# Evaporative Cooling Products

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Cooling towers and evaporative condensers are efficient and cost effective means of removing heat from air conditioning, refrigeration and industrial process cooling systems. They have been in use for more than half a century. They are compact, quiet, consume little energy and save more than 95% of the water in circulation. They are simple to operate and maintain and, with the use of a good code of practice, system efficiency and safety are assured.

Evaporative cooling is based on a natural principle. In an open circuit cooling tower the water to be cooled is distributed over a fill pack whilst air is blown or drawn through the packing. A small quantity of the water evaporates and this causes the remainder of the water to be cooled. The cooled water falls into the sump of the tower and the heat extracted from the water is carried out in the leaving air stream.

Evaporative condensers or closed circuit evaporative cooling towers have a heat exchanger or coil within the tower instead of a fill pack. Water is distributed over the heat exchange coil and heat is extracted from the refrigerant or primary fluid circulating through the coil by the same evaporative process.

Evaporative cooling combines high thermal efficiency and cost effectiveness by achieving low cooling temperatures with minimum energy and water usage. Low cooling temperatures are essential for many processes to achieve high system efficiency. These processes consume less energy and in this regard evaporative cooling contributes to preserving natural resources and the environment.

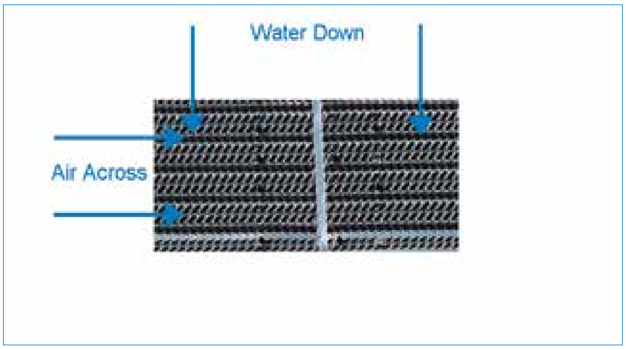
# Configurations 2

## 1. Introduction

There are three main configurations of factory assembled evaporative cooling products: crossflow, counterflow and combined flow. In **crossflow cooling products**, the water flows vertically down the wet deck or coil as the air flows horizontally across it. In **counterflow cooling products**, the water flows vertically down as the air flows vertically up it.

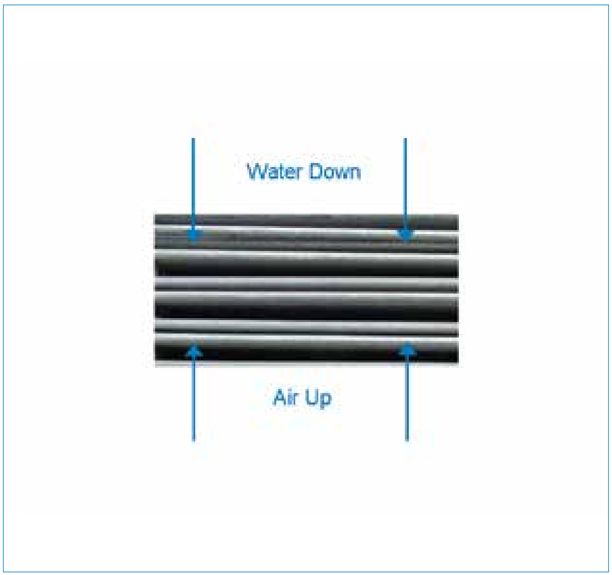
**Combined flow** is the use of both a heat exchange coil and wet deck surface for heat transfer in a closed circuit cooling tower. The addition of the wet deck surface to the traditional closed circuit cooling tower design reduces evaporation in the coil section, reducing the potential for scaling and fouling. BAC's combined flow closed circuit cooling towers utilize parallel flow of air and spray water over the coil, and crossflow air/water flow through the wet deck surface.

In parallel flow, air and water flow over the coil in the same direction. The process fluid travels from the bottom to the top of the coil, increasing efficiency by bringing the coldest spray water and air in contact with the process fluid at its coldest temperature.

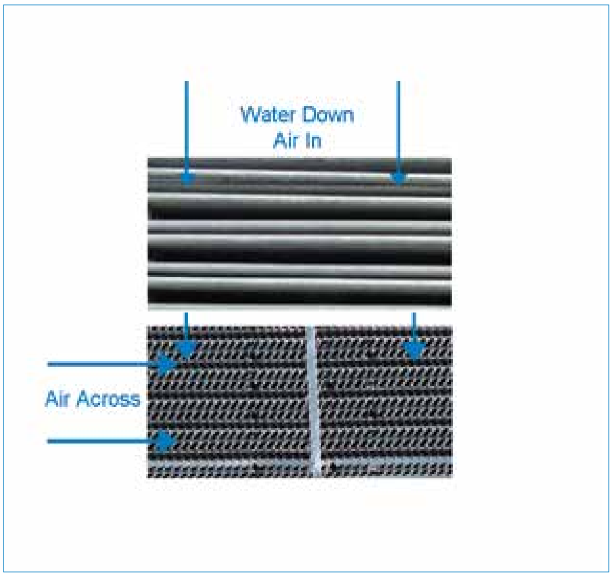



*Crossflow Configuration (open cooling towers only)*


*Counterflow Configuration (open cooling towers)*




Counterflow Configuration (coil products)



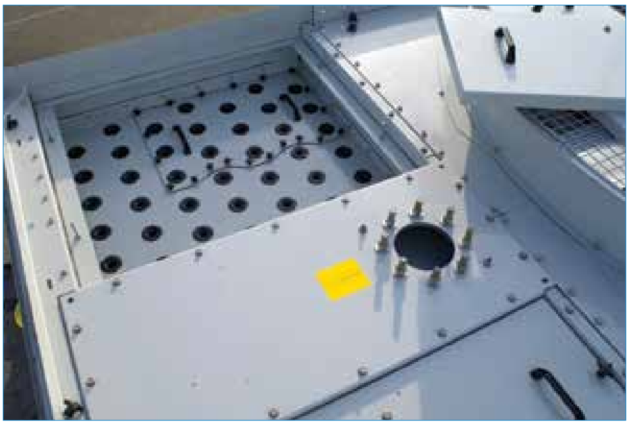

Combined flow (coil products) - Parallel flow of air and water over the coil and crossflow over the wet deck

## 2. Water Distribution Systems

Evaporative cooling products employ either gravity distribution or pressurised spray systems to distribute water over the wet deck surface.

**Gravity distribution systems**, installed on BAC's crossflow cooling towers, feature hot water basins mounted on top of the tower above the wet deck. A series of metering orifices in the floor of each hot water basin distribute the water as a function of the depth of the water in the basin. Gravity distribution systems generally require minimal pump head, can be inspected while the unit is in operation and are easy to access for routine maintenance and service.

**Spray distribution systems**, employed on counterflow cooling towers, feature a series of pipes fitted with spray nozzles mounted inside the tower above the wet deck. These systems typically require 0,15 through 0,5 bar of water pressure at the water inlet and require the unit to be out of service for inspection and maintenance.



Gravity Distribution Basin

Pressurised Spray Distribution

## 3. Fan Systems

The flow of air through most factory assembled evaporative cooling equipment is provided by one or more mechanically driven fans. The fan(s) may be axial or centrifugal, each type having its own distinct advantages.

**Axial fan units** require approximately half the fan motor kilowatt of comparably sized centrifugal fan units, offering significant life-cycle cost savings.

**Centrifugal fan units** are capable of overcoming reasonable amounts of external static pressure (≤125 Pa), making them suitable for both indoor and outdoor installations. Centrifugal fans are also inherently quieter than axial fans, although the difference is minimal and can often be overcome through the application of optional low sound fans and/or sound attenuation on axial fan units. Fans can be applied in an induced draft or a forced draft configuration.

*Centrifugal Fan*

*Axial Fan*

**Induced Draft**
The rotating air handling components of induced draft equipment are mounted in the top deck of the unit, minimizing the impact of fan noise on near-by neighbours and providing maximum protection from fan icing with units operating in sub-freezing conditions. The air being drawn through the unit hereby discharges over the inducing fan. The use of corrosion resistant materials ensures long life and minimizes maintenance requirements for the air handling components.

**Forced Draft**
Rotating air-handling components are located on the air inlet face at the base of forced draft equipment whereby fresh air is blown through the unit. This base fan position facilitates easy access for routine maintenance and service. Additionally, location of these components in the dry entering air stream extends component life by isolating them from the corrosive saturated discharge air.

# Open Cooling Towers

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## 1. Principle of Operation

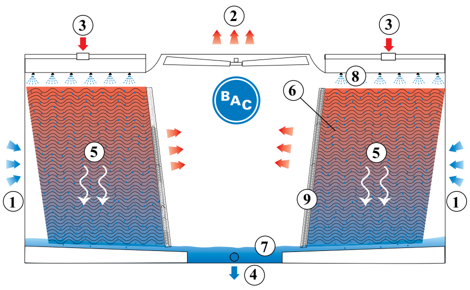
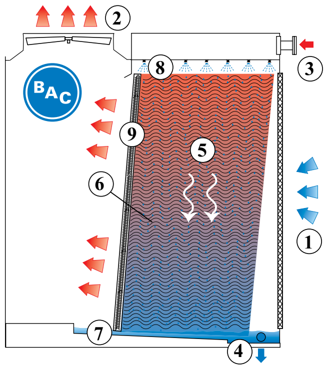
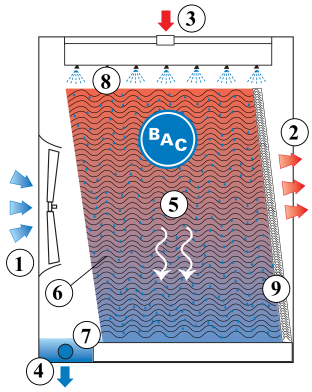
Open cooling towers reject heat from water-cooled systems to the atmosphere. Hot water from the system enters the cooling tower and is distributed over the wet deck (heat transfer surface). Air is pulled or pushed through the wet deck, causing a small portion of the water to evaporate. Evaporation removes heat from the remaining water, which is collected in the cold water basin and returned to the system to absorb more heat.

Each open cooling tower line, although operating under the same basic principle of operation, is arranged a little differently. See the schematics on the Available Product Configurations Table for product specific details.

## 2. Product Configurations

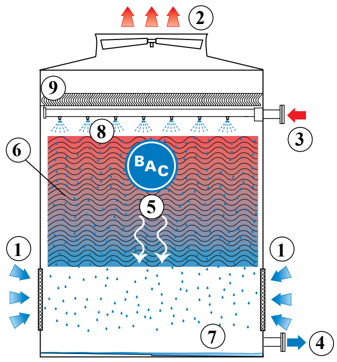
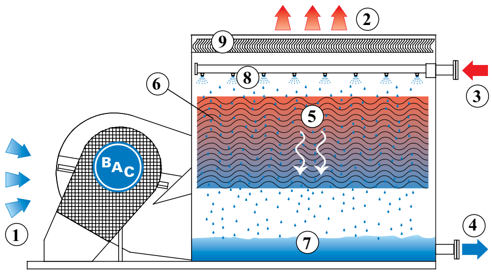
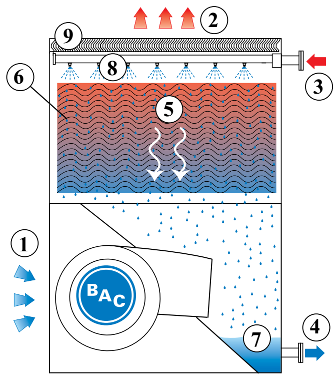
Open cooling towers provide evaporative cooling for many types of systems, and the specific application will largely determine which BAC cooling tower is best suited for a project. The Available Product Configurations Table on the next page is intended as a general guide. Specialised assistance is available through your local BAC Balticare Representative.

# Available Product Configurations

| | Crossflow | Crossflow | Crossflow |
|---|---|---|---|
| **Principle of Operation** |  |  |  |
| **Air Entry** | Axial Fan,<br>Induced Draft | Axial Fan,<br>Induced Draft | Axial Fan,<br>Forced Draft |
| **Configuration** | Double | Single | Single |
| **Water Distribution** | Gravity | Gravity | Gravity |
| **Maximum Entering Water Temperature** | 55°C PVC wet deck<br>60°C alternative wet deck material | 50°C PVC wet deck<br>55°C alternative wet deck material | 50°C PVC wet deck<br>55°C alternative wet deck material |
| **Typical Applications** | Medium to large HVAC and industrial applications<br><br>Replacement of field erected towers | Medium HVAC and industrial applications<br><br>Counterflow unit replacements<br><br>Crossflow unit replacements<br><br>Tight enclosures and installations requiring a single air inlet | Small to medium industrial applications |

1. Air in, 2. Air Out, 3. Hot Water In, 4. Cooled Water out, 5. Water; 6. Wet Deck Surface, 7. Cold Water Basin; 8. Water Distribution System; 9. Eliminators.

