

Energy use and power requirements for mechanical cooling equipment can be reduced, especially in hot weather and peak times, by using ‘water-cooled’ heat rejection equipment rather than ‘air-cooled’. Electric cost reductions are good, especially where demand charges apply, but there are tradeoffs to consider. This paper will note the tradeoffs to help decide which path is best for you (air-cooled or water-cooled)

This paper discusses the water and electricity tradeoff decision related to mechanical cooling equipment, such as air conditioning, refrigeration, and process cooling.

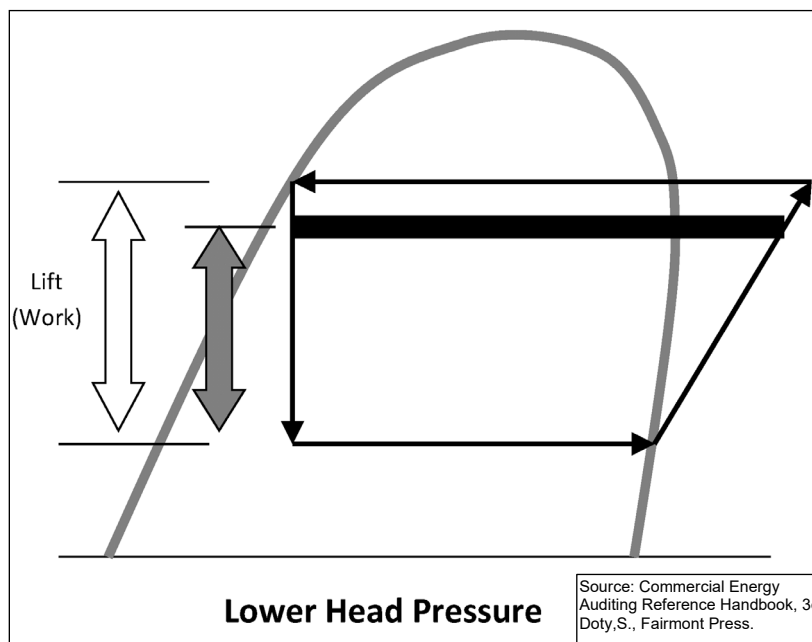
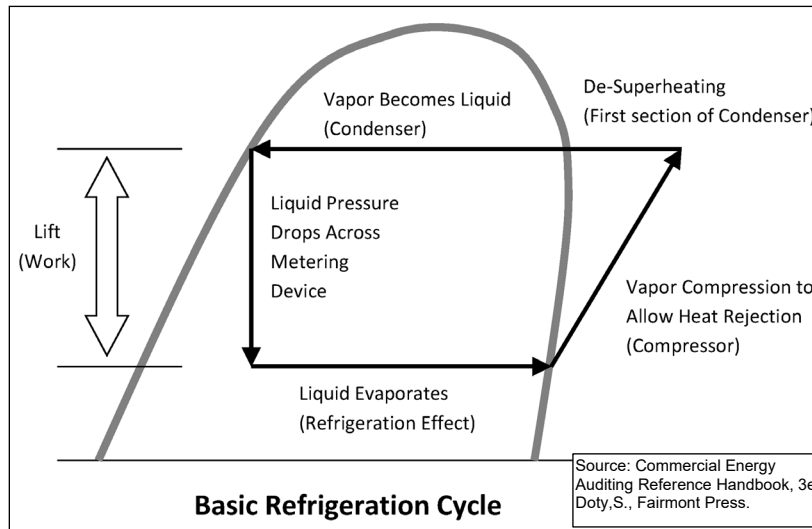
These systems all remove heat from one location (the place being cooled), and reject it somewhere else, usually outdoors. The ‘heat rejection’ equipment is called a ‘condenser’ because the working fluid (refrigerant) changes from a gas to a liquid at this point, after the heat is rejected. Electricity is used in several spots in mechanical equipment, but by far the largest power requirement is the ‘compressor’, a device that moves the refrigerant gas through the cycle and compresses it to a high enough pressure to reject the heat. The power requirement of the compressor is dependent on mass flow and pressure; a bigger cooling load must move more pounds of refrigerant per hour, and a higher condensing temperature needed for rejecting heat requires higher pressure. It is in the compression phase that the water-cooled option has the advantage for power. Water-cooled condensers condense at lower pressures and require less compressor power. The pressure rise from compressor inlet to outlet is termed ‘lift’. Compressor power is a direct function of lift: the lower the lift, the lower the power input for the compressor.

