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Total Cost of Ownership For Air-Cooled and Water-Cooled Chiller Systems

By **Ramez Naguib, P.E.**, Member ASHRAE

This article explores using total cost of ownership (see box, facing page) in comparing air-cooled and water-cooled chilled water systems in the range of 100 to 500 tons (352 to 1,758 kW) across different U.S. climate zones. This article's goal is not to provide a definitive rule for when an air-cooled or a water-cooled chiller system should be used. Instead, it discusses the process for making sound investment decisions by going beyond the simple comparison of annual energy usage for the different air-conditioning systems and technologies to exploring the wider scope when including initial and maintenance costs as well.

Energy Cost

To attempt to capture the overall economy of one system versus the other, we selected six different metropolitan cities from across the United States: Miami, Houston, Los Angeles, New York, Chicago, and Minneapolis. Each

city was selected to represent one of the first six climatic zones as outlined by the U.S. Department of Energy (DOE) and as included in ANSI/ASHRAE/IESNA Standard 90.1-2007, *Energy Standard for Buildings Except Low-Rise Residential Buildings*. Zones 7 and 8 were not

included in this analysis because their extremely cold climate characteristics are not the main focus of this study.

About 600 energy simulations were run. For each of the selected cities, a typical office building was simulated using the DOE-2.2 energy simulation engine. The simulations ranged from 100 ton up to 500 ton (352 kW to 1758 kW) capacities. The 500 ton (1758 kW) upper limit was selected as it reflects the prevailing upper limit for air-cooled chiller systems in the typical North American market.

For each capacity, two types of systems were examined: an air-cooled chiller system using screw compressors and a water-cooled chiller system with centrifugal compressors and open cooling

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towers. As a reference, the coefficients of performance (COP) used in the different simulations were based on the minimum requirements as per Standard 90.1-2007 and ARI 550/590-2003, *Performance Rating of Water Chilling Packages Using the Vapor Compression Cycle*.

The energy simulations for the water-cooled chiller systems assumed a condenser-water temperature relief control scheme with two-speed tower fans that enable the condenser-water temperature to float with the load and wet-bulb temperature. Both systems had the same air-side arrangement of VAV with reheat.

Annual energy use for the different systems in each city were computed, and the annual electric utility costs were calculated based on the 2007 through 2008 averaged rates per city as reported by the *U.S. Energy Information Administration (EIA)*.

Table 1 outlines the parameters used in the energy simulation model highlighting the different setpoints used.

Installed Cost

After estimating the energy costs, the next step was to compute the installed costs for the different systems, technologies, locations, and capacities.

To obtain an apples-to-apples comparison, we based our costs on modular chilled-water systems. This enabled us to precisely cost the systems and include all applicable costs involved in the air-cooled or water-cooled chiller setups. It also enabled accurate estimation of installation costs for the different capacity ranges.

Maintenance Cost

After calculating the energy cost and the installed cost the next step in the calculation was the actual maintenance costs for the systems, capacities, and locations for the six cities.

To accurately capture all costs involved, from the maintenance technicians to the water treatment costs and associated insurance premiums, we based our numbers on actual maintenance contract costs for the different systems, cities, and capacities. These contracts included the yearly charges for labor including the impact of local unions where applicable, insurance premiums, material costs, water-treatment costs for the cooling towers, etc., for the 100 to 500 ton (3512 kW to 1758 kW) capacity ranges, and cities.

Adding Up

After we had the three cost components (running energy cost, installed equipment cost, and ongoing maintenance cost), the final step was to compute the overall TCO for the combinations.

We used the most relevant financial comparison tool: the net present value (NPV) for the costs.² The NPV computations

were based on an estimated useful service life of 20 years and no salvage value. The average 2008 interest rates were used.

Figures 1 through 6 illustrate the consolidated results for the six selected cities in this study.

Looking Beyond the Obvious

Based on the previous analysis, the total cost of ownership of an air-cooled chiller system is consistently lower than that of an equivalent water-cooled chiller system in the 100 tons to 500 tons (3512 kW to 1758 kW) range. However, the gap closes as we go to the higher end of this range, especially for warmer climates. The reason is that energy cost becomes the dominant contributor versus initial cost.