*For projects requiring water conservation and/or plume sensitive location, forced draught centrifugal fan cooling towers can be equipped with plume abatement coils (PAC) in combination with 2-way valve arrangement. Refer to your BAC Balticare representative for more details and selections.*

| Counterflow | Counterflow | Counterflow |
|---|---|---|
|  |  |  |
| Axial Fan,<br>Induced Draft | Centrifugal Fan,<br>Forced Draft | Centrifugal Fan,<br>Forced Draft |
| Four sides | Single | Single |
| Pressurised | Pressurised | Pressurised |
| 55°C PVC wet deck<br>60°C - 65°C with alternative wet deck materials | 55 °C PVC wet deck<br>65°C with alternative wet deck materials | 55 °C PVC wet deck<br>65°C with alternative wet deck materials |
| Small to large<br>industrial applications<br><br>Dirty Water applications<br><br>Replacement of field erected towers<br>with basinless units | Small to medium HVAC and<br>industrial applications<br><br>Installations with extremely low height requirements<br><br>Indoor installations<br><br>High temperature industrial<br>applications<br><br>Tight enclosures & installations requiring a single air inlet | Small to medium HVAC and<br>industrial applications<br><br>Indoor installations<br><br>High temperature industrial applications<br><br>Tight enclosures and installations<br>requiring a single air inlet |

# Closed Circuit Cooling Towers

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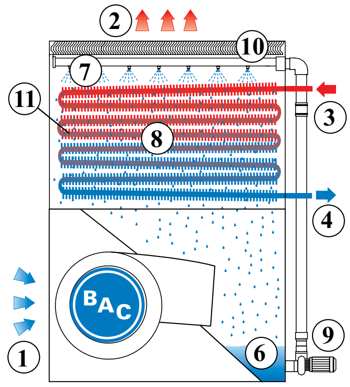
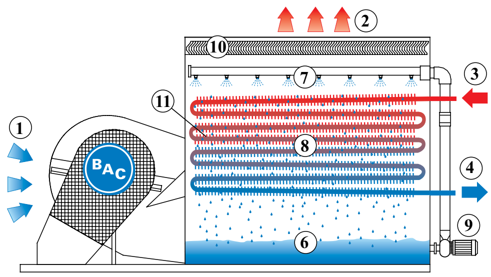
## 1. Principle of Operation

Closed circuit cooling towers operate in a manner similar to open cooling towers, except that the heat load to be rejected is transferred from the process fluid (the fluid being cooled) to the ambient air through a heat exchange coil. The coil serves to isolate the process fluid from the outside air, keeping it clean and contamination free in a closed loop. This creates two separate fluid circuits: (1) an external circuit, in which spray water circulates over the coil and mixes with the outside air, and (2) an internal circuit, in which the process fluid circulates inside the coil. During operation, heat is transferred from the internal circuit, through the coil to the spray water, and then to the atmosphere as a portion of the water evaporates.

## 2. Product Configurations

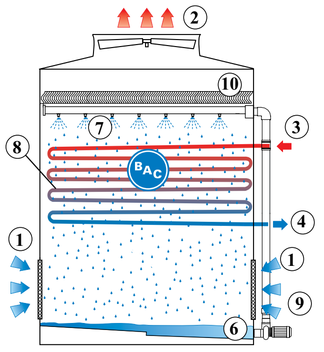
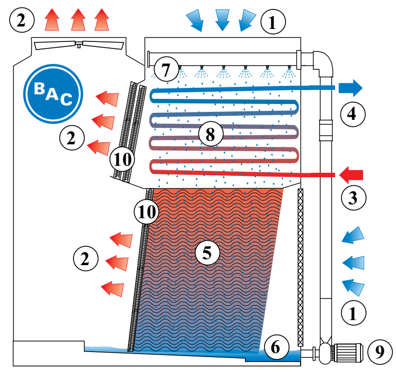
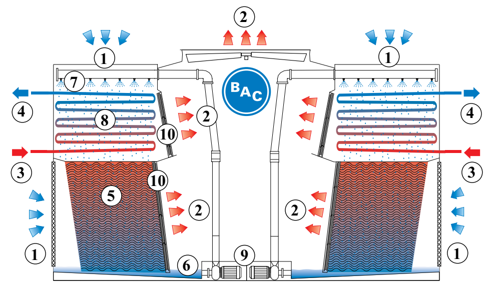
Closed circuit cooling towers provide evaporative cooling for many types of systems, and the specific application will largely determine which BAC closed circuit cooling tower is best suited for a project. The Available Product Configurations Table on the next page is intended as a general guide. Specialized assistance is available through your local BAC Balticare Representative.

## Available Product Configurations

| | Counterflow | Counterflow |
|---|---|---|
| **Principle of Operation** |  |  |
| **Air Entry** | Single | Single |
| **Fan System** | Centrifugal Fan,<br>Forced Draft | Centrifugal Fan,<br>Forced Draft |
| **Maximum Entering Water Temperature** | 82°C | 82°C |
| **Typical Applications** | Small to medium HVAC and industrial applications such as water source heat pump loops and air compressor cooling<br><br>Indoor installations<br><br>High temperature applications<br><br>Tight enclosures & installations requiring a single air inlet<br><br>Extremely sound sensitive applications<br><br>Dry operation requirement in winter time | Small to medium HVAC & industrial applications<br><br>Installations with extremely low height requirements<br><br>Indoor installations<br><br>High temperature industrial applications<br><br>Extremely sound senstive applications<br><br>Dry operation requirement in winter time |

1. Air In; 2. Air Out; 3. Fluid In; 4. Fluid Out; 5. Wet Deck Surface; 6. Cold Water Basin; 7. Water Distribution System; 8. Coil; 9. Spray Water Pump; 10. Eliminators; 11. Optional Extended Surface.

*A series of water saving and hybrid wet-dry closed circuit products are available to meet specific design requirements. Refer to the "Water Saving Products" for more details on these products.*

| Counterflow | Combined flow | Combined flow |
|---|---|---|
|  |  |  |
| Four sides | Side and top | Two sides and top |
| Axial Fan,<br>Induced Draft | Axial Fan,<br>Induced Draft | Axial Fan,<br>Induced Draft |
| 82°C | 82°C | 82°C |
| Medium to large HVAC and industrial applications<br><br>Dry operation requirement in winter time | Small to medium HVAC and industrial applications such as water source heat pump loops and air compressor cooling<br><br>Tight enclosures and installations requiring a single air inlet<br><br>Unit replacements | Medium to large HVAC and industrial applications such as electric arc furnaces and pharmaceutical plants |

## 3. General Advantages

**Open cooling towers** expose process cooling water to the atmosphere, typically as part of a chiller system loop (see Figure 1). These open towers use an efficient, simple, and economical design. All components in an open system must be compatible with the oxygen introduced via the cooling tower.

**Closed circuit cooling towers** completely isolate process cooling fluid from the atmosphere. This is accomplished by combining heat rejection equipment with a heat exchanger in a closed circuit tower (see Figure 2). A closed loop system protects the quality of the process fluid, reduces system maintenance, and provides operational flexibility at a slightly higher initial cost.

When deciding which system is best for an application, several factors should be considered.

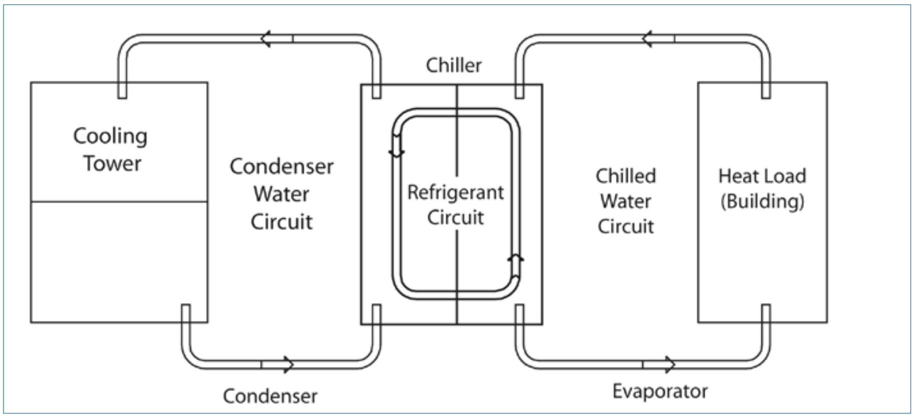



*Figure 1 : Chiller Loop with Open Tower*

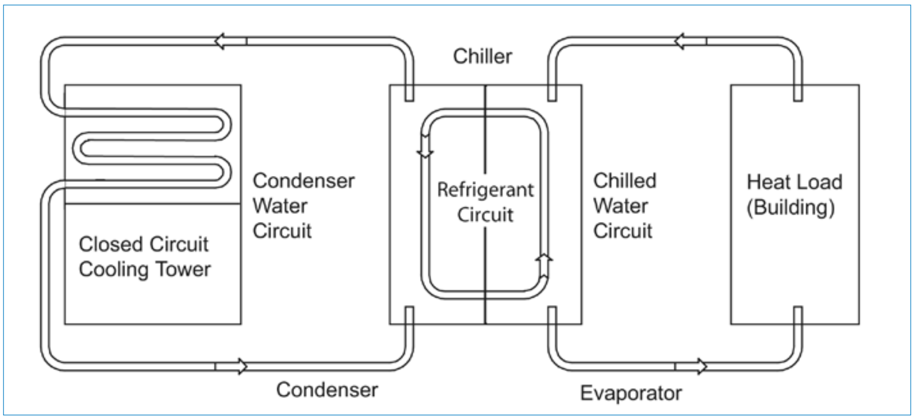



*Figure 2 : Chiller Loop with Closed Circuit Tower*

### Performance

If an application must produce full capacity throughout the year, maintaining a clean, reliable system loop is critical. Isolating the process fluid in a closed loop system prevents airborne contaminants from entering and fouling the system. Sustaining optimum performance in an open loop system will require regular maintenance to assure similar efficiency. High efficiency chillers and heat exchangers rely on clean process water to function properly and are significantly impacted by even small amounts of fouling.

### Expense

The initial equipment cost of an open loop system will be less than a comparably sized closed loop system, since the open system does not include the intermediate heat exchanger component. However, the higher first cost of a closed loop system will be paid back during years of operation through the following savings:

- Cleaner process fluid results in a cleaner internal surface area, and higher efficiency components in the system (e.g. chiller)
- Reduced system maintenance costs
- Reduced water treatment costs for evaporative equipment
- Operating in 'free cooling' mode during the winter to save energy consumption

## Maintenance

Since the process fluid of a closed loop system is completely isolated from the environment, routine maintenance is only required on the heat rejection equipment itself. The need to shut down the system periodically to clean the heat exchanger is dramatically reduced, if not entirely eliminated. Providing clean process fluid to the system will extend the life of other components in the system (condenser bundles, compressors, etc.).

## Advantages Water Treatment

Maintaining proper process fluid quality in a system may involve several steps, such as chemical treatment, filtration equipment and the addition of clean make-up water.
A closed circuit cooling tower can provide the following advantages over an open cooling tower:

- Lower volume of recirculating water to treat
- Process loop requires minimal treatment
- During periods of dry operation, the need for make-up water is eliminated

## Operational Flexibilty

Closed circuit cooling towers allow for the following modes of operation not possible with open cooling towers:

- Free cooling operation without the need for an intermediate heat exchanger: Chiller turned off
- Dry operation: Conserve water and treatment chemicals, prevent icing and eliminate plume
- Variable pumping: Closed condenser water loop allows for variable speed pumping to conserve energy

## Closed Cooling Circuit Tower versus Open Tower / Heat Exchanger

Sometimes, an open cooling tower is paired with a heat exchanger (see Figure 3) to capture some of the benefits of closed loop cooling. Choosing closed circuit cooling towers over this open tower/heat exchanger combination may still be a better choice for the following reasons:

- Total cost: Addition of a heat exchanger (pump, piping, etc.) to the open tower loop brings the initial cost much closer to that of the closed circuit tower system
- Single piece of equipment: Compact design of the closed circuit tower conserves space in a self-contained package, compared to multiple locations for the tower/heat exchanger arrangement
- Maintenance: Narrow spacing in heat exchanger (e.g. plate and frame) may trap solids introduced by the open tower, requiring frequent, time consuming cleaning to assure optimum performance
- Dry operation: Open tower/heat exchanger system cannot be run dry in the winter

These guidelines provide some general information to help decide whether a closed circuit cooling tower is better suited for a particular application than an open tower, with or without a heat exchanger. For additional assistance with a project, please contact your local BAC Balticare Representative.

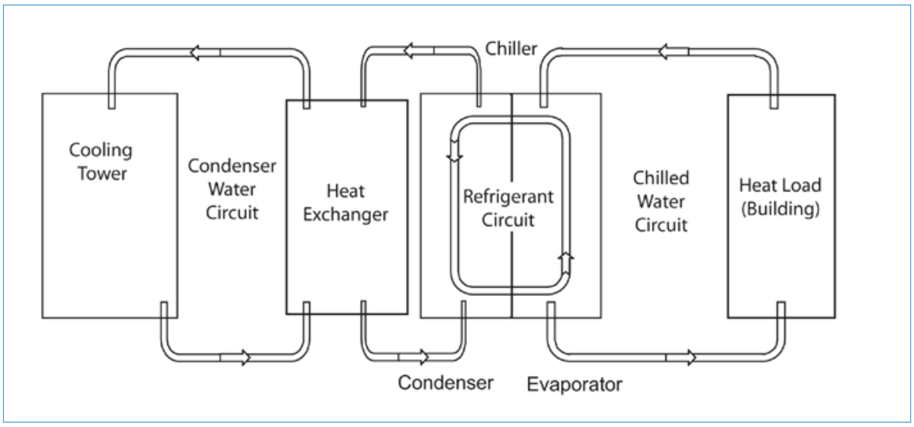



*Figure 3 : Chiller Loop with Open Tower/Heat Exchanger Combination*

# Evaporative Condensers

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## 1. Principle of Operation

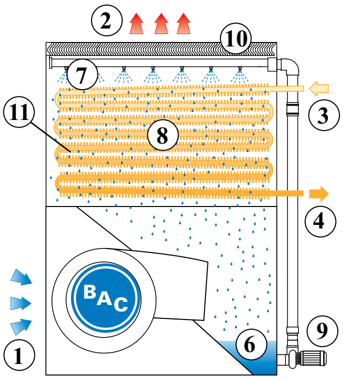
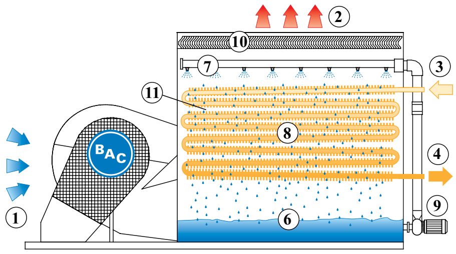
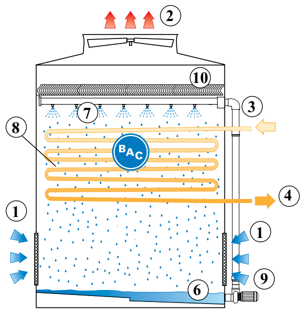
The vapor to be condensed is circulated through a condensing coil, which is continually wetted on the outside by a re-circulating water system. Air is pulled or pushed over the coil, causing a small portion of the re-circulating water to evaporate. The evaporation removes heat from the vapor in the coil, causing it to condense.

