THE DESIGN AND OPERATION OF EVAPORATIVE AND DRY WATER COOLING SYSTEMS

HOW TO MINIMISE COOLING SYSTEM ENERGY AND OPERATING COSTS

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OR

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INTRODUCTION

Cooling water is used in numerous industrial and commercial applications. The method by which the water is cooled can make a serious impact on the operating costs and operation of a system. The object of this paper is to consider the primary solutions, their advantages / disadvantages limitations and their impact on both energy consumption and operating costs.

Broadly speaking water cooling equipment uses either evaporative cooling or dry air cooling

And each type of system may be used in conjunction with refrigeration equipment to achieve lower cold or chilled water temperatures.

There are many combinations of cooling equipment and variations to their design that it is not practical to compare all types of cooling tower with all types of adiabatic and dry cooler etc. The comparisons within this paper are therefore based on the common standard selections in each instance. It is important to point out that, the particular requirements of an individual project should always be considered. However, this paper provides a good starting point for many applications.

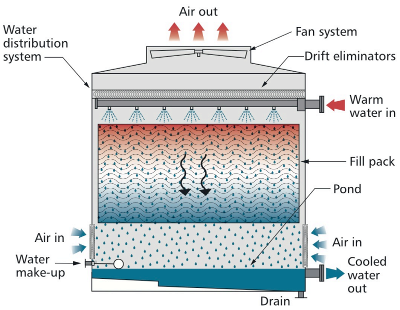
This paper considers the following types of cooling system: -

- Evaporative Cooling Towers
- Dry Coolers
- Adiabatic Coolers
- Air Cooled Chillers
- Water Cooled Chillers

EVAPORATIVE COOLING TOWERS

The open evaporative cooling tower is the most efficient way of cooling water and when operated in accordance with current legislation is entirely safe.

In evaporative cooling towers 80 % of the cooling is provided by the evaporative effect or latent heat transfer and 20% by sensible heat transfer.



Water is cooled by evaporating a small proportion of the circulating water which causes the remaining water to be cooled. The evaporative process is highly efficient. Evaporative cooling towers are capable of cooling water to within 3 ^{o}C of the prevailing wet bulb temperature giving typical minimum cold water temperatures for the UK of 23 ^{o}C.

Cooling towers must be operated and maintained in accordance with the Health & Safety Executives ACOP L8 & HSG 274 requiring risk assessments, management of the risk, monitoring and record keeping as part of the management system. There are also water treatment, cleaning and water costs associated with operation of cooling towers and these factors all need to be taken into account.

As the wet bulb temperature is always lower than the prevailing dry bulb temperature evaporative cooling towers have an automatic advantage when considering power.

Cooling Tower - Advantages

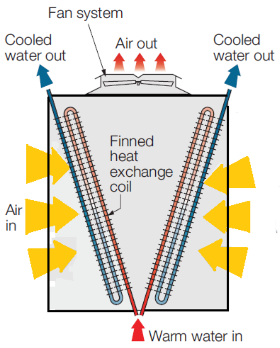
- Small plan area
- Low power consumption
- Low noise level
- Low operating costs
- Operate according to the prevailing wet bulb temperature which is lower than the dry bulb temperature.
- Cooling tower may provide "Free Cooling" for much of the year resulting in considerable reductions in energy costs when used with chillers so that the chiller only operates at peak conditions.

Cooling Tower - Disadvantages

- The potential for legionella is a concern, however there has never been a legionella outbreak in a properly maintained system.
- Not ideal in locations where water is scarce. Although blowdown from the cooling system can be returned to the cooling system after processing to reduce water consumption which can be economic on larger systems.
- Requires a recognised and managed water treatment programme and must be registered with the local authority.

DRY COOLERS

Dry coolers cool by sensible cooling only. Heat is conducted to the air from the surface of a finned coil through which the cooling water flows. They are able to cool the water to within 3 °C of the dry bulb temperature which for typical UK summer design conditions means that minimum cold water temperatures of between 35 °C to 38°C are possible.



Dry cooler

As the cooling water is completely contained within the closed system there is no legionella risk but some level of water treatment is required to ensure efficient operation albeit less than for an evaporative system.