The reduced lift from water-cooling comes from two places:

1. The cooling media, water, cooled by a cooling tower, will be below ambient air temperature. This is because the evaporative effect follows wet bulb temperature, which is always lower than dry

bulb temperature; in drier climates, the difference can be 20-30 degrees lower. This reduces compressor head pressure, lift, and power requirements significantly.

- Water-cooled heat exchange equipment more easily transfers heat than air-cooled equipment, reducing the value of 'approach' (how close the leaving water temperature can approach the ambient wet bulb temperature); water-cooled equipment approach values may be 5-10F compared to 20-30F for air-cooled equipment. The improved heat exchange approach provides additional lift reduction and power reduction.



Water-cooled refrigeration compressors use less electricity, because the nature of water cooling equipment and evaporation allows lower head pressure and less work for the same amount of cooling.

The amount of reduction varies according to how dry the climate is. In Colorado Springs the reduction can be >30% on a hot day. In humid climates, it can be half that due to the increased relative humidity, but it will always be less.

Tradeoff between electric savings and water/sewer cost

The total utility cost savings from choosing water cooling is a tradeoff between electric savings and water/sewer cost. We will look at each separately and then combine.

Electricity savings from using water-cooling is influenced by several things, but here are the basic ones:

- *Whether one is on a demand rate or not.* If on a demand rate, the electric savings during on-peak times is more valuable than reductions in off-peak times. Air conditioning is an example of when this would matter because hot summer weather (air conditioning running) aligns with on-peak times. By contrast, commercial refrigeration, such as a grocery store, runs 24-7-365 and the reductions are not limited to certain times within certain seasons.
- *Whether water-cooling creates higher efficiency for a compressor that continues to run or allows it to be fully off.* For example, converting a warehouse or manufacturing site to evaporative cooling (swamp cooler) allows the compressor to be fully off or even removed; in terms of kWh saved per gallon of water used, this is a higher return of electrical savings than making something more efficient.

The cost evaluation is akin to the old saying 'three steps forward and two steps back', where the number of steps back is predictable, but the number of steps forward varies. Re-stating the concept with numbers: for each 1000 gallons of water used, how much energy (kWh) and how much demand (kW) is reduced? i.e. what do I get in return for the water expense?

Utility Costs from Water and Sewer Use

- Water cost is clear (summer rate and winter rate for water), per cubic foot.
- Sewer charge is clear, same number of cubic feet as the water...
 - ...unless you request a 'consumptive use allowance'(CUA) credit for the evaporated water. Doing this will reduce or eliminate the sewer charge that otherwise accompanies the water use. There are some restrictions for this, with the big one being 'sub-metering' the water going to the exempt process; this means the metered flow going to an approved CUA process serves nothing else but that process. For information on CUA, please call us at 448-4800.

Utility Savings from Electricity

This piece of the savings equation is not so clear. Without consideration of on-peak and off-peak rates, or if using a 'blended rate'*, the value needed is gallons per kWh saved.

- *Blended rate is the 'all-in' cost for \$ per kWh, calculated as total dollars divided by total kWh for a billing month or billing year.

Representative values have been estimated for the Colorado Springs area and are shown in **Table 1**. These will vary somewhat by geographic area and by specific equipment. The assumptions used for the values in **Table 1** can be found in the referenced original source.

Quantifying the 'steps forward and steps backward' can be done numerically or can be approximated with nomograph in **Figure 1** and values in **Table 1**. A little experimenting with this chart will show that water-cooling will produce *good utility dollar savings in areas where water cost is low and electricity cost is high*. The reverse is also true and when the relative proportions are high on the water end, the savings will be low or there may be no savings at all. For either method, the elusive number is 'gallons of water used per kWh savings'.

Method of estimating values of 'gallons of water used per kWh savings'.

Annual energy use for cooling processes vary. If air-conditioning, a load shape will show the largest use in the warmest weather, with progressively less use in mild weather and no use in cold weather. For commercial refrigeration, there will be fairly steady use for the whole year, with an increase in summer when it is hot. For manufacturing process cooling, some of the cooling loads will be weather-dependent and some will be production-dependent.

Annual energy use is found from combining the cooling load profile with the equipment load profile. Here, air-cooled and water-cooled vary considerably. Air-cooled efficiency will follow 'dry bulb' outdoor temperature (values you see on a thermometer), while water-cooled efficiency will follow 'wet bulb' outdoor temperature. Wet bulb temperature will always be lower than dry bulb unless it happens to be 100% rH (relative humidity) outside in which case they are equal. Drier climates have a greater reduction, which means water-cooled technologies have greater energy savings in dry climates.

