2014) Commercial Boilers. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. http://energy.gov/eere/femp/covered-product-category-commercial-boilers Accessed on June 1, 2015.

- **Upgrade to High-Efficiency Dual Fuel Heat Pump**
- **Upgrade to New Dual Fuel Heat Pump**
- **Upgrade to High-Efficiency Heat Pump or Upgrade to New Heat Pump**
- **Upgrade to New Packaged Terminal AC (PTAC) with Electric Resistance Heat**
- **Upgrade to High-Efficiency Packaged Terminal AC (PTAC) with Electric Resistance Heat**

Cost: $$ - $$$

The heat pump systems recommended by the energy asset scoring tool refer to air-source heat pump systems. Although geothermal heat pumps may provide energy savings, at this time, they cannot be modeled in the energy asset scoring tool.

The components can be assembled as a single package (such as a rooftop unit) or a split system that separates the evaporator and condenser/compressor sections. Single-packaged units are typically mounted on the roof or at grade level outdoors. Split systems generally have the indoor unit or units (including fan, filters, and coils) located in an unconditioned space and the condensing unit located outdoors on the roof or at grade level. The indoor unit may also be located outdoors with the conditioned air supplied to the space via ducts; if so, the unit should be mounted on the roof curb over the roof penetration for ductwork to avoid installing ductwork outside the building envelope.

In some situations (e.g., in Climate Zones 1 and 2), it may be more cost-effective to use electric resistance heat in lieu of a heating system that uses a central furnace or boiler. Table 3 provides a general guide for selecting heat pump systems.

Table 3: Heat Pump Selection Guide

Type	Size	Heating System	Cooling Efficiency Criteria[a]
Packaged	Less than 65,000 Btu/h	All	SEER[b] = 14.0 or greater EER[c] = 11.0 or greater HSPF[d] = 8.0 or greater
Split	Less than 65,000 Btu/h	All	EER = 11.3 or greater IEER[e] = 11.4 or greater COP[f] = 3.35 or greater
Packaged or split	65,000 Btu/h to 135,000 Btu/h	Electric resistance or none	SEER = 14.0 or greater IEER = 11.0 or greater COP = 8.2 or greater
Packaged or split	135,000 Btu/h to 240,000 Btu/h	Electric resistance or none	SEER = 10.9 or greater EER = 11.0 or greater HSPF = 3.25 or greater

a) For equipment with capacities less than 65,000 British thermal units per hour (Btu/h), performance is tested in accordance with Air Conditioning, Heating, and Refrigeration Institute (AHRI) 210/240-2008. Equipment with capacities of 65,000 Btu/h or greater are tested in accordance with AHRI 340/360-2007. All variable refrigerant flow (VRF) equipment is tested in accordance with AHRI 1230-2009.
b) SEER (Seasonal Energy Efficiency Ratio) is the total cooling output (in Btu) provided by the unit during its normal annual usage period for cooling divided by the total energy input (in watt-hours) during the same period.
c) EER (Energy Efficiency Ratio) is the cooling capacity (in Btu/h) of the unit divided by its electrical input (in watts) at the peak rating condition of 95°F.
d) HSPF (Heating Seasonal Performance Factor) is a measure of a heat pump's energy efficiency over one heating season. It represents the total Btu output (including supplementary electric heat) during the normal heating season as compared to the total electricity consumed (in watt-hours) during the same period.
e) IEER (Integrated Energy Efficiency Ratio) is a measure that expresses cooling part-load EER efficiency for commercial air-conditioning equipment based on weighted operation at various load capacities.
f) COP (Coefficient of Performance) is a measure of efficiency in the heating mode that represents the ratio of total heating capacity (Btu) to electrical input (also in Btu). The COP is rated at 47°F.

Source: Federal Energy Management Program (FEMP) (2011), Commercial Air-Source Heat Pumps. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. http://file.seekpart.com/keywordpdf/2011/5/21/20115213726370.pdf

Cooling

Asset Score Report Recommendations:

Chilled Water Systems

- **Upgrade to High-Efficiency Electric Chiller**
- **Upgrade to New Electric Chiller**

Cost: $$$

Chilled water systems are commonly installed in large buildings (more than 100,000 square feet) and consume a large amount of energy; therefore, efficiency improvements can produce significant savings. While such systems are complex and provide several upgrade opportunities, an integrated approach to upgrades is necessary to ensure that individual components are compatible with overall system efficiency improvements.

