# Mission Critical Cooling

## Sensitivity Factors in Choosing Between Air- or Water-Cooled Chillers

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For a designer or facility owner, chiller selection is based on standard local practices, past experience, resource availability and legislative guidelines. However, deciding between air- or water-cooled chillers for a critical facility such as a data center, hospital or manufacturing facility having 24/7 operation depends on many factors that can impact the cost of ownership and swing the decision.

To understand the sensitivity of different parameters—such as capital cost, power cost, water cost, weather and load profile—consider the model of a typical 1,200 ton plant for a data center application operating 24/7 in four cities, representing different weather profiles:[1]

- Beijing (mixed and dry, ASHRAE Climate Zone 4);
- Singapore (hot and humid, ASHRAE Climate Zone 1);
- Dubai (hot and humid, ASHRAE Climate Zone 1); and
- San Francisco (warm and dry, ASHRAE Climate Zone 3).

For each plant location, we compared high-efficiency air-cooled screw and water-cooled centrifugal chillers, both with variable speed drives.

### Modeled Chiller Configurations

The centrifugal chiller comparison evaluates both oil-based bearings and high-efficiency magnetic bearing designs. Mission critical applications vary from small capacity (100 ton [352 kW]) to large capacity (over 2,000 ton) plants in which decision making is clearer at both ends of the spectrum. However, there is a gray zone in the mid-capacity plant from 500 to 1,500 tons (1759 to 5276 kW). Consequently, this discussion is based on a 1,200 ton (4220 kW) plant, focusing on the factors that swing the decision towards an air- or a water-cooled chiller in mid-capacity applications.

The model chillers are sized for a building load of 1,200 tons supplied by two 600-ton (2110 kW) water-cooled centrifugal chillers or three 400-ton (1407 kW) air-cooled screw chillers, all with variable-speed drives, a 60°F (16°C) design leaving chilled water temperature (without reset) and a typical 7°F (4°C) cooling tower approach temperature. (Cooling tower approach does not apply to air-cooled chillers.) Design ambient and wet-bulb temperatures for each city are represented in *Table 1*. Considering this is a mission critical application, one standby chiller of same capacity for N+1 configuration is included.

### Modeled Load Profiles

Two load profiles are considered in the comparison:[2]

1. Heavy Load Profile: Load variation between 100% to 80%, assuming a consistent high internal load application, such as a data center.
2. Medium Load Profile: Load variation between 100%

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TABLE 1 Design ambient condition.

| AMBIENT | DUBAI | SINGAPORE | BEIJING | SAN FRANCISCO |
|---|---|---|---|---|
| DESIGN DBT (°F) | 115 | 95 | 105 | 95 |
| DESIGN WBT (°F) | 86 | 83 | 78 | 68 |

TABLE 2 Utility rate for power and potable water.

| UTILITY | DUBAI | SINGAPORE | BEIJING | SAN FRANCISCO |
|---|---|---|---|---|
| ELECTRICITY RATE U.S. $/KW | 0.06 | 0.16 | 0.13 | 0.10 |
| WATER RATE U.S. $/GALLON | 0.01 | 0.006 | 0.002 | 0.01 |

to 50%, for manufacturing and health-care facilities.

To arrive at an annual load requirement, the ASHRAE Modified Bin Method is used for each city, giving total annual ton-hours and system part load value (SPLV).[3] SPLV is the annual average input kilowatt per ton (IkW/ton) for the plant including chillers, chilled water pumps, condenser water pumps and cooling towers. These figures are used to compare the annual energy cost for each city for both load profiles. Water consumption for the centrifugal chillers is based on 2.0 gallons/ton-hour (2.2 L/kW), which includes evaporation loss, drift loss of 0.005 and cooling tower bleed-off to as per four cycles of concentration (CoC).[4] The actual makeup water requirement varies between 1.7 gallons to 2.1 gallons/ton-hour (1.83 to 2.26 L/kW) based on chiller load, efficiency, CoC and ambient conditions. A 2.0 gallons/ton-hour (2.2 L/kW) is an ideal average considering heavy load profile.