There are technology variations as well: some technologies use more water in different ways and so use more, or less, water per unit of cooling. Some measures use water all year long and some use water only above a certain outside temperature (switching to air-cooled below that temperature). And, importantly, some technologies only make cooling equipment more efficient, while others supplant electric cooling loads (i.e. they allow the big motors to turn completely off).

You can see from the 'if-if-if' description, that it is not a simple task to arrive at the values of 'gallons of water per kWh saved'. As a consumer or engineering consultant trying to decide which path to take, it is essential to identify a reasonable value of 'gallons of water per kWh saved', either by calculation, or vendor data. (Note: If using vendor data, request certified test

data.) For initial review, the representative values in **Table 1** can be used. Not all possible water-cooled technologies are shown, and some of the technologies shown will not apply in humid climates.

Table 1:
Representative Values of ‘Gallons Per kWh’ Saved for Water-Cooled Measures

Source: Commercial Energy Auditing Reference Handbook 3e, Fairmont Press

Technology	Compared to	Type of Comparison	When used	Possible Business	Gal / kWh
Water-cooled AC (cooling tower)	Air cooled	Efficiency	Summer	Commercial/ Industrial	8.8
Evaporative pre-cool AC (pads)	Air cooled	Efficiency	Summer	Commercial/ Industrial	7.3
Water economizer	Compressor	In lieu of	All year	Commercial/ Industrial /Data Center	4.0
Evaporative cooling (swamp cooler)	Air cooled	In lieu of	Summer	Residential, manufacturing	3.0
Evaporative fluid cooler	Dry cooler	Efficiency	All year	Data center	8.8
Condenser, once through to drain	Air cooled	Efficiency	All year	Restaurant	206