Dry Coolers - Advantages

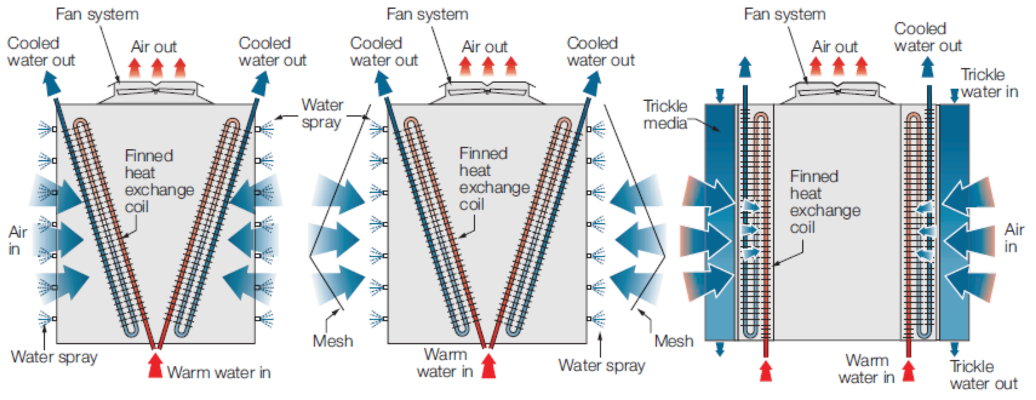
- No problem with legionella the system is completely closed
- Zero water loss ideal where water is scarce
- Can be installed in a variety of configurations
- Require very little water treatment

Dry Coolers - Disadvantages

- High power consumption
- Large plot size
- High noise levels
- High water temperatures
- High capital cost relative to cooling towers

ADIABATIC COOLERS

Adiabatic coolers –that cool the water by using a combination of sensible cooling and adiabatic cooling of the air that passes over the coil.



(a) Hybrid cooler with sprays

(b) Hybrid cooler with spray onto mesh

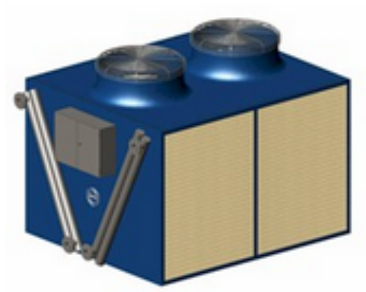
(c) Hybrid cooler with trickle onto media

There are various designs of Adiabatic or hybrid cooler, which are basically dry coolers that have a spray or water trickle system to precool the air prior to it reaching the coil through which the cooling water flows. Precooling of the air is only required at higher ambient temperatures so for much of the time the unit operates as a standard dry cooler.

They are generally less energy efficient than open evaporative cooling towers but have similar power requirements to evaporative closed circuit towers.

Adiabatic coolers are typically able to cool water to within 6 °C of the prevailing wet-bulb giving minimum design cold water temperatures for the UK of 24-26 °C.

Whilst there may not currently be a requirement to register this type of system under the Notification of Cooling Towers and Evaporative Condensers Regulations 1992. It is important to assess the risk of legionella in such systems and take appropriate measures. It is likely that some form of water treatment of the equipment will be required and the equipment monitored and risk assessed for legionella.



Adiabatic Coolers – Advantages

Next to cooling towers adiabatic coolers offer the next most efficient means of cooling water

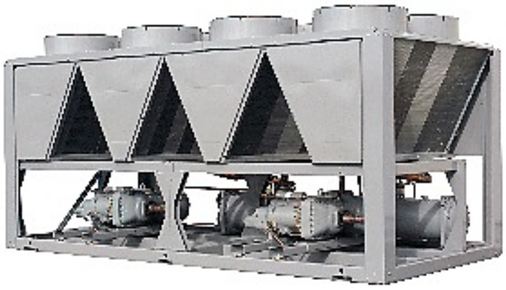
- Smaller plan area than a dry cooler
- Lower power consumption than a dry cooler
- Noise levels lower than a dry cooler
- No water loss from system
- Water consumption significantly lower than cooling towers
- Closed system very little water treatment required
- Lower water temperatures than a dry cooler

Adiabatic Coolers -Disadvantages

- Higher power consumption than a cooling tower
- Larger plot size than a cooling tower
- Higher noise levels than a cooling tower
- Higher water temperature than a cooling tower
- May be necessary to register in the same way as a cooling tower
- Approximately half the operating life of a cooling tower so the total cost of ownership can be relatively high compared to a cooling tower or other air-cooled system.