Recommendations include upgrading to a higher efficiency chiller of a different type (e.g., from a reciprocating type chiller to a screw or scroll type) or to a new chiller of the same type that improves performance compared to the existing chiller. Specific considerations will vary according to current system configuration, cooling load magnitude, full- vs. part-load operation needs, and potential staging requirements. Tables 4 and 5 provide general guidelines for selecting water and air-cooled chillers.

Table 4: General guide for selecting high-efficiency water-cooled chillers

Compressor Type	Capacity (tons)	Full-Load Optimized Applications (kW/ton) products must meet both levels		Part-Load Optimized Applications (kW/ton) products must meet both levels	
		Full-Load Efficiency	IPLV	Full-Load Efficiency	IPLV
Positive Displacement	< 75	≤ 0.75	≤ 0.63	≤ 0.80	≤ 0.60
	75 to 149	≤ 0.71	≤ 0.61	≤ 0.79	≤ 0.51
	150 to 299	≤ 0.68	≤ 0.58	≤ 0.72	≤ 0.50
	≥ 300	≤ 0.58	≤ 0.54	≤ 0.64	≤ 0.48
Centrifugal	< 150	≤ 0.62	≤ 0.60	≤ 0.64	≤ 0.36
	150 to 299	≤ 0.59			≤ 0.35
	300 to 599	≤ 0.56	≤ 0.55	≤ 0.60	≤ 0.36
	≥ 600	≤ 0.55	≤ 0.40	≤ 0.57	≤ 0.350

Source: Federal Energy Management Program (FEMP) (2014) Water-Cooled Electric Chillers. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. http://energy.gov/eere/femp/covered-product-category-water-cooled-electric-chillers Accessed on June 1, 2015.

Table 5: General guide for selecting high-efficiency air-cooled chillers

	Full-Load Optimized Applications products must meet both levels		Part-Load Optimized Applications products must meet both levels	
Chiller Capacity	Full Load Efficiency	IPLV	Full Load Efficiency	IPLV
< 150 tons	≤ 1.15 kW/ton (≥ 10.40 EER)	≤ 0.96 kW/ton (≥ 12.50 EER)	≤ 1.25 kW/ton (≥ 9.56 EER)	≤ 0.78 kW/ton (≥ 15.39 EER)
≥ 150 tons		≤ 0.94 kW/ton (≥ 12.75 EER)		≤ 0.80 kW/ton (≥ 15.07 EER)
You may choose to use either the cooling capacity (kW/ton) or the Energy Efficiency Ratio (EER; Btu/watt) to determine a product's compliance.[b]				

[a] Values are based on standard rating conditions as specified in Air-Conditioning, Heating, and Refrigeration Institute (AHRI) Standard 550/590. Only packaged chillers (i.e., none with remote condensers) are covered.

[b] Performance requirements are provided in both kilowatt (kW)/ton and energy efficiency ratio (EER or Btu/watt) units for convenience. When comparing air-cooled and water-cooled chillers, kW/ton is a common metric. When comparing only air-cooled chillers, EER (Btu/watt) is a common metric.

Source: Federal Energy Management Program (FEMP) (2014) Air-Cooled Electric Chillers. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. http://energy.gov/eere/femp/covered-product-category-air-cooled-electric-chillers Accessed on June 1, 2015.

Add Variable Frequency Drive (VFD) to Cooling Tower Fan
Cost: $$

Many older cooling towers use constant speed (on/off) or two-speed (high/low/off) fans that cycle to maintain the condenser water supply temperature setpoint. Adding VFDs to the cooling tower fans and varying fan speed to maintain the condenser water supply temperature setpoint saves energy with no associated pump penalty or sacrifice in performance.

Add Variable Frequency Drive to Condenser Pumps
Cost: $$

This measure applies to cooling plants that use water-cooled chillers and require pumping of water to the cooling towers. Many older cooling towers use constant speed (on/off) or two-speed (high/low/off) pumps; upgrading these to variable speed pumps will improve performance and reduce energy use at part load conditions.