## 2. Product Configurations

Evaporative condensers provide heat rejection for many types of systems, and the specific application will largely determine which BAC Evaporative Condenser is best suited for a project. The Available Product Configurations Table on the next page is intended as a general guide.

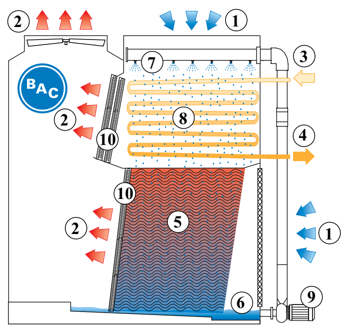
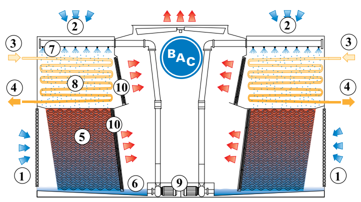
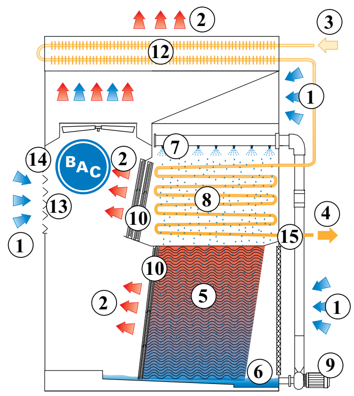
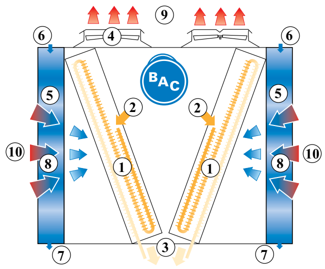
Evaporative condensers are used to provide lower condensing temperatures and compressor kilowatts savings of up to 30 percent when compared with air-cooled systems.

## Avalaible Product Configurations

| | Counterflow | Counterflow | Counterflow |
|---|---|---|---|
| **Principle of Operation** |  |  |  |
| **Air Entry** | Single | Single | Four sides |
| **Fan System** | Centrifugal Fan,<br>Forced Draft | Centrifugal Fan,<br>Forced Draft | Axial Fan,<br>Induced Draft |
| **Typical Applications** | Sound sensitive industrial refrigeration projects<br><br>Installations with limited plan area<br><br>Indoor installations<br><br>Dry operation requirement in winter time | Sound sensitive industrial refrigerations projects<br><br>Installations with extremely low height requirements<br><br>Indoor installations<br><br>Dry operation requirement in winter time<br><br>Skid packages | Industrial refrigeration applications<br><br>Dry operation requirement in winter time |

1. Air in; 2. Air out; 3. Vapour in; 4. Liquid out; 5. Wet deck surface; 6. Cold water basin; 7. Water distribution system; 8. Coil; 9. Spray Water Pump; 10. Eliminators; 11. Optional Extended Surface. 12. Dry finned coil; 13. Modulating air inlet dampers; 14. Servo motor; 15. Pressure transmitter.

For Counterflow hybrid: 1. Dry heat exchanger; 2. Fluid in; 3. Fluid out; 4. Axial Fans; 5. High efficiency evaporative coolingpad; 6. Water inlet connections; 7. Water outlet connections; 8; Adiabatic cooling of ambient air; 9. Air Discharge; 10. Air In.

| Combined flow | Combined flow | Combined flow hybrid | Counterflow / Adiabatic pre-cooling |
|---|---|---|---|
|  |  |  |  |
| Side and top | Two sides and top | Two from side | Two sides |
| Axial Fan,<br>Induced Draft | Axial Fan,<br>Induced Draft | Axial Fan,<br>Induced Draft | Axial Fan,<br>Induced Draft |
| Industrial refrigeration applications | Very large industrial refrigeration and process projects requiring low energy consumption and low sound | Industrial refrigeration applications in geographical regions where water cost is high | Small to medium industrial refrigeration projects<br><br>Locations with limited water and limited space availability |

# Water Saving Products

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## 1. Principle of Operation

Water saving and hybrid products are usually of the closed circuit type where the heat load to be rejected is transferred from the process fluid (fluid to be cooled) to the ambient air through a heat exchange coil. The coil serves to isolate the process fluid from the outside air, keeping it clean and contamination free in a closed loop.


The hybrid wet-dry products cool the liquid to be cooled by efficiently combining dry sensible air cooling with evaporative cooling. These products include two or more distinctive heat transfer surfaces or sections combined into one product optimising the use of the ambient dry and wet bulb temperature.

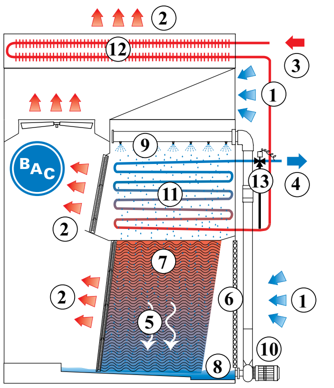
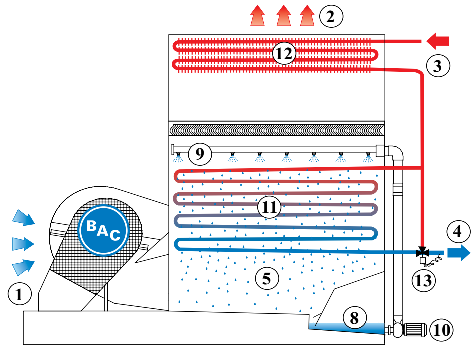
Dry fluid coolers cool the liquid in a closed circuit by means of sensible heat transfer from the high-density finned coil block to the air at ambient dry bulb temperature.

Adiabatic coolers are dry coolers equipped with an adiabatic pre-cooler section. Before the air is drawn through the high density finned coil, it is pre-cooled adiabatically as it passes through an evaporative pad where water is evaporated in the air.

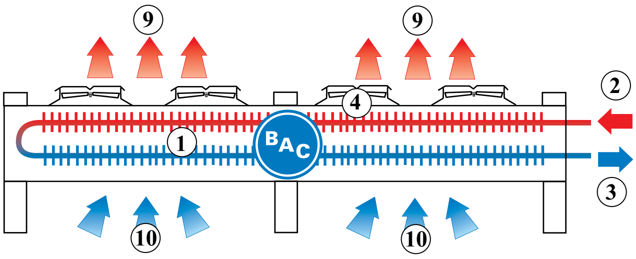
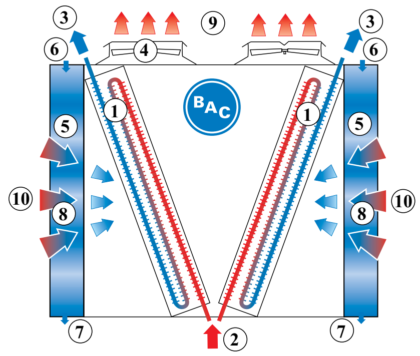
## 2. Product Configurations

Water saving and hybrid products provide cooling for many types of systems, and the specific application will largely determine which BAC product is best suited for a project. Water saving and hybrid products can be categorised within three different technologies. These are the hybrid wet-dry, dry and dry with adiabatic pre-cooling.
The Available Product Configurations Table on the next page indicates the BAC products available under each of these technologies. This overview table is intended as a general guide. Specialised assistance is available through your local BAC Balticare Representative.

# Available Product Configurations

| | Combined flow | Counterflow |
|---|---|---|
| Principle of Operation |  |  |
| Technology | Hybrid wet-dry closed circuit cooling tower combining sensible and evaporative heat transfer | Hybrid wet-dry closed circuit cooling tower combining sensible and evaporative heat transfer |
| Air Entry | Two from side | Single |
| Fan System | Axial Fan,<br>Induced Draft | Centrifugal Fan,<br>Forced Draft |
| Maximum Entering Fluid Temperature | 82 °C | 82 °C |
| Typical Applications | Medium to large HVAC and industrial applications<br><br>Installations requiring plume abatement<br><br>Installations requiring water conservation<br><br>Low energy consumption<br><br>Easy maintenance | Medium to large HVAC and industrial applications<br><br>Installations requiring plume abatement<br><br>Installations requiring water conservation<br><br>Sound sensitive locations<br><br>Indoor installations |

1. Air in; 2. Air out; 3. Fluid in; 4. Fluid out; 5. Water, 6.Combined Inlet Shields; 7. Wet deck surface; 8. Cold water basin; 9. Water distribution system; 10. Spray water pump; 11. Coil; 12. Finned coil; 13. Three way valve.

| Counterflow | Counterflow / adiabatic pre-cooling |
|---|---|
|   |   |
| Dry fluid coolers cool the liquid in a closed circuit by means of sensible heat transfer using a high-densifty finned coil block | Dry coolers equipped with an adiabatic pre-cooler cool the liquid by sensible heat transfer only. Before the air is drawn through the high density finned coil however, it is pre-cooled adiabatically as it passes through an evaporative pad where water is evaporated in the air |
| Four sides | Two sides |
| Axial Fan,<br>Induced Draft | Axial Fan,<br>Induced Draft |
| 65 °C<br>High temperature execution available on DFC,<br>max. 150 °C, max. 10 bar pressure | 60 °C |
| Small to medium HVAC and industrial applications<br><br>Locations with limited water availability<br><br>Large range, large approach applications<br><br>High temperature industrial applications | Small to medium HVAC and industrial applications<br><br>Locations with limited water and limited space availability<br><br>High temperature industrial applications |

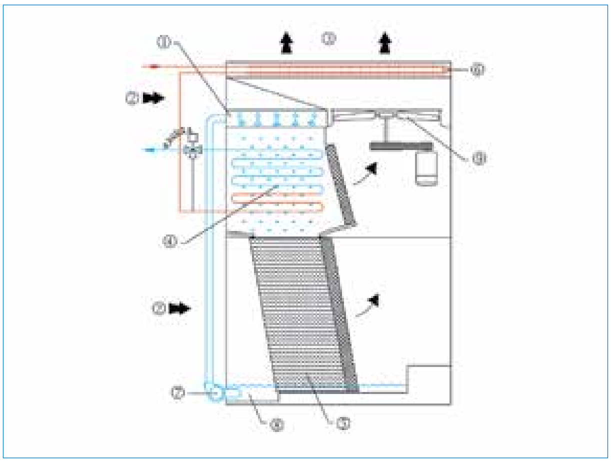
1. Dry heat exchanger coil; 2. Fluid Inlet. 3. Fluid Outlet; 4. Axial Fans; 5. High efficient evaporative cooling pad; 6. Water inlet connections; 7. Water outlet connections; 8. Adiabatic cooling of ambient air; 9. Air discharge; 10. Air in.

## 3. Operation Modes with Plume Abatement Coils and 3-Way Valves

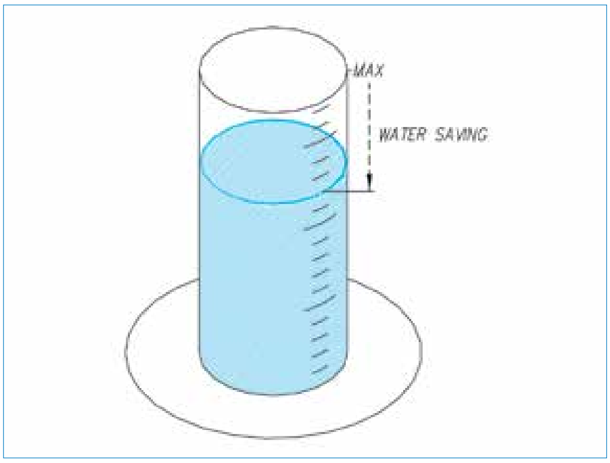
### Combined Dry / Wet Operation Mode

In this mode, the fluid to be cooled flows first to the dry finned coil and then to the prime surface evaporative coil, where the cooled fluid exits the unit. Spray water is drawn from the cold water basin and pumped to the water distribution system above the prime surface coil. Wetting the prime surface coil allows evaporative cooling to occur. The spray water falls from the prime surface coil over the wet deck surface, enhancing the evaporative heat transfer by sub-cooling the spray water. Air is drawn through both the prime surface coil and through the wet deck surface where it is saturated and picks up heat. The air is, however, still cold enough to achieve significant cooling within the finned coil, which is installed at the discharge above the fan(s).

In the dry/wet mode, both sensible and evaporative heat transfer are used. Compared to a conventional evaporative unit, the potential for plume is substantially reduced and significant water savings can be obtained, even at peak design conditions. At reduced heat load and/or ambient temperatures, the evaporative cooling portion, and hence water usage, are further reduced as the flow through the evaporative coil is gradually decreased. This is accomplished by a modulating flow control valve arrangement, which controls the outlet fluid temperature. This control arrangement automatically assures maximum use of sensible cooling in the finned coil and minimum use of evaporative cooling in the prime surface coil. The heat transfer method and flow control are arranged to achieve maximum water savings in the dry/wet mode. Plume is minimized by reducing the amount of evaporated water and the heating of the entire discharge air with the dry finned coil.