Power and potable water costs for each city are represented in *Table 2* (sourced from utility company websites in respective cities).[5–8] *Table 2* shows a substantial difference between both power and potable water costs in each city, which reflects a large difference on the annual operating cost of chiller.

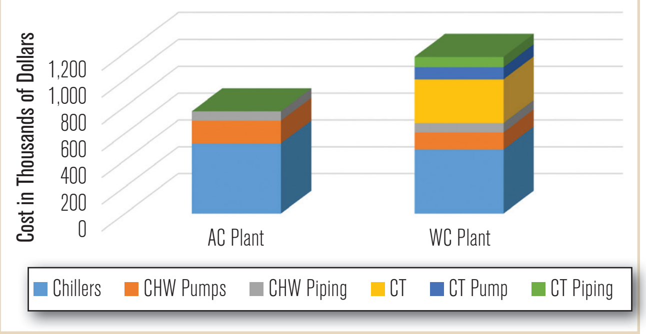
## Deciding Factors

With that model in mind, we posited initial capital costs, annual operating costs, and a combination of both, along with the total cost of ownership (TCO), all of which are typical deciding factors in equipment selection. Sensitivity to these factors influences different decisions based on capital or financing available to the building owner. Of course, many technical, commercial, compliance and site-specific factors can also influence the choice by eliminating either option as a non-starter. These factors are also discussed.

### First Cost (Capital Cost)

For a critical data center application with a 1,200 ton plant and N+1 configuration of chillers and pumps, the cost of water-cooled chillers is modeled as 10% lower than with air-cooled chillers. However, when including

FIGURE 1 Equipment cost for air-cooled (AC) and water-cooled (WC) chiller plant.




the ancillary labor associated with a water-cooled chiller plant (condenser water pumps, piping, valves and cooling tower), the air-cooled chiller plant cost is 35% lower for that plant design (*Figure 1*). Capital and labor cost considered for the comparison is using values for San Francisco. The absolute value may vary for other cities, but the costs are relative. This difference may vary based on size, design, location, material and labor cost. However, for a 1,200 ton (4220 kW) plant, an air-cooled chiller plant will have lower first cost than a water-cooled plant, although electrical system costs may have an impact.

### Load and Energy Consumption

Building annual load (ton hours) is calculated based on the ASHRAE Modified Bin Method using weather data for each of selected city. SPLV is calculated for two load profiles. For simplicity, the relationship between ambient and load is considered to be linear. The calculated annual ton-hours and SPLV (IkW/ton including chillers, primary pump, condenser water pump and cooling tower) are represented in *Figures 2* and *3*.

This calculation accounts for the cooling design power, pump peak power and heat rejection peak fan power, which include the design mechanical load component used in the proposed revision to ASHRAE Standard 90.4.[9] Air handler unit fan design power is a constant in all configurations.

Annual ton hours in both heavy and medium load profiles vary due to percent variation in load, but the

FIGURE 2 Ton-hours and plant SPLV with heavy load profile.

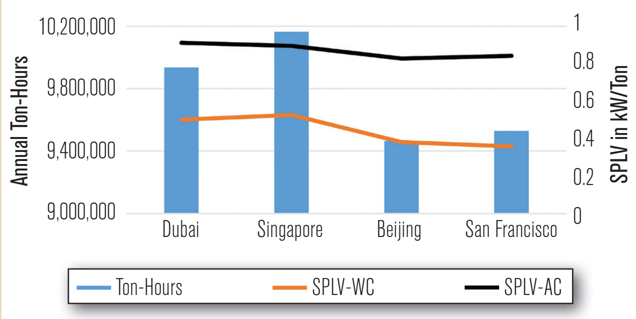
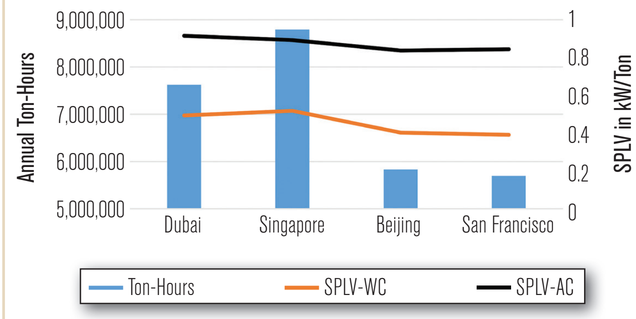