Upgrade Cooling Plant Pumping System to Constant Primary - Variable Secondary Pumping System
Cost: $$

This measure applies to cooling plants that use chillers. Chilled water pumping systems generally fall into one of two categories: primary-only and primary-secondary. In primary-only systems, one set of pumps circulates chilled water between the chiller(s) and the air handler(s). These systems can be either constant flow or variable flow. In primary-secondary systems, the primary pumps circulate chilled water through the chiller(s), and the secondary pumps draw from that loop to circulate chilled water to the air handler(s). In general, primary-only variable flow systems use less energy than primary-only constant flow and primary-secondary systems, due to reduced pumping energy usage. However, they are usually more complicated to design and operate. They are generally better suited for larger facilities with multiple chillers.

Packaged Rooftop Systems with Direct-Expansion (DX) Cooling Coils

- **Upgrade to High-Efficiency Electric DX**
- **Upgrade to High-Efficiency Electric DX with Gas Heat**
- **Upgrade to New Electric DX**
- **Upgrade to New Electric DX with Gas Heat**

Cost: $$$

Packaged rooftop units are used to condition about half of all commercial buildings in the U.S. Often it is not possible to upgrade individual components within the unit, and it is more feasible to replace the entire unit. These units have become more efficient and replacing older units with the current state-of-the-art unit can provide significant savings. Additional information can be found in the Recommended Additional Reading section at the end of this document.

Terminal Units with DX Cooling Coils

- **Upgrade to High-Efficiency Terminal Electric DX**
- **Upgrade to New Terminal Electric DX**

Cost: $$$

Terminal units with DX cooling coils are an example of decentralized HVAC equipment. The energy efficiency ratio (EER) rating of terminal units with DX coils has improved, and upgrading to the current state-of-the-art equipment often yields energy savings.

General HVAC System Improvements

Asset Score Report Recommendation:

Upgrade Fan Motors and Install Variable Frequency Drive (VFD) or Multi-speed Control on Fans
Cost: $$

Based on ASHRAE 90.1 2010, Section 6.4.3.10, air-conditioning equipment with DX cooling greater than 110,000 Btu/hr should have supply fans controlled by two-speed motors or VFD. In addition to installing VFD or multi-speed control, it is recommended that fan motors be upgraded to premium efficiency models. Consider replacing existing VFDs with higher efficiency versions or install VFDs in fan motors without them.

Add Air-Side Economizer
Cost: $ - $$

An economizer helps to provide free cooling to a building by increasing the intake of outside air when conditions are amenable. The economizer may be operated based on either the dry bulb temperature or enthalpy of the outside air, and requires the appropriate sensors. In many locations, differential enthalpy control for the economizer is often preferred, particularly where it is more humid. Costs for adding hardware to support economizers will vary based on the existing system in the building.

Add Energy Recovery ventilation
Cost: $$

Energy recovery ventilators, which transfer energy between the outgoing exhaust/relief and incoming outside air streams, can help reduce energy usage. These systems are more cost-effective in extreme climates, with hot, humid summer and/or cold winters. Energy recovery systems are of two major types: those that recover only sensible energy and those that recover both sensible and latent energy.

Improve Performance of Existing System

Cost $ - $$

In addition to the upgrade recommendations provided, overall HVAC system performance may be improved by sealing heating and cooling ducts; adjusting blower components to provide proper system airflow; inspecting cleaning, or changing the air filter in the central air conditioner, furnace, and/or heat pump; ensuring that central air conditioner refrigerant charges meet manufacturer specifications. and by adjusting equipment controls to ensure peak performance.

BUILDING HVAC CONTROL SYSTEMS

Implementing control strategies and/or adding equipment controls may significantly improve the efficiency of the heating and cooling systems in a building.

Cooling

Asset Score Report Recommendations:
Implement Chilled Water Temperature Reset
Cost: $

Chillers are more efficient at higher leaving water temperatures; therefore, in general, optimum efficiency is achieved when the chilled water supply temperature (CHWST) setpoint is as high as possible to meet the load. While increasing the CHWST reduces chiller energy use, it will increase the flow rate and hence pump energy use in variable flow systems. However, the negative impact of increased pump energy use is much less than the positive energy savings due to chiller performance. ASHRAE 90.1 2010, Section 6.5.4.3, requires chilled water and hot water supply temperature to be reset based on building loads or by outside air temperature.

