

Air-Cooled Chillers

In many types of smaller commercial and industrial buildings, air-cooled electric chillers offer an attractive alternative to the traditional cooling, direct-expansion, packaged rooftop units (RTUs). Like RTUs, electric chillers draw air across the condenser to remove heat. But instead of circulating air through the building, air-cooled chillers circulate cool water to air-handler chilled-water coils, and then supply fans draw air across the coils to deliver cool air through the building's ductwork.

Air-Cooled Chiller Characteristics

Because water has more thermal mass than air, the on-and-off cycling of the air-cooled chiller compressor doesn't cause as much fluctuation in the supply air temperature, providing occupants with a more comfortable environment. In addition, air-cooled chillers have a much greater "turndown" capability. That is, they are better able to match part-load cooling conditions than RTUs. These two factors enable air-cooled chillers to provide better humidity and temperature control, which translates into greater occupant comfort and better efficiency.

Chiller Terminology

Several terms are used to describe chiller performance and efficiency. Confusion can be minimized by first developing an understanding of the most common terms.



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Figure 1: 40-ton air-cooled chiller. Air-cooled chillers use fans to reject heat by drawing air across the condenser.

Tons. One ton of cooling is the amount of heat absorbed by one ton of ice melting in one day, which is equivalent to 12,000 Btus per hour, or 3.516 kilowatts (kW) (thermal).

Chiller performance is certified by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI), a manufacturer trade organization, according to its Standard 550/590: Performance Rating of Water-Chilling Packages Using the Vapor Compression Cycle. Two efficiency metrics are commonly used for air-cooled chillers: full-load efficiency and part-load efficiency.

Full-load efficiency. Indicating the efficiency of the chiller at peak load, full-load efficiency is the energy-efficiency ratio (EER) measured at standard AHRI conditions. This is the ratio of the cooling capacity to the total power input, expressed in Btus per hour-watt. A higher EER rating indicates higher efficiency.

Part-load efficiency. This metric indicates the efficiency of the chiller at part load, and is measured by either integrated part-load value (IPLV) or nonstandard part-load value (NPLV), depending on the particular AHRI part-load test conditions. Both give the efficiency of the chiller using a weighted average formula referencing four operating load points (100 percent, 75 percent, 50 percent, and 25 percent) and are expressed in Btus per hour-watt.

Efficiency Considerations

When selecting an air-cooled chiller, spending a little more for greater efficiency can really pay off as annual energy costs can be up to half of a chiller's purchase price. While there's some differentiation in full-load efficiency among available models, there are more-significant differences in the part-load performance as measured by the IPLV. Chillers that use variable-frequency drives (VFDs) stretch the IPLV range even further and can produce chiller energy savings of 15 to 25 percent compared to standard models. Using VFDs at a chiller plant can produce large savings where the cooling load varies significantly.

Air-Cooled Versus Water-Cooled Chillers

Air-cooled chillers are particularly well suited for facilities that have the following characteristics.

Smaller cooling loads. Due to the available product capacities, air-cooled chillers are typically used in applications that require 300 tons of cooling or less. However, many industry experts agree that with cooling loads as low as 200 to 250 tons, water-cooled chiller options should also be considered because they may provide a more cost-effective solution if other factors (such as those discussed below) don't rule them out.

Significant hours with high temperatures and humidity. Though water-cooled chillers can be more efficient in many climates, this advantage is significantly decreased where the temperature and humidity are frequently high. This may make it difficult to justify the expense of water and water treatment required for a water-cooled chiller.

Lack of trained maintenance staff. Water-cooled chillers require constant and careful maintenance of their cooling towers. Without an on-site staff or hired contractors trained to accomplish this task, the performance of the cooling system can be significantly compromised. It's much easier for facilities without trained staff or the funds to hire contractors to maintain the performance of an air-cooled chiller.

Smaller capital budgets. Air-cooled systems generally have a lower first cost than water-cooled systems.

Potential applications for air-cooled chillers include offices, schools, small malls, and medical centers.

What's Available?

Air-cooled chillers are factory assembled and available in sizes from 10 to 530 tons of cooling capacity. Multiple chillers can be used together to satisfy higher cooling requirements.

There are primarily two types of compressors available from the major manufacturers of new air-cooled chillers: scroll compressors and screw compressors. Which type to choose for a specific application is determined largely by the cooling capacity required and the trade-off between initial costs and operating costs. Scroll compressors tend to be used on smaller chillers, up to about 140 tons capacity. Screw compressors are available for chillers with capacities starting at about 80 tons up to the largest size available.

While still relatively rare, magnetic-bearing centrifugal compressors are beginning to be used in air-cooled chillers. Improved part-load performance and reduced maintenance requirements are among the benefits of this type of compressor.

Chiller Efficiency and Addendum

Minimum chiller efficiencies are dictated by local building codes rather than by U.S. federal standards as with other cooling equipment. Soon the Florida Building Code will incorporate the International Energy Conservation Code (IECC) of 2009, which references the minimum efficiency levels established by ASHRAE's Standard 90.1, the Energy Standard for Buildings Except Low-Rise Residential Buildings. In 2007 ASHRAE developed Addendum m to Standard 90.1, which increased the part-load efficiency requirements for air-cooled chillers, reflecting the availability of improved equipment. Full-load efficiency requirements remained the same. These changes, shown in Table 1, were rolled into the 2010 version of the standard.

