AIR-COOLED

A (Surprisingly) Cost-Effective Alternative to Water-Cooled Chiller Plants

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The air-cooled chiller is a cost-effective alternative to a water-cooled system, which is typically considered when energy efficiency is a secondary concern to first-cost investment. HTS Texas has discovered that recent technology innovations, combined with advances in manufacturing practices, have resulted in impressive improvements in air-cooled chiller performance, especially in efficiency, sound and footprint. These chillers now stand toe-to-toe with their water-cooled equivalent and provide many additional benefits. This technology has evolved somewhat unnoticed, in part due to the fast-paced innovations in water-cooled technology that now offer sophisticated features such as oil-less compressors with magnetic bearings.

The belief that air-cooled chillers are incapable of contributing to efficient building design and maximum energy savings persists despite technology advances. For historical reference, in 1998 air-cooled chillers had efficiency ratings of approximately 1.23kW/ton full load (9.76 EER) and 0.98 kW/ton (12.24 EER) part load -- a far cry from where efficiencies stand today. The air-cooled chiller's time is here and its biggest advantage no longer relies soley on contributing to the lowest installed first-cost.

What Has Changed?

Mono-rotor Screw Compressor Design

Enhanced component tolerances, less oil in circulation, the elimination of metal-to-metal sealing surfaces and balancing component radial forces contribute to a superior design that maximizes compression efficiency while reducing mechanical vibration and noise, leading to improved performance and reliability. Some advanced screw compressors use variable frequency drives and refrigerant economizers.

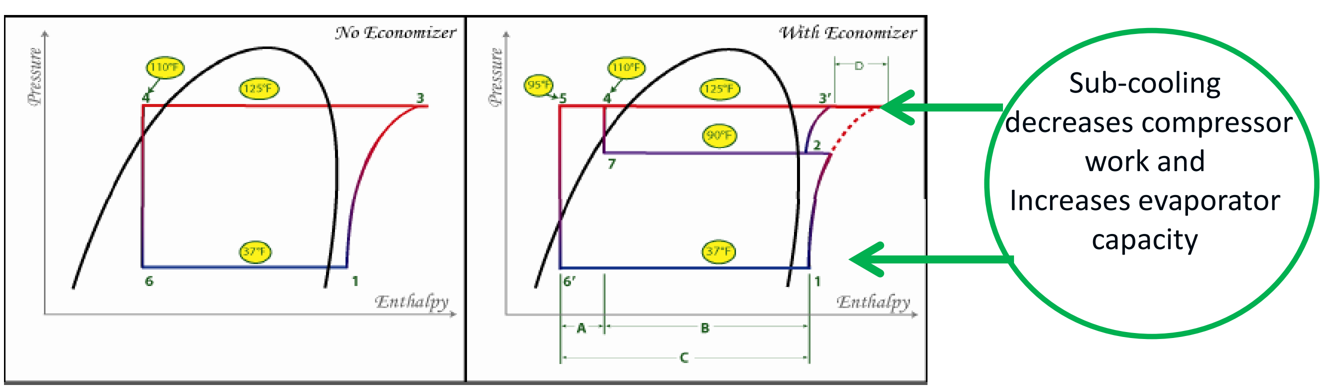
Factory-mounted Variable Frequency Drives

Variable frequency drives (VFDs) have long been credited with helping reduce the cost of operating both variable torque (dynamic) and constant torque (positive displacement) prime movers. With a chiller, VFDs help match the required refrigeration capacity to the compressor output, allowing reductions in motor speed that take advantage of an accompanying reduction in motor horsepower. One advantage of the screw compressor (positive displacement) is that it can deliver high torque (lift) at very low speeds, a factor that creates complications for centrifugal chillers (dynamic compression), resulting in instability or surge. This allows the screw chiller a wider operational window while avoiding surge, and the advantage of minimizing motor horsepower at low turndowns.