*Combined Dry/Wet Operation Mode*
1. Water Distribution System; 2. Air In; 3. Air Out; 4. Prime Surface Coil; 5. Wet Deck Surface; 6. Finned Coil; 7. Spray Pump; 8. Sump; 9. Axial Fan.

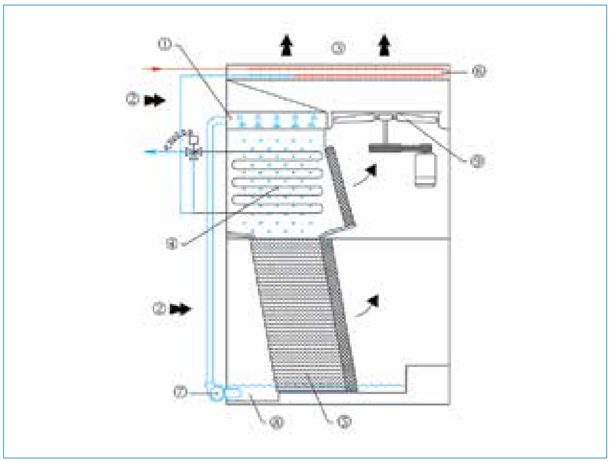



*Water Consumption*

## Adiabatic mode

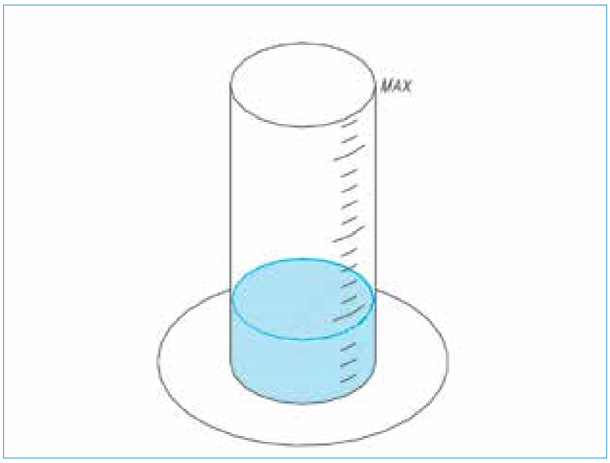
The adiabatic mode occurs when the fluid to be cooled completely bypasses the evaporative prime surface coil. No heat is rejected from this coil and the recirculating spray water merely serves to saturate and adiabatically pre-cool the incoming outside air. In most climates, the ambient air still has considerable potential for absorbing moisture.

Thus adiabatic cooling for the incoming air results in significantly lower air temperatures, which greatly increases the rate of sensible heat transfer. Compared to the conventional evaporative cooling equipment, visible plume and water consumption are greatly reduced while maintaining the low fluid design temperatures required to maximize system efficiency.



*Adiabatic Operation Mode*

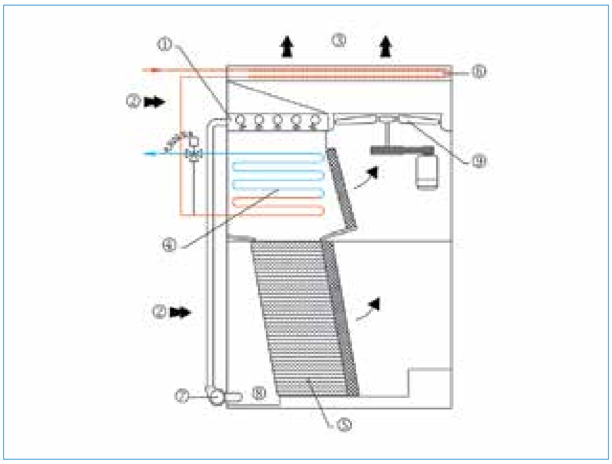
1. Water Distribution System; 2. Air In; 3. Air Out; 4. Prime Surface Coil; 5. Wet Deck Surface; 6. Finned Coil; 7. Spray Pump; 8. Sump; 9. Axial Fan.




*Water Consumption*

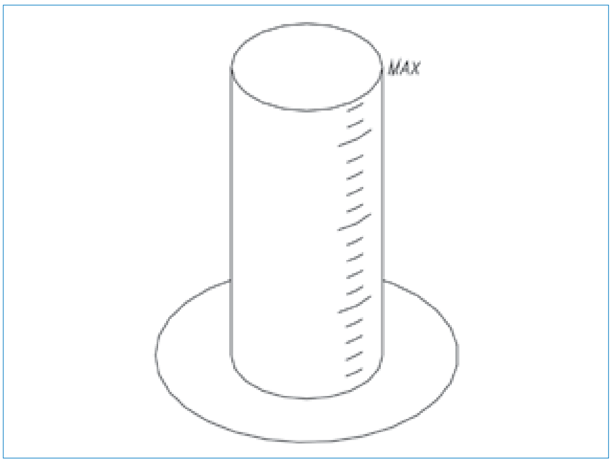
## Dry mode

During the dry operation mode the spray water system is turned off, saving on pump energy. The fluid to be cooled is fed from the finned coil to the prime surface coil. The modulating flow control valve remains fully open to ensure both coils receive the full flow in series; hence the maximum heat transfer surface is available. In this mode no water consumption occurs, and plume is completely eliminated. HXI units can be economically selected for dry bulb switchover points of 10°C to 15°C or higher, depending on the specific needs of the project. When the equipment operates in the dry mode for prolonged periods, draining the cold water basin is recommended, eliminating the need for freeze protection and water treatment.



*Dry Operation Mode*

1. Water Distribution System; 2. Air In; 3. Air Out; 4. Prime Surface Coil; 5. Wet Deck Surface; 6. Finned Coil; 7. Spray Pump; 8. Sump; 9. Axial Fan.




*Water Consumption*

# 4. Advantages Water Saving Products

## General

Low water and water treatment cost, vastly improved operational safety and virtual elimination of visible plume are the main advantages of "intelligent" water saving products from Baltimore Aircoil. With a choice between different configurations and a vast array of material options and accessories water saving technology from Baltimore Aircoil can be optimally incorporated in any application.

## Low Water Consumption

In many European countries water has become an expensive commodity and hence the cost of water often represents a significant portion of the total annual operating cost of conventional evaporative cooling equipment. To significantly reduce operating cost, BAC can offer a variety of "intelligent" water saving solutions. These solutions include air-cooled products with no water consumption at all, dry coolers with adiabatic pre-cooling and wet-dry hybrid coolers, which consume only water when needed and as much as needed. The broad array of water saving products allows to optimise a choice for each application, including the ones where low cooling temperatures need to be achieved during a hot summer day. The cost premium associated with water saving products is usually offset in short time by the operating cost savings that can be achieved.

## Lower Water Treatment Cost

The cost for water treatment in cooling applications is generally related to the amount of water consumed during a year. Water saving "intelligence" therefore also saves water treatment cost. For hybrid products and dry coolers with adiabatic pre-cooling periods of dry operation exist, where no water treatment at all is needed and the water treatment system does not need to be inspected, since there is no water in the products. In particular for dry coolers with adiabatic pre-cooling, extensive periods of dry operation can be expected. During such periods no biological contamination of the environment can happen.

## Reduction / Elimination of Visible Plume

In certain applications visible plume is considered as hinder. The use of "intelligent" water saving products from BAC will either greatly reduce the formation of visible plume or completely eliminate it. Especially when during the winter period dry operation of the products can be applied, the occurrence of visual plume will virtually be eliminated.

# Connection Guide

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## 1. Introduction

A summary of connection types used by BAC follows. The specific connection type for a particular BAC model can be found on the unit print drawing or from your local BAC Balticare Representative.

## 2. Beveled for Welding (BfW)

This connection type is a pipe stub with a "beveled" edge. The bevel allows for easier welding in the field and a full penetration weld. Weld materials fill the trimmed area between two beveled edges as shown here.

## 3. Grooved to Suit a Mechanical Coupling

This connection type is a pipe stub with a groove to accept a mechanical pipe coupler.

## 4. Stud Circle Flat Face Flange

This connection type is a standard bolt and hole pattern at the point of connection to mate to a EN 1092 Flat Face Flange. When BAC provides this connection type to a hot water basin, mounting bolts are permanently fastened to the connection plate. All other components (piping, nuts, bolts, flatwashers, etc.) are provided by others unless otherwise specified.

## 5. Male Pipe Thread (MPT)

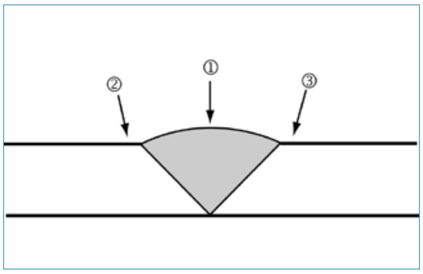
This connection type is a threaded pipe stub connection designed to mate with a Female Pipe Thread (FPT) fitting.

## 6. Sleeve Connection

A sleeve connection is used to connect two adjoining (PVC) pipes of two different sections, e.g. pump piping, of one unit. The sleeve's material is rubber and can handle pressures up to 5 bars.

## 7. Clamp Connection

4" or 6" RVS coupling with NBR seal to connect the piping from the dry to the wet coil on a hybrid cooler




*Weld Details*
1. Weld Material, 2. Beveled edge of field-installed piping, 3.Beveled Edge of BAC connection.

*Grooved Connection*
1. Grooved for mechanical coupling

*Flat Face Flange pattern is shown on this cold water basin panel to suit a EN 1092 flange*

*Flat Face Flange pattern with mounting bolts is shown on this hot water basin panel to suit a EN 1092 flange*

*Sleeve Connection*

*Clamp Connection*

*MPT Connection*

# Materials of Construction 8

## 1. Introduction

Operating environment, desired life expectancy, and budget all influence the materials of construction selected for an evaporative cooling unit. BAC products are available in a variety of materials and BAC designs focus on long life and easy maintenance. As a result, owners can maximize their operational goals.

This section describes the materials of construction available for BAC products. To determine the best material options for your specific project, consult your local BAC Balticare Representative.

## 2. Galvanized Steel

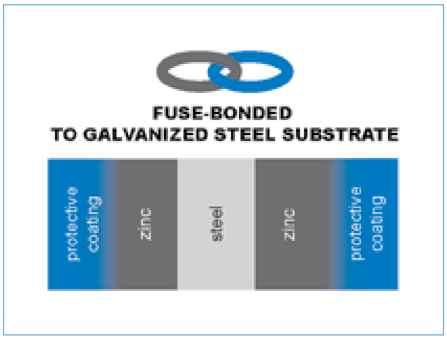
Hot-dip galvanized steel is the heaviest commercially available galvanized steel, universally recognized for its strength and corrosion resistance. To assure long-life, hot-dip galvanized steel is used as the base material for all steel products and parts, and all exposed cut edges are protected with a zinc-rich coating after fabrication. With good maintenance and proper water treatment, galvanized steel products will provide excellent service life under the operating conditions normally encountered in comfort cooling and industrial applications.

## 3. Baltiplus Protection

Hot-dip galvanized steel protected with a polymeric paint finish on the exterior after fabrication.

## 4. Baltibond Hybrid Coating

The new generation Baltibond hybrid coating is a unique system approach to evaporative cooling equipment protection. A special hybrid polymer, formulated for tenacious bonding, toughness, and impermeability to fluids, is applied by electrostatic spray to hot dip galvanized steel surfaces. The polymer undergoes a heat-activated, thermosetting cure process, fuse-bonding it to the galvanized steel substrate.




The Baltibond hybrid coating can extend the service life of equipment and alleviates concerns with white rust, virtually eliminating the need for periodic passivation of galvanized steel components.

## The new generation Baltibond Hybrid Coating


**Galvanized Steel**
Galvanized steel is the base material of the Baltibond hybrid coating. Galvanizing of the steel at the mill assures consistent quality of the zinc layer.

**Component Fabrication**
Individual components are fully fabricated prior to coating so there is no violation of the Baltibond hybrid coating finish between coating and assembly of the parts.

**Surface Preparation**
After each component is fabricated it undergoes a four step process to prepare it for powder coating. This process comprises cleaning and etching of the galvanized steel surface, rinsing and thoroughly drying.

**Powder Application and Curing**
A proprietary polymeric, thermosetting powder is applied to the pre-treated components by means of electrostatic spraying to ensure complete and uniform coverage of all surfaces.
After application of the powder, a closely controlled thermally activated curing process fuse bonds the coating to the galvanized steel substrate.

**Unit Assembly**
All parts, including panels, structural members, covers, doors, fan wheels (centrifugal), strainers and guards are coated to ensure complete, uniform protection.
The parts are assembled with compatible corrosion resistant fasteners. Sealing washers are used in water contact areas to ensure leak free construction.

## 5. Stainless Steel

In certain critical applications the use of stainless steel is preferred. BAC offers stainless steel as an optional material on most of its product lines. Two types of stainless steel are available, AISI 304 (DIN Werkst. Nr. 1.4301) or AISI 316 (DIN Werkst. Nr. 1.4401 or 1.4404). Stainless steel AISI 316 is recommended for applications with chloride concentrations of more than 250 ppm in the circulating water.

## 6. Component Construction

In addition to the various materials available for the structure of its units, BAC carefully selects the materials used for all components of its products. Additional materials such as corrosion resistant fiberglass reinforced polyester (FRP), polyvinyl chloride (PVC), aluminum and copper are used for components when necessary to provide the corrosion resistance required of a unit providing evaporative cooling service.