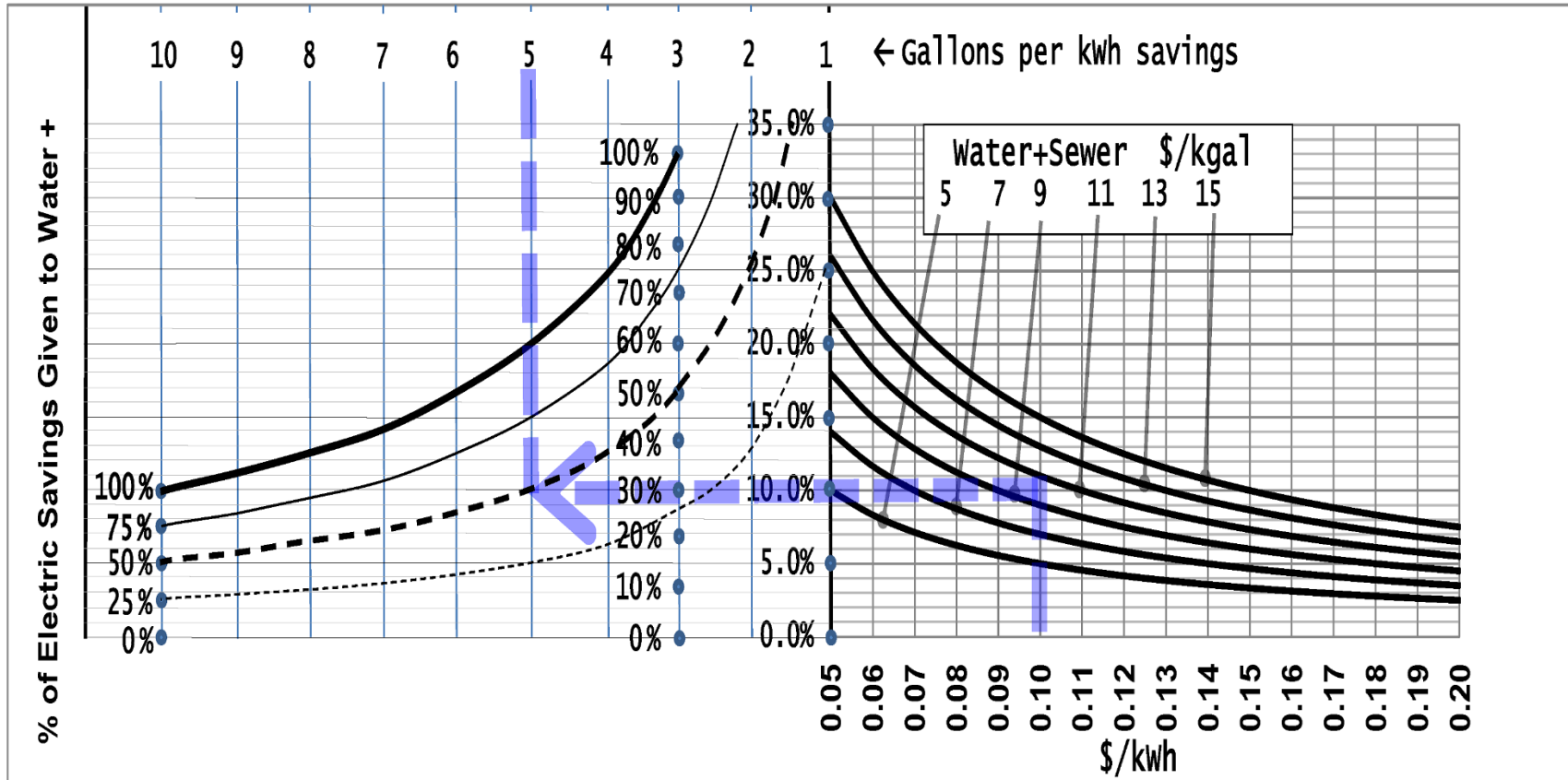


Figure 1: Percent of Electricity Savings Lost to Water/Sewer Cost

Source: Commercial Energy Auditing Reference Handbook 3e, Fairmont Press

Example use of this chart:

Given: \$0.10/kWh elec. Cost, \$10.00 per 1000 gal water+sewer cost, and 5 gallons of used water per kWh saved

- Enter the chart with electric cost in \$/kWh
- Move vertically to intersect the water+sewer cost in \$/1000 gallons
- Move horizontally to intersect the vertical line of gallons per kWh
- Read % of electricity savings lost to water/sewer cost

Examples of Water-Cooled vs. Air-Cooled Technology



Evaporative pre-cooling pads added to an air-cooled condenser



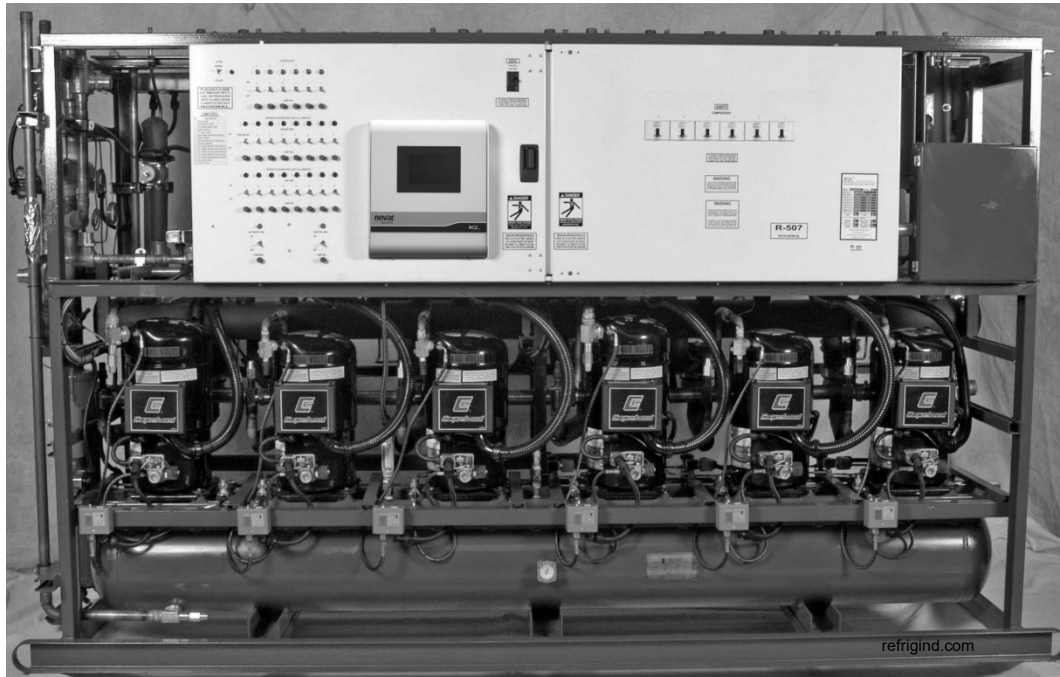
Evaporative cooling in lieu of air conditioning

Once-through cooling with potable water. Outlet goes to drain.