A generalized insight that can be drawn from this conclusion is that while energy conservation is of paramount importance, other factors weigh heavily in system selection. Factors that should be considered include local variables such as water availability, sewage disposal policies, risks associated with a *Legionella* outbreak (and the consequent system insurance premiums or potential for litigations when using water-cooled systems), ongoing local labor rates, union presence and its effect on labor rates, and insurance premiums. These factors affect the designer's choice of which air-conditioning system concept to specify. The labor cost is a case in point.

Maintenance labor cost is important in deciding whether to use an air-cooled or water-cooled chiller system early in the design phase of the project. According to statistics published by the U.S. Department of Labor, the hourly rate for a

Level 9 mechanical technician has increased from \$22.58 in 1997 to \$29.94 in 2005. That is a 32.6% increase over eight years. In the same period, the published statistics from the DOE indicated that the average retail price of electricity to ultimate customers in the commercial sector went from \$0.0759 cents/kWh in 1997 to \$0.0867/kWh in 2005, which is an increase of 14.2% (less than half the labor rate increase during the same period). Labor cost may be more of a deciding factor than energy cost in some cases.

A recent report from the International Facility Management Association that surveyed 1,032 facility professionals across North America showed that the costs of running a facility have increased by 19% since 2006 even though the average energy consumption has decreased.³ A certain design may prove more energy efficient when comparing the annual energy consumption of the equipment, but this same system may be commanding much higher consumption rates when incorporating the annualized fringe costs of installing and maintaining the system.

The main takeaway here is that focusing only on one factor

Total Cost of Ownership

Bloomsbury Business and Management Dictionary defines total cost of ownership as:

A structured approach to calculating the costs associated with buying and using a product or service. Total cost of ownership takes the purchase cost of an item into account but also considers related costs such as ordering, delivery, subsequent usage and maintenance, supplier costs, and after-delivery costs. Originally designed as a process for measuring IT expense after implementation, total cost of ownership considers only financial expenses and excludes any cost-benefit analysis.¹

Item	Values Used
Locations	ASHRAE Standard 90.1-2007 Climate Zones
Application	Typical Office Building Structure, A/C Loads and Schedules
Cooling Capacities	100 to 500 ton (~352 to 1758 kW)
Air-Side Configuration	Standard VAV With Hot Water Reheat
Cooling Thermostat Setpoints	Occupied 76°F (~24.4°C); Unoccupied 82°F (~27.8°C)
Cooling Design Temperatures	Indoor 75°F (~23.9°C); Supply 55°F (~12.8°C)
Minimum VAV Airflows	Core 40%; Perimeter 30%
Economizer	Dry-Bulb Temperature Economizer; 65°F (~18.3°C) High Limit
Air-Cooled Chillers	Packaged Air-Cooled Screw Chiller ASHRAE Standard 90.1-2007/ARI 550/590 Minimum COP Values 44°F (~6.7°C) Fixed Setpoint
Water-Cooled Chillers	Electrical Water-Cooled Centrifugal Chiller ASHRAE Standard 90.1-2007/ARI 550/590 Minimum COP Values Condenser-Water Temperature Relief Control With 2-Speed Cooling Tower Fans
Energy Simulations	DOE-2.2 Calculation Core Engine
Energy Costs	Averaged Local Utility Rates in the Selected Cities
Capital Costs	Modular Central Plants Packaged Systems (Incorporating All Equipment, Piping, Controls, Assembly and Installation Costs)
Maintenance Costs	Total Water-Side System Maintenance Contract Values (Incorporating All Labor and Materials/Chemical Costs in the Different Locations)
Life-Cycle Analysis	Based on 20-Year Life Expectancy
Financial Model	Based on NPV With Average 2008 Market Interest Rate

Table 1: The model at a glance.

(annual energy consumption) doesn't ensure the system will be economically and environmentally optimized. A more holistic view must be adopted that takes other factors into consideration. Besides, a green building is only as green as it is suitable for ongoing operations and maintenance.⁴

More Work Needed

This article is simply a primer for further scrutiny and analysis. Here are some more ideas for further studies and analysis:

The current analysis only focused on a typical office building profile. More work must be done to get more insight on other types of buildings: health-care and assisted living facilities, data centers, K-12 schools, retail applications, hospitality, etc.*

Water-cooled chillers typically have longer life expectancy than air-cooled chillers. However, the life expectancy of a cooling tower is typically shorter compared to a chiller. Future studies should try to simulate such scenarios to provide more accurate conclusions when account-

* For health-care facilities, a safe hypothesis is that simulation results may be favorable to water-cooled machines for facilities that operate 24/7 (hospitals), because there are so many more operating hours per year for the improved efficiency of water-cooled equipment to recoup the first cost investment.