AIR-COOLED CHILLERS

Air-cooled chillers cool by a combination of refrigeration and sensible cooling of the refrigerant. In simply terms it is a refrigeration machine close coupled to an air-cooled condenser.



The refrigeration circuit of the chillers rejects heat to an air-cooled condenser which in turn rejects the heat to atmosphere by conduction in much the same way as a dry cooler.

Air-cooled chillers are able to deliver water temperatures below the ambient temperature which is their greatest advantage, however they also consume the large amounts of energy.

The Cooling efficiency of a chiller is expressed as its coefficient of performance COP or energy efficiency ratio EER which is the refrigeration capacity at full load (in Watts/ electrical input power (in Watts). Typically air-cooled chillers offer COP's in the range of 2.6 to 2.9

Air Cooled Chiller – Advantages

- -Provides lowest water temperatures
- Zero water consumption
- Completely closed system requiring very little water treatment
- No legionella issues or registration requirements -

Air Cooled Chiller Disadvantages

- High power consumption
- Large plot size
- High noise levels
- High capital cost
- Low COP compared to water cooled chillers
- Operating life and reliability generally not as good as water cooled chillers.

WATER-COOLED CHILLERS

Water cooled chillers provide chilled water in the same way that air-cooled do but instead of the heat being rejected by air cooling the heat is rejected through a water cooling tower from the condenser circuit. They may also be used in conjunction with adiabatic coolers and dry coolers but this will generally lower the overall COP.

One of the main advantages of the water cooled chillers is the better COP achieved which is in the range of 4-5 compared to the 2.6-2.9 given by an air-cooled chiller.

Water Cooled Chiller – Advantages

- Energy efficient COP in the range 4-5
- Reduced plot size compared to air-cooled
- Low noise levels due to the use of cooling towers to reject the heat
- Reliability higher than air-cooled chillers
- Longer operating life and better resilience than air-cooled chillers so the total cost of ownership is significantly lower.

Water Cooled Chiller Disadvantages

- Legionella must be considered if used in conjunction with a cooling tower
- Water treatment required for condenser circuit
- High capital cost in comparison to air-cooled chillers
- Occupies basement plant space
- Installation costs higher than air-cooled

OTHER TYPES OF COOLING EQUIPMENT

There are of course a number of variations and combinations of cooling equipment that are used these include: -

- **Closed circuit cooling towers** – incorrectly considered to provide additional protection against legionella. These may be types where the water passes through a coil inside the tower or have an external heat exchanger. In both cases the footprint is larger and the power consumption greater than for a conventional cooling tower.

- **Evaporative condensers** – these provide an extremely energy efficient system but are rarely if ever used in HVAC applications due to the need to site the refrigeration plant adjacent to the condenser and or the issues with running refrigerant circuits through office space.

- **Dry coolers or adiabatic coolers**-**used in conjunction with water cooled chillers**. These overcome some of the potential legionella issues that are associated with cooling towers however they are less efficient and would generally produce a greater footprint and higher combined COP than a cooling tower.

- **Adiabatic & Dry Coolers - used in conjunction with air-cooled chillers**. These enable free cooling during the cooler months of the year and are often chosen for use in data centres. This improves energy efficiency significantly.

- **Evaporative Cooling Towers – used for free cooling with water cooled chillers** during the cooler months of the year. Considerable energy savings may be achieved with this arrangement if designed correctly.