Cooling tower, rejecting heat from water-cooled condensers



Supermarket refrigeration rack, water-cooled

Other Cost-Saving Reasons to Use Water-Cooled Instead of Air-Cooled

Reduce Demand Charges

Water-cooled HVAC and refrigeration technologies will reduce demand (kW) compared to air-cooled, especially in hot weather. For customers on a 'demand date', the on-peak demand charges can be 60% of the electric bill, give or take.

Notes on calculating demand savings using blended rates.

The nomograph in **Figure 1** uses 'blended' rates (average overall \$ per kWh) to monetize the electrical savings in order to compare with water and sewer cost for a given cooling task.

Blended rates include all electric charges, including demand charges. Using simple 'blended rates' often gives a good estimate of savings, including the demand charges. However, sometimes the blended rates can under-state or over-state cost savings associated with energy savings. Examples:

- If the electric use from cooling occurs for a short duration during on-peak times, blended rates can understate savings. The nature of demand charges is that they are the same whether used for 15 minutes or all month long. So, if the usage is brief, annual energy use would be low and the demand charge would be higher than predicted from blended rates.
- If the electric use occurs only during off-peak times, blended rates can overstate savings. Since off-peak cost of electricity is much lower, the averaging done with 'blended rates' doesn't fit well.
- If electric use is being moved from on-peak to off-peak times, such as thermal storage, 'blended rates' can under-state savings. Here, savings come from removing demand from on-peak periods where demand charges are high, shifting them to 'off-peak' time where demand charges are low. With current rate structure, CSU off-peak demand charges are 'zero' as long as off-peak kW is less than on-peak kW; so, if shifting the load to off-peak can be done and stay under on-peak demand charges, significant savings are possible.
- If a cooling electrical load is the largest electric load in the facility, changes to the power requirements (kW per unit of cooling) can alter the blended rate. To the extent that the new average \$/kWh is less than the existing average \$/kWh, the savings would be over-stated using the original blended rate.

There is always a desire to have an accurate value for cost savings, so separating demand charges is sometimes tempting; for example, the demand charges are commonly 60% of a customer's electric bill. However, if separated, calculating the rest of the electric bill can be a daunting task. *If separating the on-peak demand, the other pieces of the bill must also be*

calculated individually and cannot be accounted for with 'blended rates'. Other 'pieces' of an electric bill include off-peak demand, on/off peak energy, seasonal changes of time of day on-peaks are measured, power factor charges, minimum demand charges, taxes, and other fees. A complete description of the components of a CSU demand-based electric bill are described in the white paper **Understanding Large Commercial Electric Bills**.

Improve Electric Load Factor

'Load Factor' is the ratio of average power divided by maximum power

$$\text{Load Factor} = \text{avg. kW} / \text{max kW}$$

Load factor has a strong influence on overall cost of electricity, especially when large demands occur for short or intermittent periods. Remember, demand charges are the same if used for 15 minutes in a bill period, or constantly.

Load factor provides direct cost savings, whether embedded in blended rates or separated by dissecting the utility bill components, as described in the prior paragraph on **Reduce Demand Charges**.

In some cases, load factor can also provide indirect savings by being on a different rate. Where a high 'load factor' is a condition to be on a rate, and that rate has a lower cost of electricity, then it is possible for water-cooled technology to be an enabler for moving to the less expensive rate because of the improved load factor. The rate example is in reference to CSU "**ELG**" rate, a rate designed for customers with very large electric use that is also consistently steady, i.e. high load factor. Such large users represent a reliable 'base load' for utilities, which is a benefit in planning for electric supply requirements.

Renewable energy is another case where demand reduction from water-cooled technology can be leveraged. Consider the integrated design example of investing in solar panels to negate summer demand charges associated with air conditioning. With water-cooled equipment, the summer power requirements are less, meaning the quantity of solar panels needed to negate it would be less.