## 7. Which material option is Right for my Project?

Included within the product section of each open cooling tower, closed circuit cooling tower and evaporative condenser in this catalog is a discussion on construction options. These sections define the availability of certain materials and combinations of materials for each product. Refer to these sections for specific product information. Your local BAC Balticare Sales Representative can guide you on the proper unit construction for your specific project.

## 8. System Considerations

*Passivation of Iron Piping (Chemical Corrosion Inhibition)*

If a cooling system is to be filled but not used at a significant load for a few weeks, the system should be treated with a corrosion inhibitor at sufficient concentration to allow film formation (this is a higher concentration than film maintenance). This treatment usually involves circulating appropriate corrosion inhibitors for at least 24 hours. After this chemical treatment, the corrosion inhibitors may remain in the system while operating. As the system is operated, the chemical additives will be purged in the blow down. At the same time the calcium carbonate (which is naturally in the make-up water) will concentrate to provide corrosion protection without additional chemicals. If the equipment is to be commissioned and not used for a while, it is important that the corrosion-inhibiting chemicals remain in the unit to minimize general corrosion until the tower water is concentrated to the saturation of calcium carbonate. It is also advisable to circulate the water at least once per week to allow the corrosion inhibitors to do their job.

*Conditioning Galvanized Equipment to prevent Zincoxide*

In addition to the cleaning previously specified, immersion surfaces of new galvanized (zinc-coated) units should be conditioned by maintaining the pH of the system between 7,5 and 8,3 for 6 to 8 weeks. This protective conditioned surface will appear as a dull gray finish, replacing the shiny metallic appearance of new-galvanized sheets. Once the conditioning is established, it is permanent unless damaged by aggressive environments (pH less than 6,5) or mechanical bruising, in which case conditioning must be repeated. Failure to condition immersed areas on galvanized steel may produce a white "waxy" residue of zincoxide, called "white rust". Damage under the white rust tends to be rather shallow; therefore, unless white rust is extensive, it affects only the appearance of the unit rather than significantly shortening its life.

The preferred method for maintaining the pH range for the conditioning period is by dilution of circulating water with make-up water through blow down control. Based on make-up water analysis, the conductivity setting for the blow down controller will be adjusted to maintain the pH between 7,7 and 8,1. Periodic testing of pH will verify that the pH is within this range. During the conditioning period, water usage for blow down will likely be higher than normal; however, the cost of natural conditioning through blow down control will be more economical than conditioning with chemicals.

If make-up water is above 8,3, it is usually due to lime softening. If so, a few days of operation will reduce the pH to below 8,3. At that time, the water chemistry can be re-evaluated and a new conductivity setting can be provided to follow the above procedure.

# Selection Software

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## 1. Easy-to-Use Selection Software

BAC has developed comprehensive selection software, which simulates the performance of cooling equipment for a broad range of climatic and operating conditions and provides all technical data relevant to the selected model(s). The selection programme provides the ability to make selections for a wide range of operating conditions simultaneously for different product lines and hence allows side by side comparisons of different unit configurations.

Product selections often contain reserve capacity at the design conditions. Selections can be optimised by maximising flow rates, hot and cold water temperatures, wet bulb temperatures or approach.

## 2. Cooling Towers Selections

The cooling tower selection programme provides equipment selections for applications utilising clean or dirty water as a process fluid.

## 3. Closed Circuit Cooling Tower / Hybrid Selections

The closed circuit cooling tower selection programme provides equipment selections for applications utilizing water, aqueous ethylene glycol or aqueous propylene glycol as the process fluid.

## 4. Evaporative Condenser / Hybrid Selections

The evaporative condenser selection program provides equipment selections for applications utilizing R-717 (ammonia) and HFC refrigerants.

## 5. Dry and Adiabatic Pre-Cooling Selections

The dry and adiabatic pre-cooling selection programme provides equipment selections for applications utilising water, aqueous ethylene glycol or aqueous propylene glycol as a process fluid.

## 6. Accessories

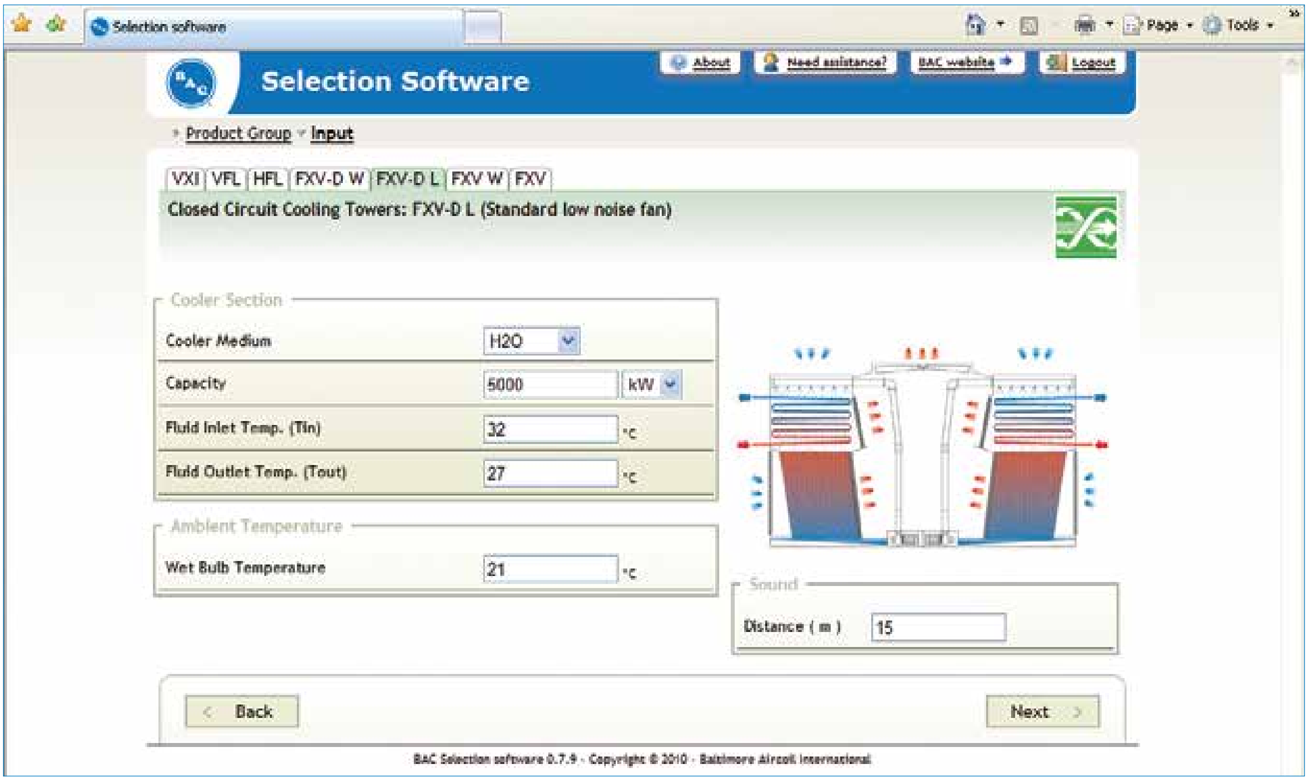
The selection program evaluates the use of accessories that may impact capacity (i.e., low-sound fans, sound attenuation, plume abatement coils, etc.)

## 7. Sound Data

The selection program provides sound ratings for standard selections at any distance for your reference. For extremely sound sensitive installations, sound ratings are also available for units with low sound fans and sound attenuation.

## 8. Website

The BAC selection software can be accessed through our web site www.BaltimoreAircoil.com (European Operations). Upon request an access code will be provided to allow on-line use of the selection programme.




*Example of the BAC web selection software*

# The Value of Standards

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## 1. Introduction

Baltimore Aircoil strongly believes in the value of standards and independent certification programmes. Through this philosophy customers can be assured of consistent level of performance and quality when using BAC products and services.

## 2. ISO9001:2008

This fundamental belief is demonstrated first and foremost by ISO9001:2008 Certification of BAC's design, engineering and manufacturing of evaporative cooling products. Compliance with ISO9001:2008 standards offers BAC customers better, more consistent quality, reliable performance, and confidence that the product can be delivered on time and per the specifications. Consistent quality also reduces the potential for installation and operational problems. Any problems reported from the field receive swift corrective and preventative actions to prevent reoccurrence. This level of performance is assured through frequent internal training and audits, backed by rigorous external audits by an independent, ISO-accredited Registrar. ISO9001:2008 also requires demonstrating continuous improvement of products, processes, and systems over time, benefiting both BAC and its many customers.

ISO 9001:2008 certified

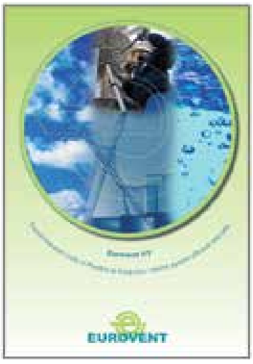
## 3. European Directives and Standards

The design of BAC products is influenced by European Directives and recognised standards. Examples include (but are not limited to) the following:

- European Machine Directive
- European Pressure Equipment Directive PED
- ATEX Directive
- Thermal performance acceptance testing of mechanical draught series wet cooling towers.
- Method of measurement and evaluation of thermal performances of wet cooling towers.

Besides supporting these directives and standards, BAC actively works with industry organisations, such as ASHRAE, ASME, CEN, ARI, CTI, EUROVENT and FM to improve their standards and technical documentation, or develop standards or guidelines where none currently exist. For instance, BAC supported the development of the "Recommended Code of Practice to keep your Cooling System efficient and safe", and the brochure "Evaporative Cooling, how efficient heat transfer technology helps to protect the environment", both published by EUROVENT. More recently BAC supported the development of the VDMA Einheitsblatt 24649 "Empfehlungen zum wirksamen und sicheren Betrieb einer Verdunstungskühlanlage". BAC is an active member of numerous trade associations in the US and in Europe.

BAC strongly encourages customers, suppliers, and competitors to join us developing and supporting recognised standards and certification programmes for the benefit of the industry and the society as a whole. BAC welcomes feedback on this subject, which can be send to info@BaltimoreAircoil.be.




*Eurovent Recommended Code of Practice*


*Eurovent Evaporative Cooling Brochure*

# Layout Guidelines

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## 1. Introduction

Open circuit cooling towers, closed circuit cooling towers and evaporative condensers all depend upon an adequate supply of fresh, ambient air to provide design capacity. Other important considerations such as the proximity to building air intakes or discharges also must be taken into account when selecting and designing the equipment site. Included are the design layout guidelines for evaporative cooling products in several situations typically encountered by designers. These guidelines represent **minimum recommended spacing requirements**; more open spacing should be utilized whenever possible.

As the size of an installation increases, the total amount of heat being rejected to the atmosphere and the volume of discharge air increase - to the point where the units can virtually create their own environment. As a result, it becomes increasingly difficult to apply a set of general guidelines for each case. Such installations, and particularly those in wells or enclosures, will recirculate and the problem becomes one of controlling the amount of recirculation and/or adjusting the design wet-bulb temperature to allow for it. Consequently, any job that involves four or more cells should be referred to your local BAC Balticare Representative for review.

## 2. Location

Each unit should be located and positioned to prevent the introduction of the warm discharge air and the associated drift, which may contain chemical or biological contaminants including Legionella, into the ventilation systems of the building on which the unit is located or those of adjacent buildings.

*For detailed recommendations on layout, please consult your local BAC Balticare Representative.*

For forced draught counterflow products, bottom screens or solid bottom panels may be desirable or necessary for safety, depending on the location and conditions at the installation site.

## 3. General Considerations

When selecting the site for a cooling tower, closed circuit cooling tower, an evaporative condenser or a water saving hybrid wet/dry product, consider the following factors:

♦ Locate the unit to prevent the warm discharge air from being introduced into the fresh air intakes of the building(s) served by the unit, intakes of neighbouring buildings, or from being carried over any populated area such as a building entrance.

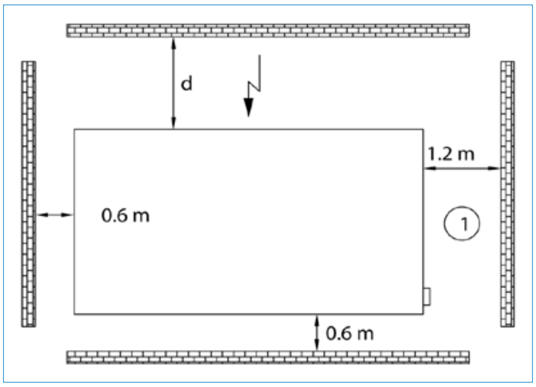


*Figure 1: Plan view for single air inlet unit*
1. Connection end

- Consider the potential for plume formation and its effect on the surroundings, such as large windowed areas, and pedestrian or vehicular traffic arteries, particularly if the unit(s) will be operated during low ambient temperatures.
- Provide sufficient unobstructed space around the unit(s) to ensure an adequate supply of fresh, ambient air to the air intake. Avoid situations that promote recirculation of unit discharge air, such as units located:
  a. Adjacent to walls or structures that might deflect some of the discharge air stream back into the air intake.
  b. Where high downward air velocities in the vicinity of the air intake exist.
  c. Where building air intakes or exhausts, such as boiler stacks in the vicinity of the unit, might raise the inlet wet-bulb temperature or starve the unit of air.
- Provide adequate space around the unit for piping and proper servicing and maintenance, as shown in the figures.

Besides the layout situation, a distinction can be made between different unit configurations:
- unit with only one air intake side
- units with two air intake sides
- units having air intakes on all four sides

For forced draught counterflow units the connection end is situated at the opposite end of the air intake.

