

Water-Cooled Chillers

In many types of larger commercial and industrial buildings, water-cooled electric chillers offer an attractive alternative to air-cooled electric chillers and packaged rooftop units (RTUs). As their name implies, water-cooled chillers use water to absorb heat from the chiller and disperse it through a cooling tower, as opposed to air-cooled chillers and RTUs, which disperse heat only by using air-cooled condensor coils.

Water-Cooled Chiller Characteristics

The use of the cooling tower gives water-cooled systems an efficiency edge over air-cooled systems and RTUs. In addition, unlike RTUs, which circulate cool air through ducts, all chillers circulate chilled water to air-handler units, where fans push air across heat exchanger coils to deliver cooling. Because they circulate water, which is more energy dense than air, water-cooled chillers can offer a more efficient and effective cooling option than RTUs.

Water-cooled chillers are most commonly used in buildings larger than 200,000 square feet, where the cooling load is large enough for increased efficiency gains to offset the higher equipment cost. However, they're also a viable choice in smaller buildings with more than two stories because they don't have to push air through ducts across multiple stories. Potential applications for water-cooled chillers include multistory structures, universities, large office buildings, and hospitals.



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Figure 1: 100-ton water-cooled chiller. Water-cooled chillers use cooling towers to reject heat through evaporation.

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.

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 water-cooled chillers: full-load efficiency and part-load efficiency.

Full-load efficiency. The efficiency of the chiller at peak load and at AHRI standard conditions is measured in kilowatts per ton (kW/ton). A lower kW/ton rating indicates higher efficiency.

Part-load efficiency. The efficiency of the chiller at part load 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 kW/ton.

What's Available?

Water-cooled chillers are available in a wide range of sizes—from 20 tons to several thousand tons of cooling capacity. New water-cooled chillers commonly use one of three types of compressors: centrifugal compressors, which are the most efficient, followed by screw compressors, and then scroll compressors. The centrifugal category includes magnetic-bearing compressors. These use magnetic fields to levitate the compressor shaft in midair, eliminating the need for traditional oil-lubricated bearings. They generate less noise and vibration than other compressors and offer significantly better part-load efficiencies in some applications.

How to choose. Which type of chiller to choose for a specific application is determined largely by the cooling capacity required and the trade-off between initial costs and operating costs. In general, for conditions that require less than 300 tons of cooling capacity, chillers with screw or scroll compressors are common. Screw chillers dominate the upper end of this capacity range, but magnetic-bearing compressors are gaining ground as they enable variable-frequency operation, which hasn't been a readily available option in the past in this size range. For requirements of more than 300 tons of cooling capacity, chillers with centrifugal compressors are typically used.

Specification considerations. Specifying an efficient water-cooled chiller system can be a challenging process. Many parameters affecting system efficiency and performance need to be considered, such as:

- » Chiller efficiency
- » Full-load versus part-load chiller operation
- » Variable-frequency drive (VFD) versus
- » Constant-speed compressors
- » Auxiliary component efficiency (pumps and fans)
- » Operating strategies
- » Interactions between components and operating strategies

Deciding which chiller is the best option for a building requires an in-depth analysis in order to maximize efficiency opportunities. This analysis is best conducted by design consultants and other professionals who can run computer simulations of the various equipment options, load factors, and operating strategies.

ASHRAE 90.1-2007 Addendum m

This addendum reflects continuing improvements in VFD technology, which has improved chiller part-load efficiencies and encourages the use of higher-efficiency equipment. This publication ushered in several changes to the chiller requirements in ASHRAE Standard 90.1, the Energy Standard for Buildings Except Low-Rise Residential Buildings.

The biggest change was to replace a single compliance path with two different paths. Path A affects applications that spend a significant amount of time at full load. Path B affects applications that spend a significant amount of time at part load. This specification encourages the use of chillers with better IPLVs in part-load applications and full-load efficiencies in full-load applications. For either path, minimum requirements for both full load and IPLV must still be met.

| | ASHRAE 90.1 before 1/1/2010 | | ASHRAE 90.1 as of 1/1/2010 | | | |
|-------------------------------|-----------------------------|---------------|----------------------------|---------------|--------------------|---------------|
| Water-cooled chiller | Full load (kW/ton) | IPLV (kW/ton) | Path A | | Path B | |
| | | | Full load (kW/ton) | IPLV (kW/ton) | Full load (kW/ton) | IPLV (kW/ton) |
| Positive displacement chiller | | | | | | |
| < 75 tons | 0.790 | 0.676 | 0.780 | 0.630 | 0.800 | 0.600 |
| ≥ 75 and < 150 tons | 0.790 | 0.676 | 0.775 | 0.615 | 0.790 | 0.586 |
| ≥ 150 and < 300 tons | 0.717 | 0.627 | 0.680 | 0.580 | 0.718 | 0.540 |
| ≥ 300 tons | 0.639 | 0.571 | 0.620 | 0.540 | 0.639 | 0.490 |
| Centrifugal chiller | | | | | | |
| < 150 tons | 0.703 | 0.669 | 0.634 | 0.596 | 0.639 | 0.450 |
| ≥ 150 and < 300 tons | 0.634 | 0.596 | 0.634 | 0.596 | 0.639 | 0.450 |
| ≥ 300 and < 600 tons | 0.576 | 0.549 | 0.576 | 0.549 | 0.600 | 0.400 |
| ≥ 600 tons | 0.576 | 0.549 | 0.570 | 0.539 | 0.590 | 0.400 |