Heating/Cooling

Asset Score Report Recommendations:

Implement Demand Controlled Ventilation (DCV)
Cost: $$

HVAC control system hardware with the ability to implement demand controlled ventilation reduce energy use by reducing the quantity of outdoor air supplied to the space during periods of low occupancy (while still maintaining proper per-occupant outdoor ventilation).

Implement Fan Static Pressure Reset
Cost: $

For systems with direct digital controls of individual zone boxes reporting to the central control panel, the static pressure setpoint should be reset based on the zone requiring the most pressure (i.e., the setpoint is lowered until one zone damper (of many dampers) is nearly wide open). Adding hardware to implement this control algorithm will reduce fan energy use by preventing over-pressurization in the duct for the given demand conditions.

Implement Supply Air Temperature Reset
Cost: $

Multiple zone HVAC systems should include hardware to support controls that automatically reset the supply-air temperature in response to changes in building loads or outdoor air temperature. The controls should typically reset the supply air temperature by at least 25% of the difference between the design (or prescribed) supply-air temperature and the design room air temperature.

Lower VAV Box Minimum Flow Setpoints
Cost: $

With VAV systems, reducing the zone supply airflow during periods of low cooling and heating load will result in measurable energy savings at the central equipment. During periods of no heating and cooling, VAV boxes must still deliver air to the zones in order to provide ventilation air for the occupants. Often this minimum airflow rate is set higher than needed. Energy savings can be realized by lowering the minimum airflow rate to a level that still provides adequate ventilation air for the occupants, but will result in reduced fan and reheat energy used by the system.

OTHER BUILDING HVAC CONTROL SYSTEMS

The recommendations below are currently not included in the Asset Score Report but may improve your building's energy efficiency. Consult with an energy auditor or other professional to determine whether any of these options should be considered for your buildings.

Implement Optimal Start / Stop Strategy for HVAC Equipment (Building Operation)
Cost: $

To achieve the required temperature (setpoints) in a building, major air-conditioning systems are sometimes started unnecessarily early to condition the space before occupants arrive. An optimal start strategy can be implemented to start the heating and cooling equipment based on indoor and outdoor conditions. This typically saves energy and reduces wear and tear on equipment because the system will not have to start as early during mild weather conditions to pre-condition the space. Implementing an optimal start/stop program for major air-conditioning systems would provide savings opportunities by reducing large fan running time.

Install Occupancy Sensor and Implement Weekend & Holiday Scheduling
Cost: $

It is recommended that occupancy control hardware and software be added to air-conditioning units. The occupancy sensors will relay data to the terminal box controller, signaling unoccupied setback, and save energy when the building is not in use by setting back the temperature.

Implement Setpoint Scheduling / Setback (Building Operation)
Cost: $

Automatic low and high limits commonly maintain spaces no lower than 64^{o}F and no higher than 82^{o}F. Widening these set points will save more energy at night and on weekends, but may increase demand in the morning. Note that some buildings do not use setbacks; implementing a temperature setback program for these buildings will save energy during unoccupied times.

Implement Condenser Outdoor Air Temperature Water Reset Strategy and Optimization
Cost: $

If the building management system maintains a constant supply condenser water temperature regardless of outside air conditions and cooling demand, resetting the condenser water temperature based on outside air wet bulb temperature would provide an energy savings opportunity. Installing control hardware to implement a lower condenser water temperature with corresponding control of the chiller will reduce energy use.

Implement Chilled Water Differential Pressure Reset
Cost: $

Install hardware to implement a chilled water differential pressure setpoint reset strategy to control the primary chilled water pumps. Air handlers' chilled water valves are partly closed during operation at low and middle load ranges. If, instead of maintaining the constant differential pressure setpoint that was calculated to satisfy the maximum chilled water flow through the units, the controls reduce the differential pressure setpoint at the low/middle load range, less pumping energy would be required to provide the necessary chilled water flow through the units' chilled water coils.