Factory-installed Refrigerant Economizer

Refrigerant economizers have been used on centrifugal chillers for many years and have recently become available on some screw chillers. Through the addition of a brazed plate heat exchanger and Thermostatic Expansion Valve (TXV) on each refrigerant circuit, the refrigerant is both sub cooled for additional capacity and diverted to the interstage of the screw compressor for increased efficiency. The increase in refrigeration capacity has led to the development of large-tonnage chillers with remarkably small footprints.

Without Economizer With Economizer



The Air-Cooled Advantage

Many small- to medium-sized chiller plants already use air-cooled chillers in nominal capacities ranging from 150 to 550 tons. Air-cooled screw chillers offer very good performance, particularly at partial load. These compressors are typically modulating (slide valve or VFDs) rather than stepped which produces more accurate control. Advantages of air-cooled chillers include:

- ✓ Positive displacement compression, no surge
- ✓ Avoids cooling towers
- ✓ Avoids city water costs
- ✓ Avoids water waste (improves environmental sustainability)
- ✓ Avoids chemical costs (improves environmental sustainability)
- ✓ In a natural disaster there are no water issues
- ✓ Avoids condenser pumps & piping
- ✓ Avoids high maintenance costs
- ✓ Saves mechanical room space
- ✓ Easier to control (no tower bypass) and operate (no tower freezing) in cold climates
- ✓ Excellent choice for applications where maintenance may be lacking

Modern premium air-cooled chillers excel in efficiency. The table below compares two air-cooled units, one based on 1998 efficiency levels and the other is one of today's most efficient models. Modern air-cooled chillers can perform at full load efficiencies up to 17 percent higher and part load efficiencies up to 37 percent greater than those models available only a few years ago.

Chillers	Full Load	NPLV
1998	9.75EER 1.23kW/Ton	12.24EER 0.98kW/Ton
Today	11.8EER 1.01kW/Ton	19.4EER 0.61kW/Ton

Applying Dollars and Sense

How does a premium air-cooled chiller really stack up against its present day water-cooled rival? What follows is a simple comparison of four chillers including one premium high-efficiency air-cooled screw chiller and three water-cooled centrifugal chillers. The air-cooled chiller was selected at its highest efficiency point, in part because the premium model available from the manufacturer came standard, fully equipped. All water-cooled centrifugal chillers were selected based on the capability of the software to select and rate the unit that contributes to the best life-cycle value, making it the most attractive to own.

A high-level, simplified comparison can help determine the available chiller alternatives that can be further explored using site-specific metrics and validation processes.

Each chiller analyzed was selected for a job HTS Texas worked on and required a full load capacity of 385 tons, its performance based on standard AHRI conditions. The kW/ton values were calculated by the software and applied to the formula 0.01A + 0.42B + 0.45C + 0.12D (typical of AHRI part load methodology) to derive chiller-only electrical consumption. An allowance of 0.08kW/ton (full load, 0.01A) and 0.06kW/ton (part load, all other points) was then added to each water-cooled chiller to account for the additional cooling tower fan and pump energy required. The assumption was that the tower fans would run at 50 percent speed and the condenser pumps at 100 percent flow during part load operation. Energy cost is based on $0.08/kWh, typical of the utility rate structure in Houston. The tables below illustrate the overall energy costs for each chiller. The results provide a comparison between models showing how they would perform under assigned operational conditions.

Premium Efficiency Variable-Speed Air-Cooled Screw Chiller

Full Load Tons	Applied Value	Operational Cost
385	0.632	$102,485

Constant-Speed Water-Cooled Centrifugal Chiller

Full Load Tons	Applied Value	Operational Cost
385	0.587	$89,659

Variable-Speed Water-Cooled Centrifugal Chiller

Full Load Tons	Applied Value	Operational Cost
385	0.480	$75,934

Variable-Speed "Magnetic Bearing" Water-Cooled Centrifugal Chiller

Full Load Tons	Applied Value	Operational Cost
385	0.405	$66,683

The air-cooled chiller had the highest chiller-only operational cost, while costs attributed to each water-cooled chiller dropped as efficiency improved. An owner could maximize operational cost savings by purchasing the water-cooled, magnetic bearing chiller. This finding prompted HTS Texas to explore whether the air-cooled chiller has become a viable efficiency alternative.