CONSIDERATIONS

In any cooling system there are a number of factors to consider when selecting the type of water cooling equipment to be used. These factors will include: -

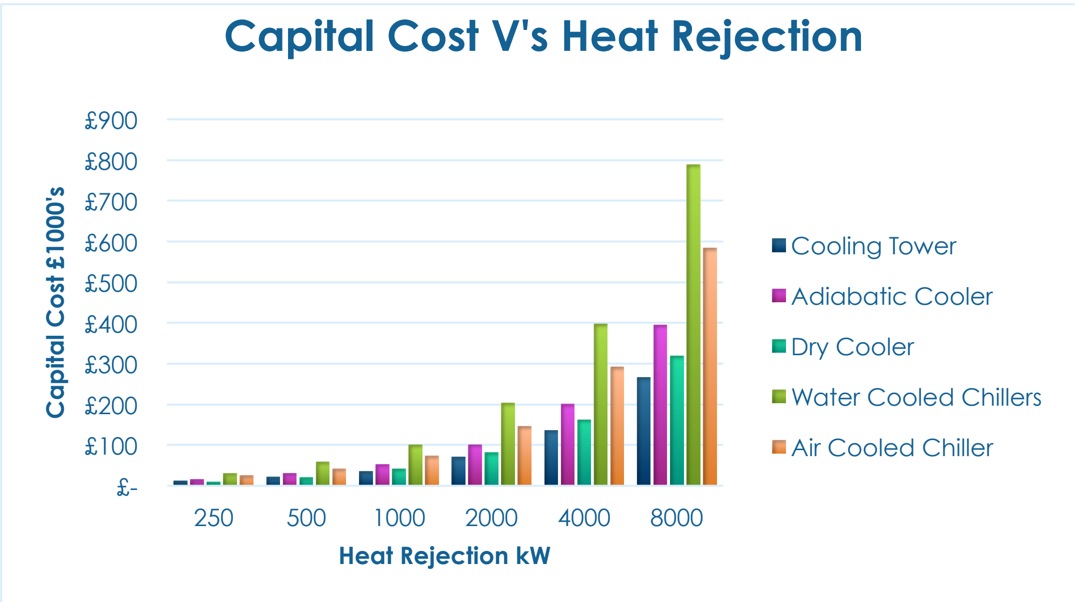
1. ***Cooling Load*** – for example the cooling load for a chemical production plant or data centre compared to that of a small office development will be significantly different and would warrant very different cooling solutions.

   It may be possible to demonstrate an energy saving and lower capital cost on smaller systems for a particular solution but in absolute terms the saving is unlikely to be significant enough to outweigh the disadvantages of an evaporative system.

   The capital cost below includes the cost of the main cooling plant and associated equipment it does not include installation costs which are particular to each installation.

   In the case of the water cooled chiller it includes condenser pumps, cooling tower and water treatment plant.

   The capital Cost included for each system is as follows: -
   - Cooling tower cost plus water treatment plant
   - Adiabatic cooler cost only
   - Dry Cooler cost only
   - Water Cooled chiller plus cooling tower, condenser pumps & water treatment plant
   - Air cooled chiller cost only