Control Perimeter System Dispatch, Precool/Preheat Perimeter Zone (Building Operation)
Cost: $

Controlling systems serving perimeter zones to activate first to attempt to hold the core of the building at temperature thresholds will mitigate excessive heating or cooling loads on all systems.

Recover Heat from Dry Cooler
Cost: $$

Systems using DX cooling coils use dry coolers in the condensing portion of the refrigeration cycle. Heat rejected to the atmosphere from the dry cooler may be recovered through heat exchangers and used to preheat service hot water.

Implement Staged Cooling
Cost: $$$

Multi-stage direct expansion units provide two or more levels of cooling output. These units will reduce cooling energy during periods of low cooling demand by operating only a single stage instead of operating both stages and overcooling the air.

Install Dedicated Outdoor Air System
Cost: $$

A dedicated outdoor air system (DOAS) reduces energy use by decoupling the dehumidification and conditioning of ventilation air from sensible cooling (e.g. resulting from solar heat gain or electric equipment in the space) and heating in the zone. The outdoor air is conditioned by a separate DOAS that is designed to dehumidify the outdoor and to deliver it dry enough (i.e., with a low enough dew point) to offset space latent loads (resulting from moisture and humidity), thus providing space humidity control.

Implement Enthalpy Economizer Mode on Existing AHUs with Economizers (Based on Climate Zone)
Cost: $

Significant free cooling opportunities are missed for the mixed-air dry bulb temperature type economizer mode compared to the enthalpy-comparison type of the economizer mode. economizers with hardware to support enthalpy sensing consider both the temperature and the humidity of the air, enabling them to provide free cooling for more hours annually.

Add Waterside Economizer (Based on Climate Zone)
Cost: $$

This recommendation applies to large buildings that utilize a water-cooled chilled water system. A waterside economizer system can be added to this system to increase the cooling plant system efficiency. With this system, the chiller is turned off during cool outside air conditions and condenser water temperature is lowered enough to draw heat from the chilled water loop and maintain the required chilled water temperatures. Adding a waterside economizer system to an existing chilled water plant usually consists of adding a heat exchanger between the condenser water and chilled water loops, and revising the controls to enable the waterside economizer (bypass the chiller) when outside air temperatures are low enough.

Upgrade Constant Speed Chiller to Variable Speed Chiller
Cost: $

This measure applies to centrifugal chillers only. At low load, these chillers are less efficient than the full load efficiency and these chillers have limited turndown capability. Part-load efficiency and turndown can be improved, saving energy by converting the compressors from constant speed to variable speed through the addition of a VFD.

Add Night Cycling
Cost: $

Night cycling is used for cycling on an air system when one or more zones become too hot or too cold. The usual situation is that the central air handler is turned off at night. However if the building gets too cold there might be condensation on the walls and other damage. Thus the control system with the ability to support night cycling is usually programmed to turn the system on if 1 control thermostat or any thermostat shows a zone temperature of less than a night time set point. Similarly there might be a concern about a building getting too hot. Again the control system is programmed to turn the air handler back on if one or any zone temperature exceeds a night time cooling set point.

Control Outside Air Damper
Cost: $

A controllable outdoor air damper should be closed during unoccupied hours to minimize or eliminate outside ventilation air when outside air enthalpy[3] is greater than return air enthalpy. The total energy of the return air is less than the total energy of the outside air.

Replace Boilers and Change Heating Plant Pumping System with Variable Flow Primary
Cost: $$$

Most large office buildings, especially older facilities, use non-condensing boilers in a primary-only constant flow piping arrangement as their heating plant. Replacing the boilers with condensing boilers and converting the piping system to a variable flow primary system would reduce energy usage of the heating plant through increased boiler efficiency, reduced pumping energy due to VFDs installed on the pumps, and reduced heat loss through the secondary piping due to lower loop temperatures.

[3] The enthalpy of air includes the enthalpy of the dry air (i.e., sensible heat) and the enthalpy of the evaporated water (i.e. latent heat).

SERVICE HOT WATER SYSTEMS

Water heating systems should be sized to meet the anticipated peak hot-water load of the building. Some equipment recommendations may suggest implementing the same type of equipment; this implies installing a newer and more efficient version. Recommendations that suggest installing a new water heater imply replacing the existing water heater with one that has an efficiency level that is complaint with current code; whereas recommendations that suggest upgrading to a high-efficiency water heater imply replacing the current water heater with one that has an efficiency level that exceeds the current code.