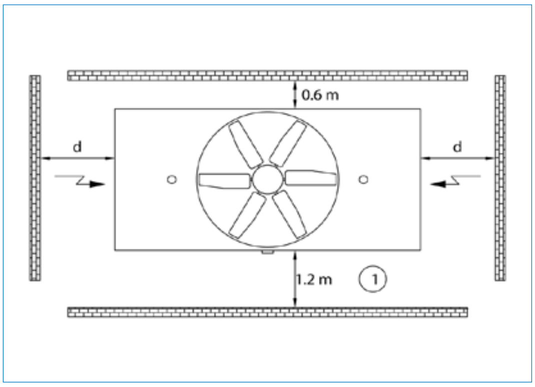


*Figure 2: Plan View for dual air inlet unit*
1. Connection End.

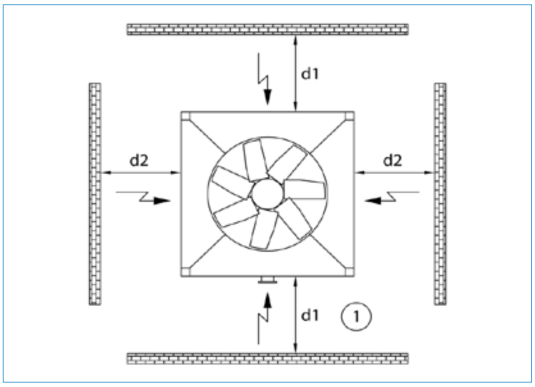


*Figure 3: Plan View for four air inlet unit*
1. Connection End.

- The top of the fan discharge cylinder, velocity recovery stack, or discharge sound attenuation must be at least level with, and preferably higher than any adjacent walls or buildings.
- When possible, orient the unit so the prevailing summer wind blows the discharge air away from the air intakes of the unit(s).
- When the unit is installed with intake sound attenuation, the distances should be measured from the face of the intake sound attenuation.
- On larger unit installations, the problem of ensuring an adequate supply of fresh, ambient air to the tower intake becomes increasingly difficult. See the "Multi Unit Installation" section of this article for specific considerations.
- If the installation does not meet the recommended guidelines, the units will have a greater tendency to recirculate and the design conditions should be altered to include an allowance for the recirculation. For instance, if the design conditions are 32 / 27 / 21°C and it was estimated that the allowance for recirculation rate was 1 °C, then the new design conditions would be 32 / 27 / 22°C and the units should be reselected based on the new design conditions.

The "Layout Guidelines" describe several typical site layouts for BAC's cooling towers, closed circuit cooling towers, water saving hybrid wet-dry products and evaporative condensers.

In most cases, the site layout can be categorised according to one of the following situations:
- Adjacent to a building or wall
- Well installation
- Louvered well installation
- Multi unit installation
- Indoor installation
- Dry Coolers and Dry Coolers with Adiabatic Pre-Cooling

If these guidelines do not cover a particular situation or if the layout criteria cannot be met, please refer the application to your BAC Balticare Representative for review. Please indicate prevailing wind direction, geographic orientation of the unit(s), and other factors such as large buildings and other obstructions that may influence layout decisions.

# 4. Adjacent to a Building or a Wall

*General*

- **Unit Orientation:**
  When a unit is located near a building wall, the referred arrangement is to have the unit situated with the cased end or blank-off side (unlouvered side) facing the adjacent wall or building.
- **Air Inlet Requirements:**
  Should it be necessary to install a unit with the air intake facing a wall, provide at least distance "d" between the air intake and the wall, as illustrated in the figures that follow (see "Examples").

Below is the method for determining the minimum acceptable dimension "d" for a unit located with the air intake facing a solid wall:
The maximum acceptable envelope air velocity for all products - except centrifugal fan units with tapered hood - is 1,5 m/s, as illustrated in the following equation:

$$\textbf{Evenlope Velocity} = \frac{\text{Unit Airflow}}{\text{Envelope Area}} < 1{,}5\ \text{m/s}$$

For centrifugal fan units with a tapered hood the maximum acceptable air velocity increases to 2 m/s as illustrated in the following equation:

$$\textbf{Evenlope Velocity} = \frac{\text{Unit Airflow}}{\text{Envelope Area}} < 2\ \text{m/s}$$

The envelope area is illustrated in the figures that follow hereafter (see "Examples"):
[((L+0,6+0,6) x d) + 2(H+h) x d], where:

- "H" = height of the air intake face in meter
- "h" = elevation of the unit from the roof/ground/pad in meter. The maximum elevation is 1,2 meter
- "L" = length of the air intake in meter
- "d" = minimum acceptable distance between the wall and the air intake face in meter

Example: VXT-1200 adjacent to a solid wall

What is the minimum distance required between the air inlet of the VXT-1200 when installed facing a wall?

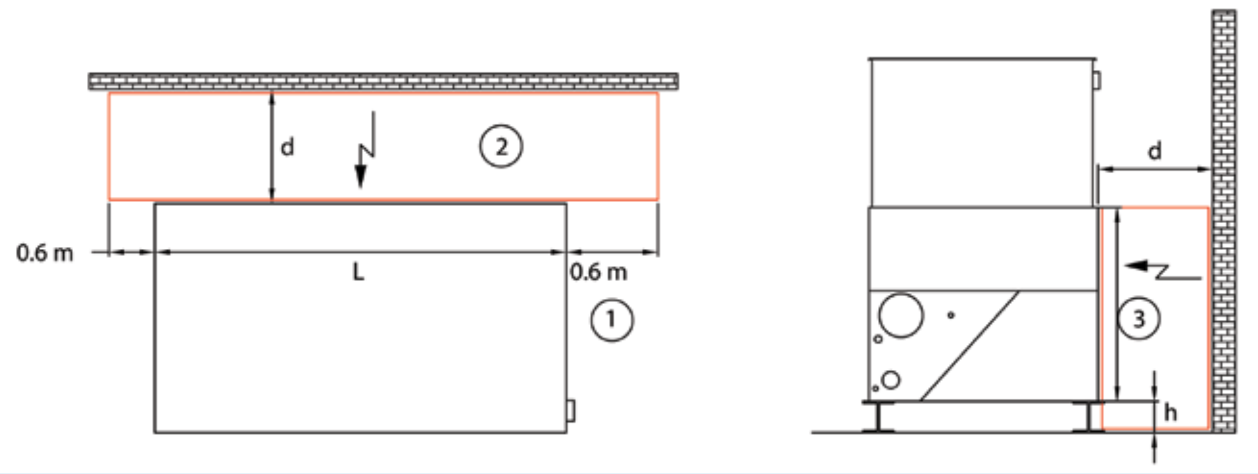


*Figure 4: Unit with Single Air Inlet adjacent to a Wall*
1. Connection End; 2. Envelope Area; 3. Air Intake Height

Unit Airflow = 109,87 $m^3$/s
H intake = 2,54 m
h = 0 m
0,60 + L + 0,60 = 12,10 m
1,5 m/s = maximum acceptable envelope air velocity with no hood
Envelope Velocity = Unit Airflow / Envelope Area

Solving for "d":

$$d = \frac{\text{Unit Airflow}}{1{,}5\ [2(H+h)+(L+1{,}2)]}$$

$$d = \frac{109{,}87}{1{,}5 \times [2(2{,}54+0)+(10{,}9+1{,}2)]}$$

$$d = 4{,}3\ \text{m}$$

Therefore, the air intake should be no less than 4,3 meter from the wall.

Example: S3-D1301-L adjacent to a solid wall

What is the minimum distance required between the air inlet of a single cell S3-D1301-L when installed facing a wall?

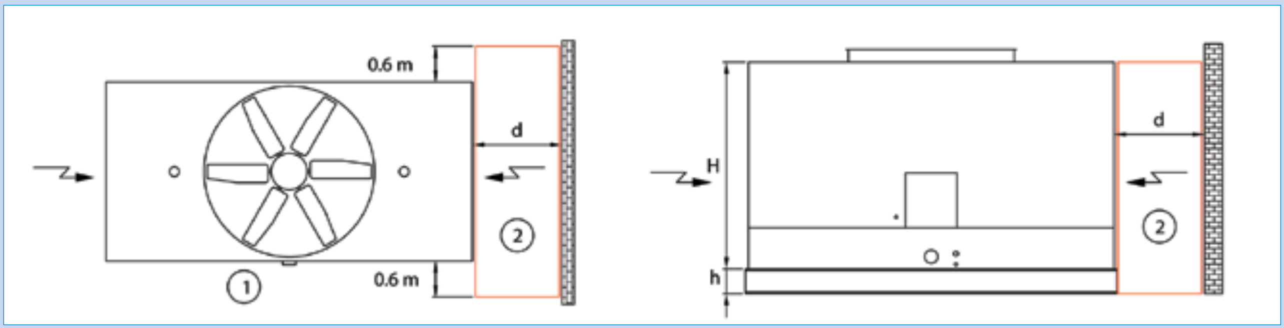


*Figure 5: Unit with two Air Inlets adjacent to a Wall*
1. Connection End; 2. Envelope Area

Unit Airflow = 138 $m^3/s$
H = 6,77 m
h = 0 m
L = 4,25 m
1,5 m/s = maximum acceptable envelope air velocity for a cooling tower

Envelope Velocity = Unit Airflow / Envelope Area

$$1{,}5\ \text{m/s} = \frac{138\ \text{m}^3/\text{s}\ /\ 2\ \text{air intake sides}}{[(0{,}60+4{,}25+0{,}60) \times d] + [2(6{,}77+0) \times d]}$$

$$d \times 18{,}99\text{m} = \frac{69\ \text{m}^3/\text{s}}{1{,}5\ \text{m/s}}$$

$$d = \frac{69\ \text{m}^3/\text{s}\ /\ 1{,}5\ \text{m/s}}{18{,}99\ \text{m}}$$

$$d = 2{,}42\ \text{m}$$

This is rounded up to the next 0,1 m increment. Therefore, the air intake should be located no less than 2,5 meter from the solid wall.

Example: PTE 0812A-3N-L1 adjacent to a solid wall

Below is the method for determining the minimum acceptable dimension “d” for a PTE located adjacent to one or more solid wall(s). The recommended envelope air velocity for a PTE Cooling Tower is 1,5 m/s.
We must solve the following equations for the desired distance, “d”:

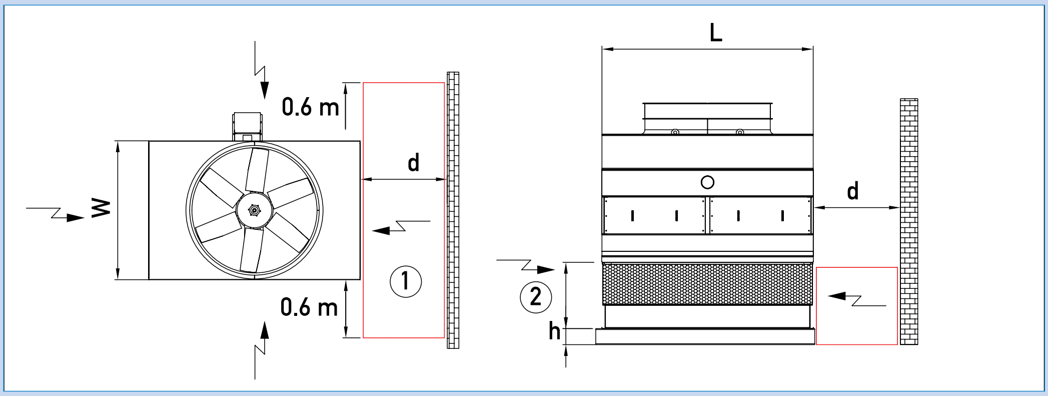


*Figure 6: Unit with Four Air Inlets adjacent to a Wall*
1. Envelope Area; 2. Air Intake Height

Envelope Air Velocity = % Airflow per Inlet / Envelope Area
% Airflow per Inlet = L (or W) / Total Air Inlet Perimeter
Total Air Inlet Perimeter = 2L + 2W

Envelope Area = [(L x d) + 2(A x d)] or [(W x d) + 2(A x d)], where:
- “A” = height air intake section
- “L” = length in meter
- “W” = width in meter
- “d” = minimum acceptable distance between the wall and the air intake face

What is the minimum distance required between the air inlet of an PTE 0812A-3N-L1 with air inlet face “L” when installed facing a wall? Find minimum acceptable distance “d”.

Unit Airflow = 31,7 $m^3/s$
A = 0,99 m
L = 3,60 m
W = 2,40 m
Total Air Inlet Perimeter = 2L + 2W = 12 m
1,5 m/s = suggested envelope air velocity for a cooling tower

Envelope Velocity = Airflow per Inlet / Envelope Area
% Airflow to Inlet = W / Total Air Inlet Perimeter = 2,40 / 12 = 20%

$$\mathbf{1{,}5\ m/s} = \frac{31{,}7\ m^3/s \times 20\%}{(2{,}40 \times d) + 2(0{,}99 \times d)}$$

Solve for “d” to find the distance from the “L” side of the unit to the wall:

$$\mathbf{d \times 4{,}38\ m} = \frac{6{,}34\ m^3/s}{1{,}5\ m/s}$$

$$\mathbf{d \times 4{,}38\ m} = \frac{6{,}34\ m^3/s\ /\ 1{,}5\ m/s}{4{,}38\ m}$$

**d =** 0,96 m

This is rounded up to the next 0,1 m increment. Therefore, the air intake should be located no less than 1 meter from the solid wall.

# 5. Well Installation

*General*

The following method is used to determine the minimum acceptable dimension "d" for units installed in a well layout.