Chiller capacity	ASHRAE 90.1 before 1/1/2010		ASHRAE 90.1 as of 1/1/2010		Best-available high efficiency		Best-available VFD	
	Full load (EER)	IPLV (EER)	Full load (EER)	IPLV (EER)	Full load (EER)	IPLV (EER)	Full load (EER)	IPLV (EER)
< 150 tons	9.562	10.416	9.562	12.500	10.900	16.000	NA	NA
≥ 150tons	9.562	10.416	9.562	12.750	11.600	15.400	11.600	19.800

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 Notes: Metrics for high-efficiency units are the best available without a VFD. EER=energy-efficiency ratio; IPLV=integrated part-load value; VFD=variable frequency drive; NA=not available

Table 1: Air-cooled chiller minimum and best-available EERs and IPLVs. There is a much bigger differentiation in IPLV than EER for available products.

As shown in Table 1, there is, at most, a 2-point difference in full-load efficiency, measured in EER, between the standard model required by ASHRAE 90.1 and the best-available models on the market across all sizes. In contrast, the difference between standard and best-available part-load efficiency, measured in IPLV, ranges from 3.7 points for high efficiency to 7.0 points for models with VFDs.

It's important to keep in mind that a chiller's EER efficiency rating is calculated when operating at one specific ambient air temperature, while a chiller's IPLV efficiency rating references four operating load points: 100 percent, 75 percent, 50 percent, and 25 percent. Given the complexity of chiller systems, it's therefore helpful to simulate the performance of the entire chiller plant and look at the full range of expected operating conditions. This calculation will consider the operating hours of a facility, the climate it's located in, and the use of VFDs or other product options. Design consultants and other professionals can model these factors as well as various operating strategies.

VFD Options

Some manufacturers offer VFDs for air-cooled screw chillers, but VFDs aren't available for scroll chillers. Most manufacturers, or their sales representatives, can also provide VFDs for chiller auxiliary equipment (pumps and air handlers) either as a standard part of a unit or as an option.

Condenser fans. Condenser fan energy use is factored into the chiller's EER and IPLV. Thus any efficiency improvement from a VFD that is included as part of a product's standard offering is already factored into the unit's efficiency metrics. VFD condenser fans also allow the chiller to operate at lower outdoor air temperatures. This is more likely to be helpful for cooling process loads.

Chilled-water pumps. These aren't made by the chiller manufacturers themselves, but can often be purchased through the same sales representatives offering chillers. Using a VFD on the chiller water pump could save 10 percent of pumping energy in constant-flow applications (water flow through the chiller is constant but is varied through the air handlers with bypass valves to match the load) and up to 50 percent in variable-flow applications.

VFD Applications

Applications where VFDs can be particularly cost-effective include those that have the following characteristics.

Low chiller load factors. In applications where chillers spend a lot of time at low loads, VFD units will save the most energy and have the best chance of a quick payback.

Long cooling hours. Facilities that log more annual cooling hours are able to recoup the cost of cooling system improvements more quickly than those with limited or seasonal operating hours, such as a K-12 school.

Presence of multiple chillers. Many facilities have two or more chillers that can be staged as load changes. This can create a good opportunity to install one or more VFD chillers to improve capacity control. Using a VFD on only one chiller allows you to more fully load the non-VFD chillers and use the VFD chiller to make up the difference in needed capacity. Using a VFD on all chillers in a plant allows you to balance run hours on all the equipment while still reaping the energy-efficiency benefits of VFDs.

Presence of a building automation system. While not as common in smaller versus larger buildings, if a building automation system is present, it can help building staff track whether any of the various operating strategies that can be used on a VFD plant are helping or hindering overall plant efficiency.

Economics

Air-cooled chiller costs vary by manufacturer, location, and technology options. A survey of the major manufacturers shows an average cost for the chiller itself of approximately \$350 to \$1,000 per ton, depending on capacity (see Table 2).

Installed costs are difficult to estimate as they vary according to a number of factors, including local labor rates, building details, and the type of chilled-water pumps used. However, air-cooled chiller installed costs are typically lower than water-cooled chiller installed costs.

In general, price per ton goes down as cooling capacity goes up, and price per ton goes up as efficiency goes up. Two manufacturers report that high-efficiency models tend to run 10 to 15 percent more, and adding a VFD to the chiller adds approximately \$50 per ton.

It's worth noting that while VFDs add significant capital cost to a chiller plant, installing a VFD chiller can allow you to reap capital cost savings in other ways:

- » **Install fewer chillers.** Because VFD chillers operate efficiently at low loads, it's often possible to install fewer, larger chillers that can be regulated to match loads. This also saves on costs for piping, pumps, controls, and real estate.
- » **Eliminate the pony chiller.** Many plants include a small "pony" chiller used to meet night or weekend loads. Because a VFD chiller can operate efficiently down to 10 percent of its full load capacity, there's less need for a pony chiller.
- » **Install a smaller emergency generator.** In critical facilities such as hospitals and data centers, where the emergency power generator is sized to keep the cooling system running through a power interruption, the soft-start capability of a VFD chiller can reduce the size and cost of the generator.

Tons	Dollars per ton
< 150 tons	\$400 – \$1,000
≥ 150 tons	\$350 – \$500

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Table 2: Average cost for air-cooled chillers. Price per ton increases significantly as tonnage decreases due to fixed costs in manufacturing.