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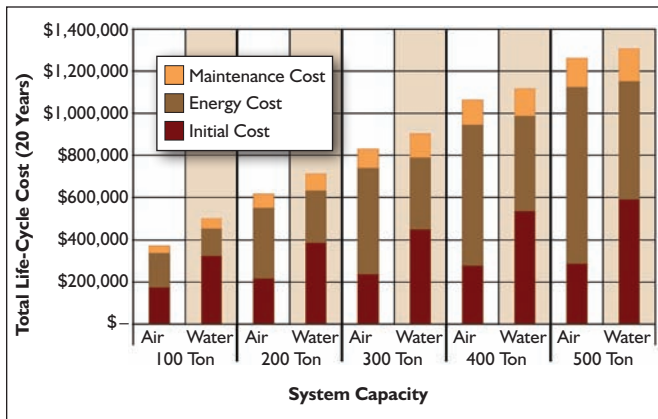


Figure 1: Miami (Standard 90.1-2007 Climate Zone 1).

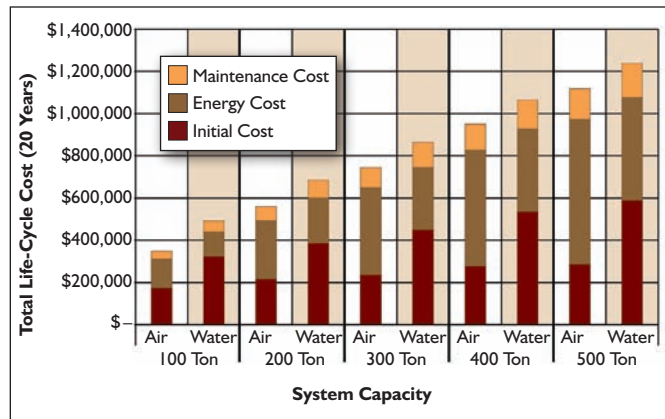


Figure 2: Houston (Standard 90.1-2007 Climate Zone 2).

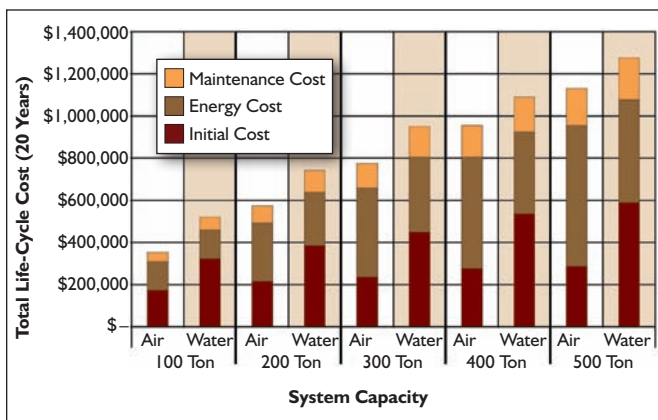


Figure 3: Los Angeles (Standard 90.1-2007 Climate Zone 3).

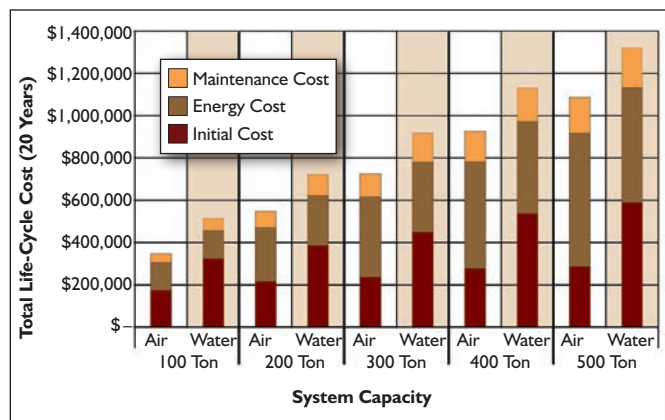


Figure 4: New York (Standard 90.1-2007 Climate Zone 4).