The maximum allowable downward air velocity for a well installation is 2 m/s. The downward velocity is determined using the following equation:

$$\textbf{Downward Air Velocity} = \frac{\text{Unit Airflow}}{\text{Usable Well Area}} < 2 \text{ m/s}$$

*Note: The louver face airflow for the combined flow units is 70% of the total unit airflow. The remaining 30% of the airflow enters the unit through the top of the coil section.*

The useable well area at each air intake face is defined as illustrated in the figures that follow hereafter (refer to the section "Examples").

Useable Well Area = [(d)(1,2m+L+1,2m)] + [(1,2m x 0,3m) + (1,2m x 0,3m)], where:

- "d" = minimum acceptable distance between the air intake of the unit and the wall of the well in meter.
- "L" = length of the air intake of the unit in meter.

## Example 1a: Model VXI-144-3 in a Well Enclosure

If the VXI-144-3 has a tapered discharge hood, what is the minimum distance between the air inlet of the VXI-144-3 in a well?

Unit Airflow = 40,2 $m^3/s$
Length = 3,5 m
2 m/s = maximum allowable downward velocity for a VXI with tapered hood

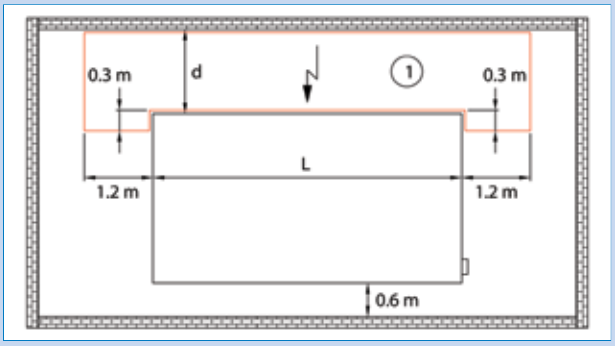


*Figure 7: Unit with Single Air Inlet in a Well Enclosure*
1. Useable Well Area.

$$\textbf{2 m/s} = \frac{40{,}2 \text{ m}^3/\text{s}}{(d\ (1{,}2 \text{ m} + 3{,}55 \text{ m} + 1{,}2 \text{ m})) + 2 \text{ x } (1{,}2 \text{ m x } 0{,}3 \text{ m})}$$

$$\textbf{d x 5,95 m + 0,72 m}^2 = \frac{40{,}2 \text{ m}^3/\text{s}}{2 \text{ m/s}}$$

$$\textbf{d} = \frac{(40{,}2 \text{ m}^3/\text{s} \ / \ 2 \text{ m/s}) - 0{,}72 \text{ m}^2}{5{,}95 \text{ m}}$$

**d =** 3,26 m

This is rounded up to the next 0,1 m increment. Therefore the air intake should be no less than 3,3 meter from the enclosure walls.

### Example 1b: Model FXV-443-M in a Well Enclosure

Unit Airflow = 31,9 $m^3/s$
L= 3,69 m
2 m/s = maximum allowable air downward velocity for a cooling tower
Downward Air Velocity = Louver Face Airflow / Useable Well Area

Solving for "d":

$$\mathbf{2\ m/s} = \frac{31{,}9\ m^3/s \times 70\%}{(d)(1{,}2 + 3{,}69 + 1{,}2) + 2x(1{,}2 \times 0{,}3)}$$

$$\mathbf{d \times 6{,}09\ m\ + 0{,}72\ m^2} = \frac{22{,}33\ m^3/s}{2\ m/s}$$

$$\mathbf{d} = \frac{(22{,}33\ m^3/s\ /\ 2\ m/s) - 0{,}72\ m^2}{6{,}09\ m}$$

**d =** 1,72 m

This is rounded up to the next 0,1 m increment. Therefore, the air intake should be no less than 1,8 meter from the enclosure walls.

### Example: Model S3-D1056-2L in a Well

Unit Airflow = 110,6 $m^3/s$ x 2 cells = 221,2 $m^3/s$
L= 2 x 3,60 m = 7,20 m
2 m/s = maximum allowable air downward velocity for a cooling tower
Downward Air Velocity = Unit Airflow / Useable Well Area

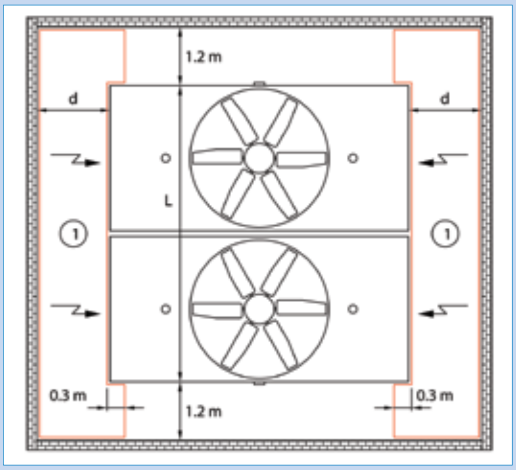


*Figure 8: Unit with Two Air Inlets in a Well Enclosure*
1. Useable Well Area

Solving for "d":

$$\mathbf{2\ m/s} = \frac{221{,}2\ m^3/s\ \times\ 2\ \text{air intake sides}}{(d)(1{,}2 + 7{,}2 + 1{,}2) + 2x(1{,}2 \times 0{,}3)}$$

$$\mathbf{d \times 9{,}6\ m\ + 0{,}72\ m^2} = \frac{110{,}6\ m^3/s}{2\ m/s}$$

$$\mathbf{d} = \frac{(110{,}6\ m^3/s\ /\ 2\ m/s) - 0{,}72\ m^2}{9{,}6\ m}$$

**d =** 5,68 m

This is rounded up to the next 0,1 m increment. Therefore, the air intakes should be no less than 5,7 meter from the enclosure walls.

# 6. Louvered Well Installation

*General*

Check to see if the layout meets the requirements for a well installation. If the criteria for the well installation are met, the layout is satisfactory. If the layout does not satisfy the criteria for the well installation, analyze the layout as follows:

- **Air intake requirements:**
  Units should be arranged within the enclosure such that:
  a. The air intake directly faces the louver or slot locations as shown in the following figures (see "Examples").
  b. Maintain a distance of at least 0,9 m between the unit air intake(s) and the louvered or slotted wall for uniform air distribution.

- **Louver Requirements:**
  a. Louvers must provide at least 50% net free area to ensure that the unit airflow is not reduced due to friction or dynamic losses and that sufficient air is drawn through the openings and not downward from above.
  b. The required total louver or slot area is based on drawing the total unit airflow through the net free area of the louvers at a velocity of 3 m/s or less.
  c. Locate the louver area in the walls of the enclosure such that air flows uniformly to the air intakes.
  d. If the unit is elevated to ensure the discharge is at the same level or above the top of the enclosure, it is acceptable to extend the louvered or slot area below the base of the units up to 0,6 m if needed to achieve the minimum gross louver area. To calculate air velocity through the louver, the useable louvered or slot area may extend beyond the ends of the unit, by 1,2 m maximum.

Calculate the louver velocity as follows:

$$\textbf{Louver Velocity} = \frac{\text{Total Unit Airflow } (m^3/s)}{\text{Louver Free Area (\%) x Useable Louver Area (m2)}} < 3 \text{ m/s}$$

Example: Model S3-D436 L in a Louvered Enclosure

The enclosure is 8 m long x 6 m wide x 3 m tall. The enclosure walls are equal in elevation to the unit discharge height.
The louvers are 70% free area and 0,9 m from the air inlet of the tower. The louvers extend the full width of the enclosure (5 m) on both air intake ends and they extend 2,5 m vertically of the 3 m enclosure height.

Unit Airflow = 49,2 $m^3/s$
Unit Length = 3,0 m
d max. = 1,2 m per side
Useable Louver Length = 1,2 + 3,0 + 1,2 = 5,4 m
(of total 6 m louver length)
3 m/s = Maximum Allowable Louver Velocity

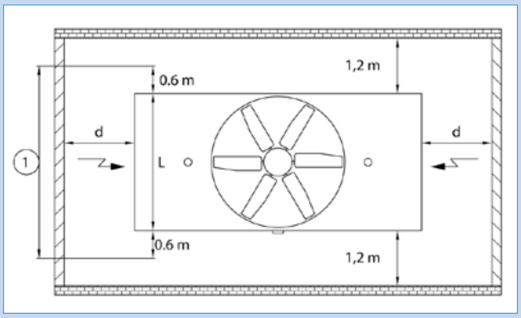


*Figure 9: Unit with Two Air Inlets in Enclosure with Louvered Walls*
1. Useable Louver Length

$$\textbf{Louver vel.} = \frac{\text{Louver Face Airflow } (m^3/s)}{\text{\% Louver Free Area x Useable Louver Area}}$$

$$\textbf{Louver vel.} = \frac{49{,}2\ m^3/s\ /\ 2 \text{ intake sides}}{70\% \text{ x } [(1{,}2+3{,}0+1{,}2) \text{ x } 2{,}5]}$$

$$\textbf{Louver vel.} = \frac{24{,}6\ m^3/s}{9{,}45\ m^2}$$

**Louver vel.** = 2,60 m/s

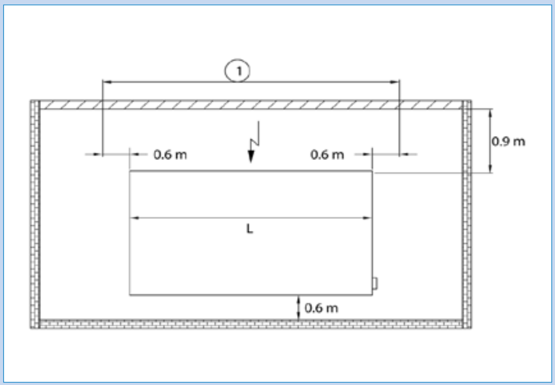


*Figure 10: Unit with Single Air Inlet in Enclosure with Louvered Wall*
1. Useable Louver Length

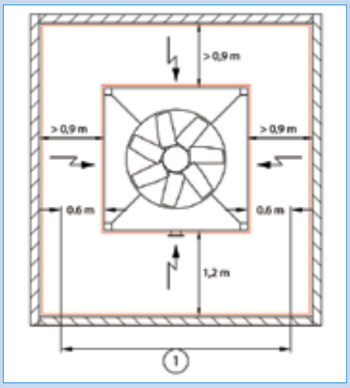


*Figure 11: Unit with Four Air Inlets in Enclosure with Louvered Walls*
1. Useable Louver Length

Therefore, louver sizing is sufficient because 2,6 m/s < 3 m/s maximum allowable. The same procedure as described above, can be followed in order to determine whether the layout meets the requirements for a louvered well installation.

## 7. Multi Unit Installation

- Multi unit installations adjacent to a building (wall) or in a well enclosure are subject to similar air velocities as those specified for individual units.
- An installation, consisting of several units, creates a "wall" of moist discharge air which could easily be swept into the air intakes due to prevailing wind. To minimize the potential of recirculation of the discharge air, the units should be situated with adequate spacing between air intakes.
  Therefore for units that are arranged with the air intakes facing each other, the distance between air intakes should follow this equation: M = (2 x d) + [(number of cells per module) x 0,3 m], where "d" is obtained from the appropriate model.
- Multi unit installations should be elevated a minimum of 0,6 m whenever possible to allow air equalisation under the cells, and minimize recirculation.
- When more than two units are installed indoor, it's recommended to use individual ductworks.

## 8. Indoor Installation

Many indoor installations require the use of inlet and/or discharge ductwork. **Units installed with inlet ductwork must be ordered with solid-bottom panels.** Generally, intake ducts are used only on smaller units while the equipment room is used as a plenum for larger units. Discharge ductwork will normally be required to carry the saturated discharge air from the building.
Both intake and discharge ductwork must have access doors to allow servicing of the fan assembly, drift eliminators, and water distribution system. All ductwork is supplied and installed by others and should be symmetrical and designed to provide even air distribution across the face of air intakes and discharge openings. Such ductwork may increase the external static pressure on the unit, requiring a larger fan motor to be installed. This external static pressure must be quantified (in Pa) to BAC to allow for suitable fan motor sizing.

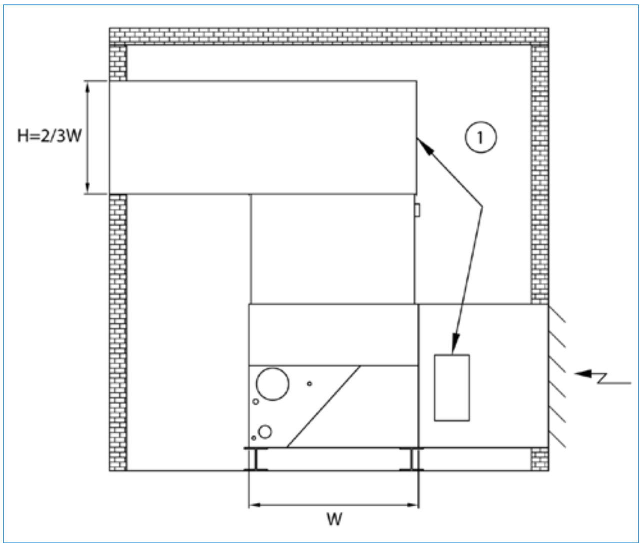


*Figure 12: Ducted Unit Enclosure*
1. Access Doors

**The discharge opening must be positioned to prevent the introduction of discharge air into the fresh air intakes serving the unit or the ventilation systems of adjacent buildings.**

*Axial fan units are not generally suitable for indoor or ducted installations. In such situations, centrifugal fan units are recommended.*

**Ductwork Requirements**

- Air velocities in the inlet duct should be kept below 4 m/s to hold static pressure losses to a minimum and ensure a uniform supply of air to all fans. In general the maximum allowable ESP on centrifugal fan units is 250 Pa. Consult your local BAC Balticare Representative for any ESP greater than 250 Pa.
- Air velocities in the discharge duct(s) should not exceed 5 m/s to reduce friction losses in the duct, and more importantly, to ensure uniform air through the unit.
- Turns in inlet or discharge ducts should be avoided. Where turns must be used, velocities should be minimized in the vicinity of the turn. Turns in discharge ducting should be designed in accordance with the "2/3 rd rule" shown in Figure 12.
- Where individual fan sections are to be cycled for capacity control, each fan section must be ducted as a separate system on both inlet and discharge to avoid recirculation within the ductwork. All ductwork systems should be symmetrical to ensure that each fan section operates against the same ESP.
- Access doors must be provided in both the inlet and discharge ducts.
- When multi-units are located indoors with the room as a plenum, the installation must be operated as a single unit to avoid pulling air through an idle cell.