Asset Score Report Recommendations:

- **Upgrade to High-Efficiency Fossil Fuel Service Hot Water Boiler**
- **Upgrade to New Fossil Fuel Service Hot Water Boiler**
- **Upgrade to High-Efficiency Natural Gas Service Hot Water Boiler**
- **Upgrade to New Natural Gas Service Hot Water Boiler**
- **Upgrade to New Electric Heat Pump Water Heater**
- **Upgrade to New Electric Water Heater**

Cost: $$

Distributed Water Heater Tank System

A distributed water heater tank system may be replaced with a higher efficiency unit, such as:

a) Electric resistance water heater
b) Electric heat pump water heater
c) Efficient gas water heater

Recirculating Hot Water Systems

The service hot water requirements for office buildings are typically very low and confined to restrooms, janitor closets, and break rooms. Long wait times for hot water delivery can cause difficulties, especially when the water heater is located far from the end use. The typical remedy for wait times is a pumped return to ensure immediate hot water delivery. Here, the pump return energy and heat loss through the piping may outweigh the actual energy consumed to produce the required hot water. Upgrading to a more efficient pump could be considered. In addition, under certain circumstances or applications, instantaneous water heaters and point-of-use systems may provide higher overall efficiency.

Evaluating Efficient Water Heating Options

Gas-Fired Water Heater

This type of water heater requires a vent to exhaust the combustion products. An electronic ignition is recommended to avoid the energy losses from a standing pilot.

Electric Resistance Storage Water Heater

Thermostats controlling the heating element may be an immersion or surface-mounted type. Where electric resistance heaters are used, consider point-of-use water heaters with few fixtures to eliminate the need for a recirculating loop.

Electric Resistance Instantaneous Point-of-Use Water Heater

This compact, under-cabinet or wall-mounted water heater has an insulated enclosure and minimal water storage capacity. A thermostat controls the heating element, which may be an immersion or surface-mounted type. Heaters should provide water at a constant temperature, regardless of input water temperature. Instantaneous water heaters are more efficient and point-of-use versions will minimize piping losses; however, instantaneous water hears can significantly affect peak electric demand and this should be taken into account during the evaluation. Where particularly high hot water loads (showers or laundry) are present during peak electrical use periods, electric storage water heaters are recommended over electric instantaneous types.

Electric Heat-Pump Water Heater

Both air-to-water and water-to-water heat pumps are available. A storage tank may be required depending on load needed (typically, offices do not have a large load and therefore would not need a water storage tank). To be cost-effective, a storage tank should be 90% efficient or higher and the heat pump should have a coefficient of performance of at least 3.0.

Solar Hot Water Systems

Solar hot water systems are most efficient when they collect heat at low temperatures. It is typically not economical to design solar systems to satisfy the full annual service water heating load. Consider sizing the system to meet the full load on the best solar day of the year. This will result in the system being able to furnish 50-80% of the annual load. In general, there should be 1-2 gallons of storage per square foot of collector. Glazed flat plate systems often cost $100-150 per square foot of collector. Optimal tilt for the collector is approximately equal to the latitude of the building's location.

Hot Water System Improvements

Asset Score Report Recommendation:

- **Improve performance of existing system**
- **Add low flow faucets**

Cost $$

System efficiency may be improved by insulating the existing storage tank (e.g., adding an insulation blanket) and pipes (e.g., for pipes with a diameter less than 1.5 in, insulate by 1 in.; otherwise, insulate by 1.5 in.), installing faucet aerators and flow-reducing shower heads (where applicable), and decreasing service hot water temperature where viable.

RECOMMENDED ADDITIONAL READING

- The *ASHRAE Advanced Energy Design Guides*
  http://energy.gov/eere/buildings/advanced-energy-design-guides
- The *ASHRAE Advanced Energy Retrofit Guides*
  http://energy.gov/eere/buildings/advanced-energy-retrofit-guides
- *ENERGY STAR® Building Upgrade Manual*
  http://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/save-energy/comprehensive-approach/energy-star