The Next Step

The next step was to factor in the cooling tower water and water treatment costs associated with each water-cooled chiller. Shown below are the most recent City of Houston commercial water rates, with volume water and sewer charges (per 1000 gallons).

Commercial – TU 21-60:

Consumption is no longer included with the basic charge. The volume charges are applied to all usage.

Rate	Meter Size (Inches)	Basic Water Charge	Basic Sewer Charge
Basic Charge (0 consumption)	5/8	$ 4.74	$8.34
	3/4	$ 4.89	$8.34
	1	$ 5.88	$8.76
	1.5	$ 8.90	$10.16
	2	$10.48	$10.58
	3	$27.74	$18.96
	4	$37.82	$21.48
	6	$64.82	$30.70
	8	$169.25	$74.56
	10	$169.25	$90.63
Volume Charge	All	+ $3.74 per 1,000 gallons	+ $5.30 per 1,000 gallons

A comparison of water rates in Houston and other major U.S. cities proved to be challenging because of differences in municipal water rate structures due to various peak, off-peak, service, commodity, and block consumption charges. However, one major Pacific Northwest city published rates between $4.50 - $6.03/1000 gallons and another large Midwestern city showed a simple rate structure of $3.50/1000 gallons (sewer charges not included). While these cities were comparable, it is important to determine the actual water rate structure specific to the location of any project.

A recent report in *USA Today* showed users pay 75 percent more for water today than in 2000. The report predicted water rates will increase by a whopping 5 percent to 15 percent per year, outpaced only by heating oil. The City of Houston water rates are shown above, with a volume charge of $3.74 per 1,000 gallons for commercial users. Unless the customer is separately metering the tower make-up water to account for waste, volume sewer charges (additional $5.30/1000 gallons) also may apply. In Houston a separate water meter must be purchased from the utility company and that cost is not included in this analysis. Of course, water must be accounted for when calculating the total cost of operating water-cooled equipment and will become increasingly important in future.

In an effort to determine how much water the cooling tower would consume and what the cost impact would be, a number of variables were considered: the ambient wet bulb temperature, tower loading, tower turn down, chiller/tower control strategy, the type of chemical treatment used, the cycles of concentration allowed, and the type of tower installed. Shown below is our estimated tower water consumption for the water-cooled chillers considered in this article. HTS Texas considers consumption to be waste based on evaporation, drift and blow-down which are all lost to the surrounding atmosphere. Using City of Houston rates, our water consumption would then result in a cost of $19,097 per year.

Total make-up water includes:

- Evaporation
- Drift
- Blow down…….**0.0145/gpm** (1)

385 Tons X 3 gpm/ton = 1155 gpm X .0145 = **16.75gpm**

GPM	% Load	% Run Time	Gal/Yr
16.75	100	1	88,038
16.75	75	42	2,773,197
16.75	50	45	1,980,855
16.75	25	12	264,114
		Gal/Yr	**5,106,204**

Tower Water Consumption

Other cost considerations are maintenance, not included in this analysis, and the cost of chemicals or water treatment. A nominal cost of $3.00 per 1,000 gallons for water treatment was added based on input from facility managers in the Texas Medical Center who maintain large central chilled water plants. Note that costs associated with water treatment may vary considerably based on the specific technology applied. When water and chemical costs are combined, the total reaches $34,409 per year. Water costs can now be added to the chiller-only electrical costs (for each water-cooled chiller) and a more realistic evaluation can be made. The table below ranks each chiller based on total annual operational cost, including electricity and water. The water-cooled magnetic bearing centrifugal chiller still proves to be the most advantageous (op-cost), but the premium air-cooled chiller follows closely behind, decisively outperforming the other two water-cooled options.