FIGURE 3 Ton-hours and plant SPLV with medium load profile.




plant energy efficiency SPLV curves of both air-cooled and water-cooled plants are similar. Gaps between air-cooled and water-cooled plant SPLV for all cities have a difference from 40% (Singapore) to 60% (San Francisco) with the water-cooled chiller being more energy efficient in all cases. Operating cost can further be reduced in some cities, such as Beijing, with the use of an economizer for both air-cooled and water-cooled chillers. However, the efficiency differential between the two systems will be similar.

### Operating Costs (Energy and Water)

This comparison accounts only for operating power, not the cost of power and water consumption nor for water-cost variations in different cities. By including the water utility cost, we arrive at the total operating cost.

The difference between air-cooled and water-cooled is about 10% to 15% for cities like Beijing, Singapore and San Francisco. For Dubai, which has a very low cost of power and high cost of water, the air-cooled chiller (AC)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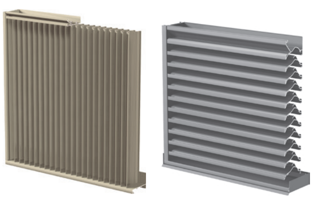

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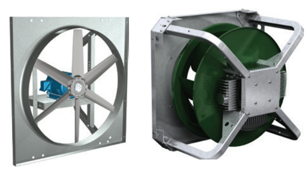

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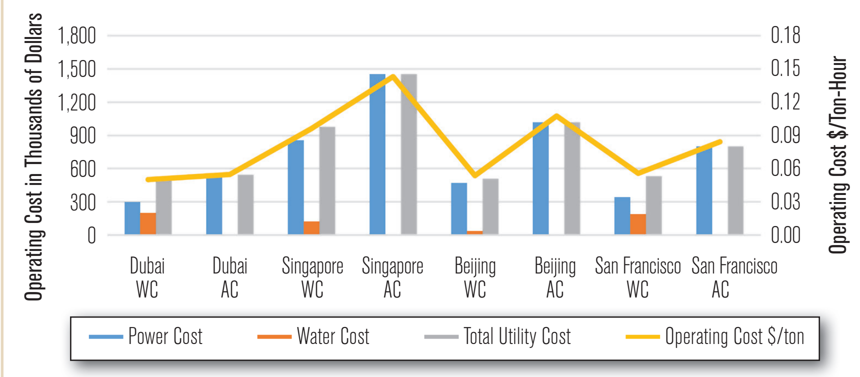
For the heavy load profile in Dubai, the trend is very similar. The dollar amount is based on the current cost of electricity and water (*Figure 5*). However, if resources costs go up due to an increase in utility rates, the comparison will change accordingly.

FIGURE 4 Operating cost, power and water—heavy load profile.




## Total Cost of Ownership (TCO)

When deciding between equipment types, it is valuable to compare the TCO for a plant using a detailed analysis based on operating cost, which includes both energy and water costs for the facility.

For all cities except Dubai, the operational cost savings produced a payback in one year for Singapore, 1.3 years for Beijing, and 2.8 years for San Francisco, regardless of the higher capital cost of water-cooled chillers used in those locations. This payback was reduced by half for a heavy load profile due to more ton hours than with the SPLV for a medium load profile. A comparison of capital costs and multiyear operational costs are included in *Figure 6*. This figure is based on a medium load profile, but the metrics for a heavy load profile are similar.

For Dubai (ASHRAE Climate Zone 1), the operating cost savings for a water-cooled chiller plant are marginal, so the payback period is 17 years. This case is unique, because, compared to all other cities, the cost of electricity is lower and the cost of water is high (*Figure 2*). Consequently, when the high capital cost of a water-cooled chiller plant is factored in, the operational savings are insufficient to shorten the payback period.