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Notes: IPLV=integrated part-load value; kW/ton=kilowatt per ton

Table 1: Water-cooled chiller minimum efficiency requirements. The latest version of ASHRAE Standard 90.1 not only contains two compliance paths but also requires the use of more-efficient equipment.

Addendum m also instituted four other changes for water-cooled chillers:

- » It required the use of more-efficient equipment in most size categories.
- » It changed how efficiency is expressed, from coefficient of performance (COP) to kW/ton to reflect industry practice.
- » It created a new size category for centrifugal chillers at or over 600 tons.
- » It combined all positive displacement (reciprocating, screw, and scroll) chillers into one category.

All of these changes were rolled into the latest version of ASHRAE Standard 90.1-2010 and were adopted by the International Energy Conservation Code (IECC) of 2009. The new minimum efficiencies are shown in **Table 1**. Note that there are no U.S. federal minimum efficiency standards for chillers.

VFD Options

While many manufacturers offer chillers with a VFD option, only some offer the magnetic-bearing compressor technology. Scroll chillers aren't available with VFDs, though some manufacturers are now using digital scrolls, which perform better at part load than nondigital scrolls. VFDs can also be added to the chilled and condenser water pumps as well as the cooling tower fans.

Generally, as chillers spend most of their operating time at only 40 to 70 percent load, installing a VFD on the chiller and/or auxiliary equipment in hot, humid climates can produce energy savings. For example, ASHRAE computer simulations run during the development of Addendum m showed a 21 percent efficiency improvement in a large Miami office building cooled by a single 600-ton water-cooled centrifugal chiller with a VFD, compared to a constant-speed chiller. It's important to note that when there are multiple chillers, savings may be less with the amount of decrease depending on the control strategy employed. VFDs aren't recommended for chillers that operate predominantly at full load because they can decrease chiller full-load efficiency by up to 4 percent.

Before purchasing a VFD chiller or auxiliary equipment, it's a good idea to conduct an hourly simulation analysis to evaluate the opportunity for a given application.

Application considerations. The cost-effectiveness of a VFD for a water-cooled chiller is affected by several factors. Applications where VFDs are more likely to be cost-effective include those with the following characteristics:

- » **Low chiller load factors.** In applications where chillers spend a lot of time at low loads, VFDs 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 an ideal 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.** Because VFD chiller plants can be operated in different ways, a building automation system can help building staff determine whether operating practices are helping or hindering overall plant efficiency.

It's possible to retrofit a VFD on an existing water-cooled centrifugal chiller in the field. However, care must be taken to integrate the capacity and other controls correctly, and it's advisable to enlist the services of an experienced design professional to ensure success.

Economics

Water-cooled screw and scroll chiller costs vary by manufacturer, location, and technology options. A survey of the major manufacturers shows an average cost of approximately \$250 to \$350 per ton for the chiller itself, depending on capacity.

For centrifugal chillers over 400 tons, prices range from \$200 to \$500 per ton for the chiller itself; for centrifugal chillers less than 400 tons, prices range from \$250 to \$600 per ton for the chiller itself. A VFD can add from \$30 to \$80 per ton (see **Table 2**). The cost to retrofit a VFD on an existing centrifugal chiller would be the cost of the VFD plus approximately 30 percent.

Estimating general installed costs for a water-cooled centrifugal chiller is difficult because rules of thumb don't apply. Centrifugal chillers are sometimes referred to as "infinitely configurable" as they offer more options than other

chillers, and costs don't always follow linearly with size. They also use specialized motors and starters, the cost of which can often be more than the chiller itself. Without accounting for specific application details, you could estimate the total installed cost for a new chiller plant at \$1,500 to \$1,800 per ton, including the chiller.

Additional capital cost savings. 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.

| Chiller options | Dollars per ton |
|---|-----------------|
| Screw and scroll chillers | \$250 – \$350 |
| Centrifugal chillers < 400 tons | \$250 – \$600 |
| Centrifugal chillers > 400 tons | \$200 – \$500 |
| Adding a VFD to a new centrifugal chiller | \$30 – \$80 |

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Note: VFD=variable-frequency drive

Table 2: Average cost for water-cooled chillers. Chiller costs vary significantly, making a “back-of-the-envelope” estimation difficult.