Chiller Type	Applied kW/ton	Energy Cost $/yr	Water & Chemicals	Op-Cost $/yr
#2 Premium Air-Cooled	0.632	$102,485	$0	**$102,485**
#4 CS Centrifugal	0.587	$89,659	$34,409	**$124,068**
#3 VFD Centrifugal	0.480	$75,934	$34,409	**$110,343**
#1 Mag-Bearing Centrifugal	0.405	$66,683	$34,409	**$101,092**

The Total Value Story

Sometimes a client's purchasing decision is based solely on energy savings and sometimes the decision is based on first-cost alone. In reality a choice must be made that includes both first-cost and operational cost so a value-based purchase can be made.

The pricing shown below helps establish the first cost of each chiller system. It is for the equipment only (chiller included) with contractor mark-up added (installation and labor not included). A cooling tower is added to each water cooled chiller because it is required. Tower pricing includes a single condenser pump, condenser piping, water treatment equipment and additional controls. The tower was valued at $92,400 ($240/ton). Additional refrigerant monitoring and mechanical room ventilation also would be required for the indoor chiller, although this is not included.

Chiller	Equipment "First-Cost"
Premium Air-Cooled Chiller	#1 $227,487 ($591/ton)
Traditional CS Cent. Chiller + Tower	#2 $266,542 ($692/ton)
Traditional VFD Cent. Chiller + Tower	#3 $292,320 ($759/ton)
Magnetic Bearing Cent. Chiller + Tower	#4 $336,574 ($874/ton)

The life cycle cost (LCC) for a project or a piece of equipment is its total cost to purchase and operate over its entire service life. This cost should include purchase, operation - including energy cost, maintenance and disposal. (2) While this article does not go into the depth necessary to include all aspects of a true LCC study, it helps establish insight into the cost of ownership for each alternative to determine which offers the best value.

Note: the financial impact due to installation labor and materials, maintenance and disposal, tax implications, as well as savings based on unneeded mechanical room space are not included. Although important, this is left for the reader to assign value based on personal experience.

Chiller	Equipment $	15-Year Op-Cost	Additional Cost of Ownership
#1 Premium Air-Cooled Chiller	$227,487	$1,772,316	**BASE**
#4 Traditional CS Centrifugal Chiller	$266,542	$2,412,102	**+$678,841**
#3 Traditional VFD Centrifugal Chiller	$292,320	$2,200,528	**+$493,045**
#2 Magnetic Bearing Chiller	$336,547	$1,748,226	**+$84,970**

It is not necessary that the life cycle study period be identical to the equipment's service life and in this case a 15-year time frame was deemed suitable (3). Resulting life-cycle operational costs include a two percent per year escalation added to utility rates. The table above includes both equipment first costs and operational costs for each chiller and reveals that the air-cooled option is capable of delivering the lowest combination.

When each chiller was evaluated in this manner it became easier to assign value to the total cost of ownership. The table above ranks each chiller within three key cost categories. It is interesting to note that had any of the water-cooled chillers been judged solely on their chiller-only energy costs (water not included and first cost ignored) each may have been considered superior to the air-cooled unit in contributing more overall value to the owner. When broader views of cost are measured it is demonstrated that the premium air-cooled chiller provides an impressive impact on the owner's bottom line, in this case outperforming other prospects.

While this is not a complex study into the overall life-cycle operation of any of the chillers, it provides new information in the process to qualify the true benefits of air-cooled chillers. The table below ranks and compares each chiller based on its ability to perform in the categories of op-cost, first cost and cost of ownership. Where once the air-cooled chiller was considered a low-cost alternative in favor of a more efficient design, it has proven itself to be a surprisingly cost effective contender in the overall value proposition.

Item	Op-Cost	First-Cost	Cost to Own
Premium Air-Cooled Chiller	#2	#1	#1
Traditional CS Centrifugal Chiller	#4	#2	#4
Traditional VFD Centrifugal Chiller	#3	#3	#3
Magnetic Bearing Chiller	#1	#4	#2

References:

(1) HVAC Water Chillers & Cooling Towers: Fundamentals, Application & Operation, Herbert W. Stanford, Stanford White Associates, Consulting Engineers.
(2) Guide to Energy Management, Capehart,Turner and Kennedy.

(3) It is the author's view that emerging technology may render major HVAC equipment purchases made today obsolete and in need of replacement long before its normal service life is over.

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