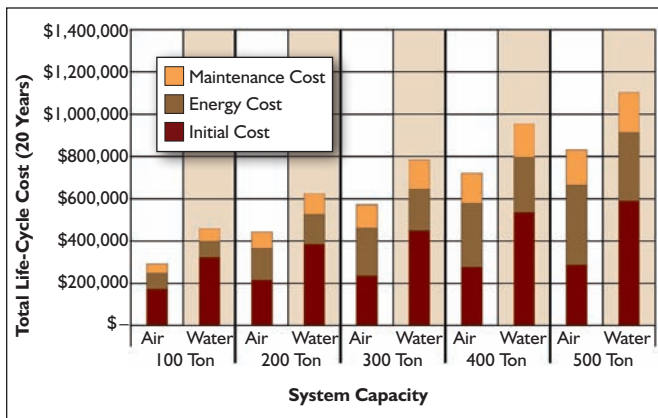


Figure 5: Chicago (Standard 90.1-2007 Climate Zone 5).

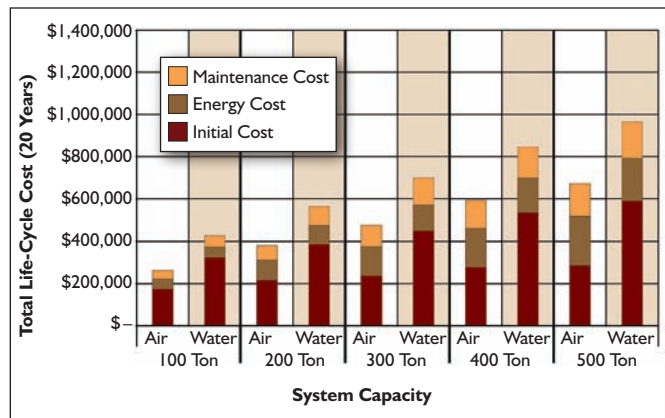


Figure 6: Minneapolis (Standard 90.1-2007 Climate Zone 6).

ing for the replacement costs of the different components. A good reference to build on here is Chapter 36, especially Table 4, of the 2007 ASHRAE Handbook—HVAC Applications.

Mostly humid cities were selected in the six main climate zones in this study. How much of the chiller market do these cities represent? Zone 3 Humid rather than Zone 3 Dry may have captured more of the chiller market, for instance. And, Zone 3 Humid is experiencing one of the most acute water shortages in the United States. An expanded analysis differentiating between humid and dry climates must still be undertaken.

For redundancy, a sizable portion of the chilled water systems below 500 tons (1758 kW) are multiple chiller installations, so future research should consider this in the analysis.

The current simulations went up to 500 tons (1758 kW) only as mentioned previously. Centrifugal chillers become less expensive per ton in larger sizes. It might be interesting to see what the simulations would predict at, say, 800 tons (2814 kW) since larger sizes may make water-cooled more attractive.

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What happens when we already have a water-cooled chiller plant, and we want to add another machine? Would the economics turn out the same as outlined in this article?

Here we considered one control scheme, but other control schemes should be examined. For example, since water-cooled chillers rely on the wet-bulb temperature, they tend to have lower condensing pressures (since the wet-bulb temperature is always lower than the dry-bulb temperature), so the compressor must do less work in the refrigeration cycle resulting in less energy use. However, this efficiency advantage quickly erodes at part-load conditions since the dry-bulb temperature (used by air-cooled chillers) will typically have a larger swing than the wet-bulb temperature. So an air-cooled system will get more “bang-for-the-buck” from a condenser relief setup. Will this be the case with other control schemes?⁵ This topic needs further investigation.

Averaged city-level utility rates were used here as an acceptable representation. However, not every kWh costs the same, and air-cooled efficiency improves more than water-cooled efficiency at night. Demand charges are typically set during the day, or a pull-down cycle. It is prudent when evaluating actual projects to compare energy costs while taking demand changes into consideration.

Beyond the COP

In conclusion, the chilled water system designer is encouraged to look beyond the COP, integrated part-load value

(IPLV), or nonstandard part-load value (NPLV) numbers to a broader view encompassing the system in its entirety: its cost effectiveness, safety and security, sustainability, accessibility, functionality, productivity, historical preservation, and aesthetics.⁶

A final word is that the designer must ensure that while designing any system the actual end use of the system is not forgotten. A designer should not optimize energy or the overall life-cycle cost of the system at the expense of occupant comfort.⁷

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