Re-using Process Water in a Cooling Tower or Air Scrubber

Where utility water is used in process, there is waste-water that is relatively clean that can be re-used in a cooling tower, making the water cost in the water-cooled process very economical. Examples are reverse osmosis 'reject' water, and product rinse water where the water is still fairly-clean or can be filtered. When the mineral content of the 'free' water is higher than normal 'city water', an adjustment is required to the water treatment program for the cooling tower. The higher mineral content means there must be more 'blow down' and so the water use per unit of cooling will be higher. This is also true for

using non-potable water in a cooling tower; the difference here is the water is 'free', i.e. it reduces or can sometimes eliminate the need for purchased water for cooling tower use. The extent and cost of filtration are an obvious factor; a few flecks of debris would be easy to filter out, compared to mud.

Electrical service capacity

Peak demand for water-cooled equipment is notably less than for air-cooled. In cases where the facility building wiring is close to capacity, and cooling is being added, the use of water-cooled technology can avoid the cost of expensive upgrades to the electrical switchgear for the facility.

Other Tradeoffs

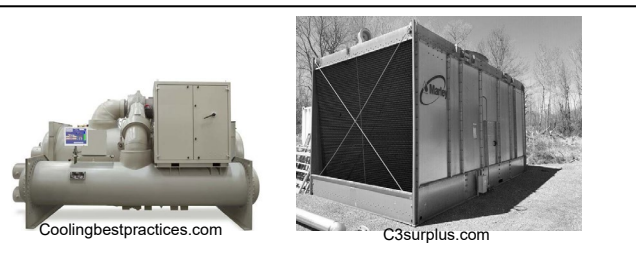
For completeness, there are other tradeoffs as well as utility cost:

Physical size. For large cooling operations, the physical size and space requirements of air-cooled condensers is a deterrent; this is to say water-cooled equipment offers compactness.



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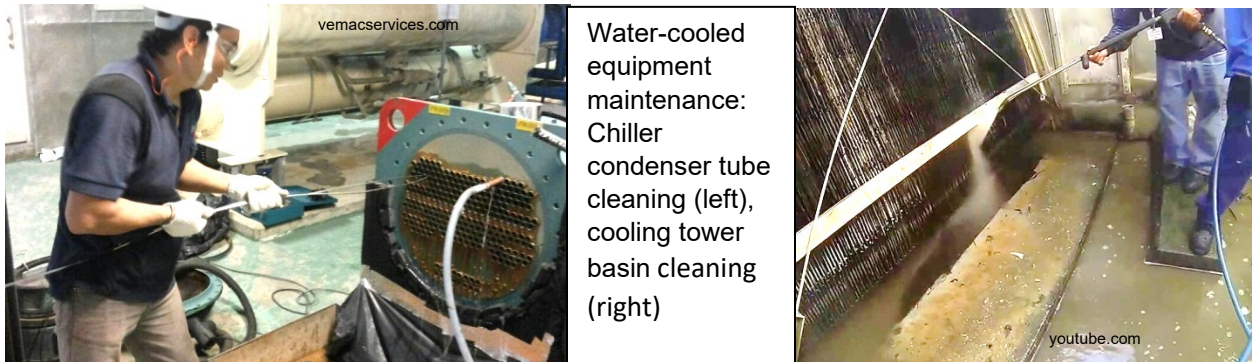
Physical size comparison for 500 tons cooling capacity using air-cooled (top) and water-cooled equipment (bottom)



First cost. Water-cooled equipment costs more than air-cooled equipment, when considering the condenser pump, condenser piping, cooling tower, water treatment, and controls.

Maintenance. Anything using water that is exposed to the atmosphere or 'open air' will have periodic maintenance to 'clean the media', 'clean the water basin', 'clean the tubes', etc. Water-cooled equipment also requires constant attention to water treatment, so assure the proper use of additives to

the water, or other methods, to slow the effects of scaling and corrosion, and control biological growth. For some facilities, choosing air-cooled is attractive, despite the extra energy cost, because it avoids the added maintenance.



Summary

Water-cooled equipment will use less electricity than air cooled, especially in summer. Historically, it was almost always safe to say water-cooled options reduced operating cost substantially, and the main consideration was the size of the facility. What made this choice easy for engineers was low cost water compared to the energy dollars saved.

Today, the ratio of electric and water costs is different, and the choice is not so automatic. Choosing air-cooled over water-cooled will make sense for some applications and not for others. A value of this white paper can be the planning phase of new designs, renovations, and major equipment replacement.

There are several factors to keep in mind besides electricity savings vs. water cost:

- Future projected utility rates – especially the relative cost of water and electricity.
- Availability of lower cost water.
- Value placed on simplicity and ease of maintenance.
- Available space for air-cooled equipment.
- Available capacity in the facility electric service – peak demands are higher when air-cooled.