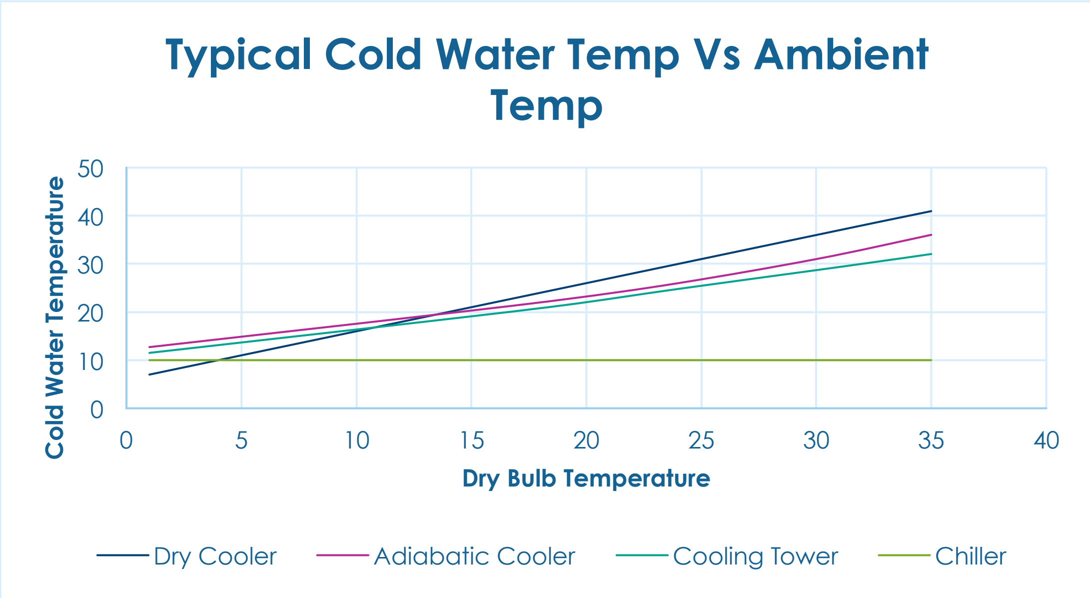


2. ***Cold water Temperature*** –for UK applications each system is able to offer a minimum cold water temperature at summer design conditions

Chillers – no minimum cold water temperature

Cooling towers	23 °C
Adiabatic coolers	26 °C
Dry Coolers	33-35 °C

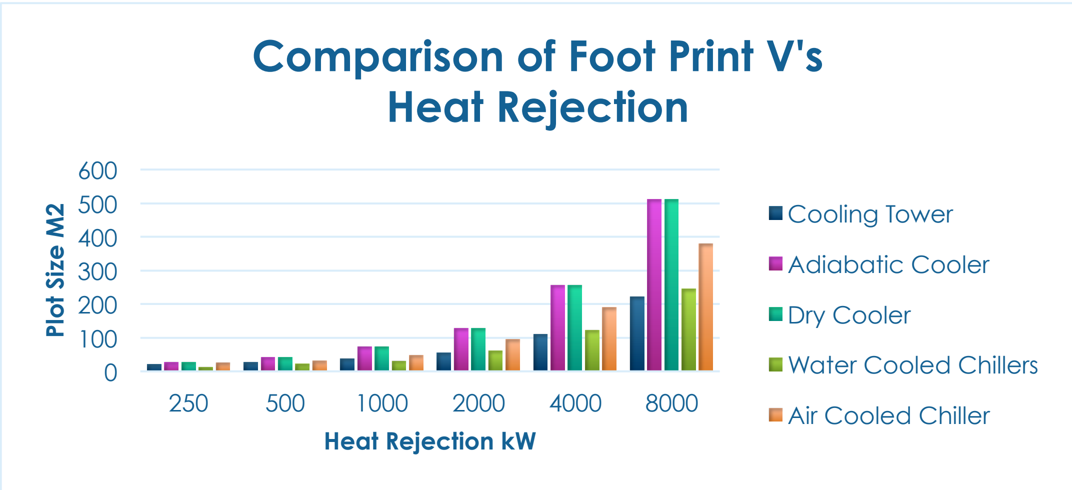
For cooling towers and adiabatic coolers the wet bulb temperature is more important than the dry bulb so the graph below assumes the typical relationship between dry bulb temperature and wet bulb temperature for the UK



3. ***Foot Print*** – particular buildings or process locations may require particular solutions. Where there is only limited space or building space is at a cost premium foot print may be a significant factor warranting the selection of a particular type of cooling system.

   The graph above includes the necessary space around each piece of equipment for air intake with the exception of the water cooled chiller which includes the space required for the chiller only.

   An approximation of total area required for the water cooled chiller can be obtained by adding the area for the cooling tower to the area for the water cooled chiller.



4. ***Environmental considerations*** – power, noise and water are significant factors and there are some constraints imposed that may favour a particular cooling system. These must be quantified and considered for the particular application.

5. ***Perceived risk or preference*** for particular plant by the user. The concerns regarding legionella and indeed the requirement to consider other forms of cooling in preference to cooling towers may rule these out as particular option.