## Factors Outside the Chiller Itself

**Water Source:** Although centrifugal chillers may have lower operating costs, potable water for cooling towers may be scarce. In such cases, other sources like sea, lake, river or pond water, or even treated sewage effluent may be used. However, these sources may require more expensive construction materials, corrosion protection, etc., which result in lower heat exchanger efficiency. This will offset some of the energy efficiency benefits of the water-cooled centrifugal chiller system. A detailed study is needed to consider local water quality and materials requirement. The higher cost of water treatment and corrosion protection could favor an air-cooled chiller system, as in the Dubai example above.

**Sewage Water Cost:** Many of the city municipalities charge for sewage disposal, which may need to be accounted for considering the bleed off from the cooling tower based on the cycle of concentration with a consequent impact the payback period for water-cooled chillers.

**Site Limitation:** Due to depleting water resources in many parts of the world, water availability may be a challenge in the near future or be uncertain over the long term. Stakeholders that face this issue may consider a hybrid system. Hybrid systems combine air-cooled and water-cooled chillers in different ratios of 30/70 or 40/60 or 50/50 based on the load profile, storage capacity and critical base demand, etc. The hybrid approach can mitigate future risks and optimize present resources. Desert and hilly regions are particularly challenged, but so are major cities that are unable to meet the potable water demands and are subject to strict guidelines and regulations. Receding ground water level can cause municipal authorities to stop ground water drilling for commercial use. Under such uncertainties, building a mission critical facility with a water-cooled chiller is unrealistic.

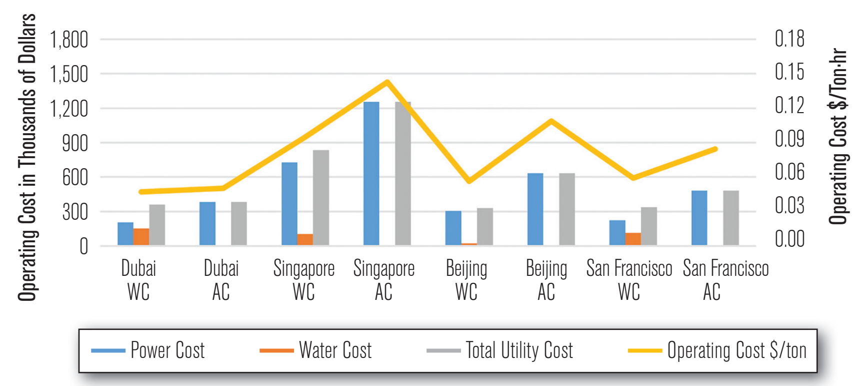
**Repair and Maintenance Costs:** Repair and maintenance factors are difficult to assess. These costs depend on a complex subset of variables, including the quality of air and water, size and complexity of plant design, quality and make of equipment, location and distance from nearest service center, and labor cost per hour for skilled manpower in a particular city. The easiest assessment is based on an inventory of the number and types of equipment that will require maintenance. Although repair and maintenance costs are more subjective than factors with an immediate cost, they should be considered based on the experience of the designer/user. Also, new chiller technologies can be factored in that use magnetic-bearing centrifugal compressors, which can reduce maintenance costs and increase chiller life. For ease of comparison, equal maintenance costs are assumed in the model.

**Demand Load and Electrical System:** Demand or connected load charges are normally higher for air-cooled chiller plants due to higher design peak kW load requirements. These costs can be considered while performing an energy cost comparison. Electrical equipment and system costs are based on total connected load, which is higher in an air-cooled plant and may impact overall budget of a building's utilities. This cost impact has not been considered in the capital cost comparison above. With a higher connected load requirements for an air-cooled chiller and a higher associated electrical system cost, overall capital cost of both systems may be very close.

**Space and Building Construction:** Space availability and cost is a major concern for builders in large cities, where real estate costs can be as high as $4,000 per square foot ($43,000 per square meter). Water-cooled chillers are normally housed in an enclosed space within the building or a separate building nearby. This lost space is an opportunity loss for the builder who could otherwise sell or rent out the floor area. In contrast, air-cooled chillers are normally kept on the roof of the building, not occupying valuable saleable space.

Where space cost is not at a premium, space cost is not a factor. Building construction cost may be relatively small, or go substantially higher if local codes require extra load bearing capacity for an air-cooled chiller or a seismic design requirement of the site. In this regard, an air-cooled chiller has an advantage, because it can be kept on the roof without any change in roof construction

FIGURE 5 Operating cost, power and water—medium load profile.

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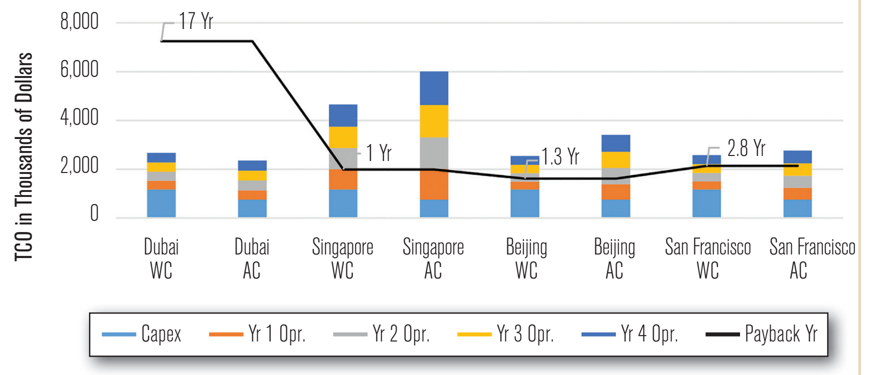
cost. However, if a water-cooled chiller must be kept on the roof for floor space, not only the load bearing capacity of the roof should be increased due to concentrated load, the equipment must also be modified to withstand ambient conditions outdoors.

FIGURE 6 TCO and payback period with medium load profile.




### Factors that Result in a Simple Go/No-Go Decision

**Local Guidelines and Legislation:** As previously mentioned, some cities have regulations that constrain chiller choices, making the default chiller selection obvious. Such regulations may concern:

**Scarcity of Water:** Water as a resource is scarce and will become more scarce in the future considering the growing population of cities and receding ground water levels. As a result, some city municipalities (for example, Mumbai) do not allow water usage for commercial buildings.

**Legionnaires' Disease:** In many European cities, the use of cooling towers is prohibited due to the threat of Legionnaires' disease from cooling towers. Or expensive water treatment for cooling towers may be required. In these cases, commercial building owners will select air-cooled chillers.

**Green Building Requirement:** An owner looking for green building certification may not be able to get the desired energy points or meet the base energy level requirement with air-cooled chillers. In fact, the base case for obtaining the highest energy efficiency level is a water-cooled centrifugal chiller over 400 tons. This fact may encourage the owner to look at alternative water sources or expensive sewage water management system to meet the LEED guidelines and energy level requirements.[10] (From the perspective of overall sustainability, each additional kWh consumed also uses water at the power-generation plant). From an environmental perspective, overall $CO_2$ emissions should be considered based on $CO_2$ generation at the power plant level. Emissions would be higher with air-cooled chillers considering their higher electricity consumption.

**Sound Emission:** Many cities have local guidelines/legislation that limit the sound pressure level at the boundary of the buildings. These regulations can have a significant impact on both air-cooled chiller performance and capital cost due to additional acoustic enclosures to reduce transmitted noise.

## Conclusion

Each mission critical site and application is unique and warrants a detailed analysis of factors to make the best chiller selection. But the variables influencing mid-capacity mission critical applications can be modeled to simplify air-cooled screw or water-cooled centrifugal variable-speed chiller selections. After determining the capital expenditure and annual energy and water cost for a particular facility, the total cost of ownership can be evaluated based on the particular financial model being used by the owner. Whether using a non-performing asset (NPA), simple payback, internal rate of return (IRR), opportunity cost of capital, or some other budgeting method, the total cost of ownership determined by the model can be used to reach a sound decision about selecting air-cooled or water-cooled chillers for the application.

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