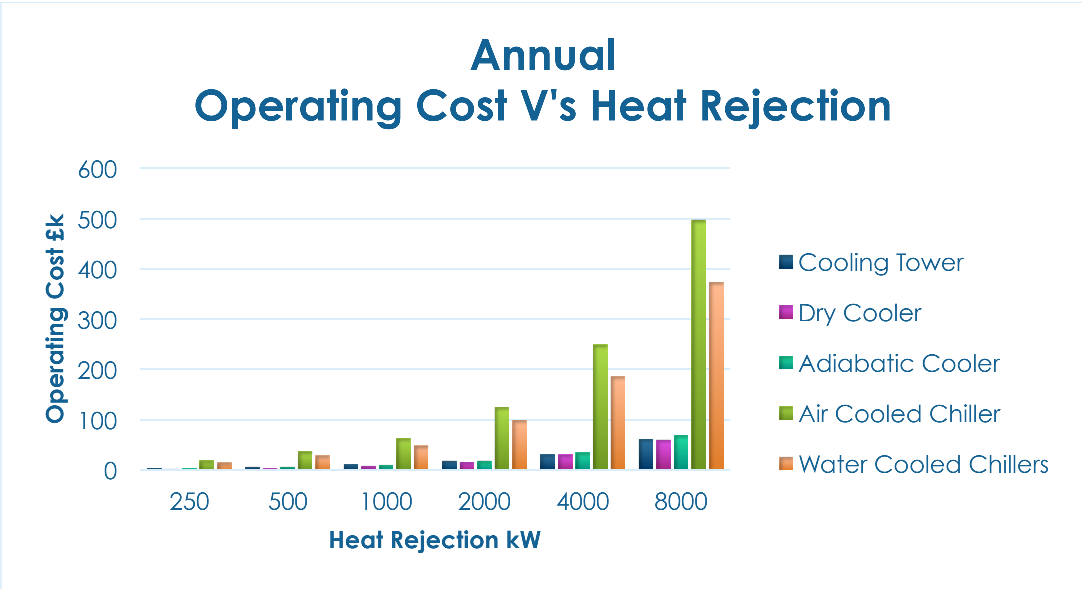
   It is however important to remember that legionella can be easily controlled and all outbreaks that have occurred have been due to a sequence of major omissions or complete disregard for established requirements for legionella control.

6. ***Financial Considerations*** total operating and capital costs are a major factor. On smaller systems the marginal benefits in operating costs may be completely outweighed by the lower installed costs of some systems.

The operating costs include shown in the chart below include :-

- Estimated energy costs corrected for typical load and ambient temperature profiles
- Water treatment
- Water costs plus effluent charges.
- The water cooled chiller includes the cooling tower and condenser pump operating

Further adjustment to these costs are required to cater for the loss of efficiency due to the higher water temperatures produced by the dry cooler and adiabatic cooler. This will depend on the type of system that it is serving.



Comparing the operating costs for the air cooled chiller with the water cooled chiller the typical payback period in typically under two years.

SUMMARY / CONCLUSION

Cooling water system requirements for process and HVAC applications are generally different.

Process Cooling

For process cooling applications there is not always the necessity for a chilled water supply and the cooling tower offers the lowest total cost of ownership.

Where chilled water is required a cooling tower can offer significant savings in energy costs by providing "free cooling" for much of the year. In borderline cases where only peak conditions necessitate a chiller hire chillers can be used for the limited time that the cooling tower cannot provide water at low enough temperatures.

Adiabatic systems provide similar operating costs although the footprint will be larger and total lifetime costs considerable higher.

Only dry coolers and air-cooled chillers overcome the issue of legionella completely but at the expense of cold water temperature in the case of the dry cooler and a significant capital cost and operating cost penalty in the case of the air-cooled chiller.

HVAC

In HVAC applications there will invariably be a requirement for a chilled water supply and the cooling tower plus water cooled chiller offers the best overall energy efficiency and lowest lifetime operating costs. However, in absolute terms the cost savings really only become significant above 1000 kW heat rejection.

It is likely that there will invariably be preferences for particular types of cooling plant irrespective of the cost and size of cooling equipment however space and environmental considerations may take precedence over these preferences but again there is little to match the low lifetime cost for evaporative cooling equipment if used to its maximum advantage.