## 9. Dry Coolers and Dry Coolers with Adiabatic Pre-Cooling

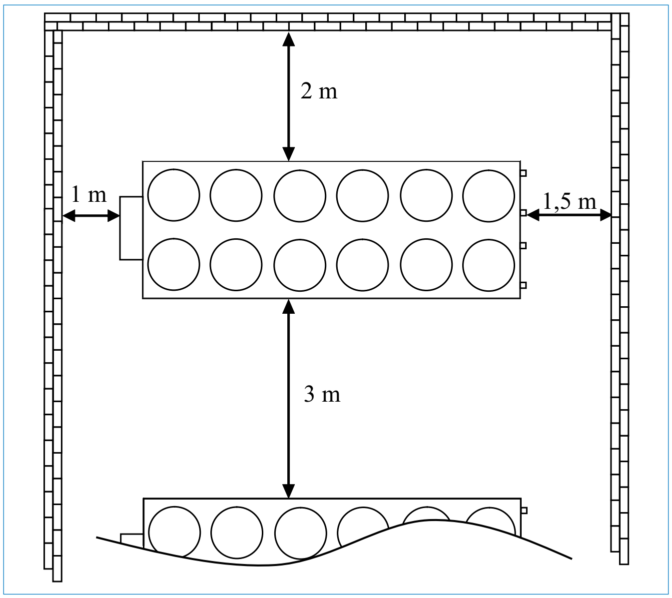

*Figure 13: V-shaped Dry Cooler*

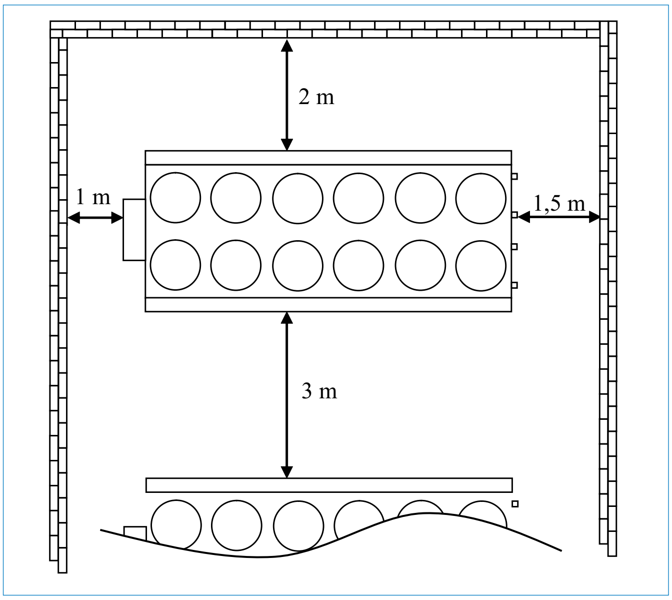

*Figure 14: Dry Cooler with Adiabatic Pre-Cooling*

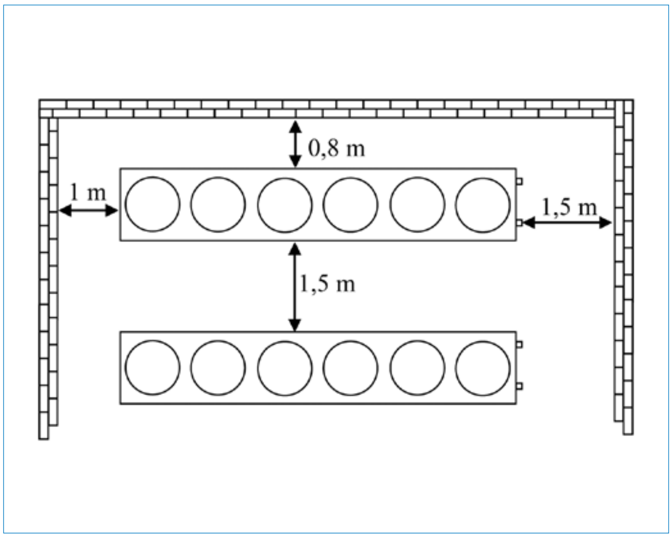

*Figure 15: Horizontal Dry Cooler - single row fans*

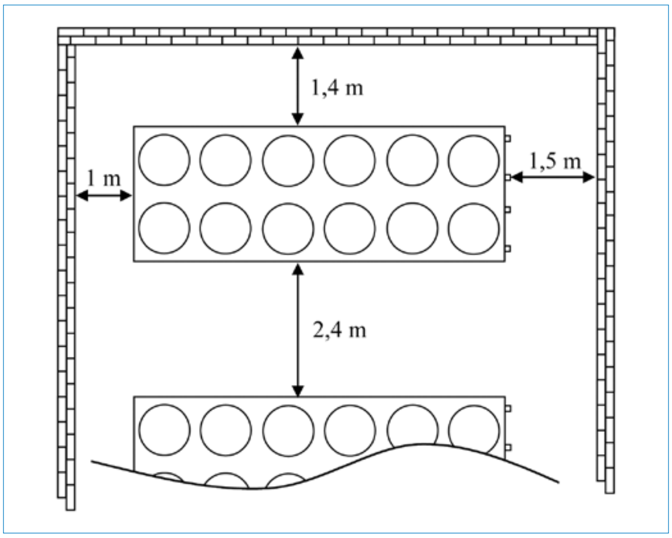

*Figure 16: Horizontal Dry Cooler - double row fans*

# Selection of Remote Sump Tank

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## 1. For an Open Cooling Tower

Remote sump tanks are used on evaporative cooling systems to provide a means of cold water basin freeze protection during cold weather operation. The remote sump tank is usually located in a heated, indoor space, and may preclude the need to winterize the evaporative cooling equipment. A remote sump tank must provide sufficient storage volume to accommodate all the water that will drain back to it during cooling system shutdown, including:

- **Cooling tower volume:** the total volume of water contained within the cooling tower during operation
- **System piping volume:** the volume of water contained in all system piping located above the operating water level of the remote sump tank
- **System components volume:** the volume of water contained within any heat exchanger, or other equipment located above the operating water level of the remote sump tank that will drain to the tank when the cooling system is shut down

The maximum volume of water contained within the cooling tower is the volume of water to the overflow level. Besides the water in the cold water basin during operation, this volume will take into consideration water in the distribution system, water in suspension in the wet deck, plus an allowance for the external pulldown from piping and other equipment. This simplified method is a conservative approach as it will not consider any volume reductions based on flow rates. For specific information for your application, contact your local BAC Representative.

*Safety Factor*
When designing a remote sump tank, make sure that your basin has a net available volume that is 5% greater than the total volume required. The net available volume is the volume between the operating level and the overflow level in the remote sump tank. The minimum operating level must be maintained in the remote sump tank to prevent vortexing of air through the tank's suction connection.

*Example*

A VTL-059-H will be installed on a cooling tower/heat exchanger system that will utilize a remote sump tank. The tower side volume contained in the heat exchanger is 95 liters. The system has been designed with 10 meter of DN 100 pipe that will be above the operating level of the remote sump tank. What is the correct remote sump tank volume?

Solution:
From the information on the website the cold water basin volume at overflow for the VTL-059-H is 555 liters.
From the information on the website, the DN 100 pipe will contain 8,2 liters of water per linear meter pipe. The total volume contained in the DN 100 pipe is 82 liters. The tower side volume of the heat exchanger is 95 liters.

The total volume required is:

| | |
|---|---|
| Cooling Tower Volume at Overflow | (555 liters) |
| + System Piping Volume | (82 liters) |
| + System Components Volume | (95 liters) |
| = Total Volume 732 liters | |

732 liters x 1,05 (safety factor) = 770 liters required.

From the above calculation the minimum volume of the remote sump tank must be 770 liters.

## 2. For a Closed Circuit Cooling Tower or Evaporative Condenser

*Note: This section provides instruction in the selection of a remote sump tank for a closed circuit cooling tower or evaporative condenser only.*

Remote sump tanks are used on evaporative cooling systems to provide a means of cold water basin freeze protection during cold weather operation. When the recirculating pump of a closed circuit cooling tower or evaporative condenser is not operating, all of the recirculating water drains by gravity to the remote sump. The remote sump tank is usually located in a heated, indoor space, and may preclude the need to winterize the cold water basin.

The remote sump must be sized to accommodate the suction head for the pump plus a surge volume to hold all the water that will drain back to the tank when the pump is shut down. This surge volume (also called drain down volume) includes water in the evaporative cooling equipment and water held in the piping between the unit and the remote sump. The volume of water in the evaporative equipment includes the water in suspension (water within the spray distribution system and falling through the heat transfer section) and water in the cold water basin during normal operation. The tables on the website provide the volume of water in suspension plus the water in the cold water basin, labeled as "basin volume at overflow level." The table on the website can be used to calculate the volume of water in the piping between the unit and the remote sump (includes riser and drain piping) for applications where piping is Schedule 40.

To select a remote sump tank for a particular application, determine the total volume (spray water volume plus piping volume) and select a remote sump tank with a net available volume that is 5% greater than required.
HFL hybrid closed circuit cooling towers do not require remote sumps. Due to their small water volume and the unique sump/ plenum design, they can switch from wet to dry operation and vice versa without the need to drain the sump. Electrical sump heaters will protect the sump from freezing at ambient temperatures as low as -25°C, even when the fan(s) is (are) in operation.

*Application Notes*
The standard close-coupled centrifugal pump normally furnished with BAC units is designed and selected specifically for the pump head and flow rate required when the pump is mounted on the unit. **This pump cannot be used for remote sump applications and is therefore omitted.**
The following factors should be considered when selecting remote pumps:

- Total static head from the remote sump tank operating level to the inlet of the evaporative equipment.
- Pipe and valve friction losses.
- For all closed circuit cooling towers and all evaporative condensers, 14 kPa water pressure is required at the inlet of the water distribution system.
- Required spray flow rate as shown in the relevant tables on the website

**A valve should always be installed in the pump discharge line so that the water flow can be adjusted to the proper flow rate and pressure.** Inlet water pressure should be measured with a pressure gauge installed in the water supply riser near the equipment inlet. The valve should be adjusted to permit the specified inlet pressure, which results in the design water flow rate.

Accurate inlet water pressure and flow rate are important for proper evaporative equipment operation. Higher pressure (in excess of 70 kPa) can cause leaks in the spray distribution system. Lower pressure or low flow may cause improper wetting of the coils, which will negatively affect thermal performance, promote scaling, and may also cause excessive drift.

On remote sump applications, the standard float valve(s) and strainer(s) are omitted from the cold water basin and a properly sized outlet connection is added. The remote sump outlet connection is located on the bottom of most units. On smaller counterflow forced draught units, the connection is located on the end or back side of the unit. To clarify the location of the remote sump outlet connection, refer to the appropriate unit print, available from your local BAC Balticare Representative or at www.BaltimoreAircoil.com.

Another effect of using a remote sump is that the operating weight of the evaporative unit is reduced (design changes, the omission of the integral spray pump, and/or changes in cold water basin volume can contribute to this deduct).

*Example*

An FXV-422 will be installed on a system that will also utilize a remote sump tank. The system has been designed with 12 meter of DN 150 mm pipe that will be above the operating level of the remote sump tank. What is the correct volume of the remote sump?

Solution:
From the table on the website, the spray water volume for an FXV-422 is 997 liters.
From the table on the website, the DN 150 mm pipe will contain 18,7 l/s of water per linear meter. The total volume contained in the DN 150 mm pipe is 12 meter x 18,7 liter/meter = 225 liters.

The total volume required is:

Spray Water Volume (997 litres)
+ System Piping Volume (225 litres)
= Total Volume 1222 litres

1222 litres x 1,05 (safety factor): 1283 liters required.

From the above calculation the minimum volume of the remote sump tank must be 1283 litres.

# Condenser Engineering Guidelines

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## 1. Introduction

The objective of a mechanical refrigeration system is to remove heat from a space or product, and to reject that heat to the environment in some acceptable manner.

Evaporative condensers are frequently used to reject heat from mechanical refrigeration systems. The evaporative condenser is essentially a combination of a water-cooled condenser, utilizing the principle of heat rejection by the evaporation of water into an airstream travelling across the condensing coil.

Evaporative condensers offer important cost-saving benefits for most refrigeration and air-conditioning systems. They eliminate the problems of pumping and treating large quantities associated with water-cooled systems. They require substantially less fan horsepower than air-cooled condensers of comparable capacity and cost. And most importantly, systems utilizing evaporative condensers can be designed for a lower condensing temperature and subsequently lower compressor energy input, at lower first cost, than systems utilizing conventional air-cooled condensers.
As with all mechanical equipment, it is essential that an evaporative condenser be correctly engineered to specific job requirements. It is the purpose of this manual to provide engineering and application data to accomplish this task.

## 2. The Refrigeration System

A schematic of a basic vapour compression system is shown in Figure 1 below. The corresponding heat transfer processes can be represented on a plot of pressure versus enthalpy as shown in Figure 2.

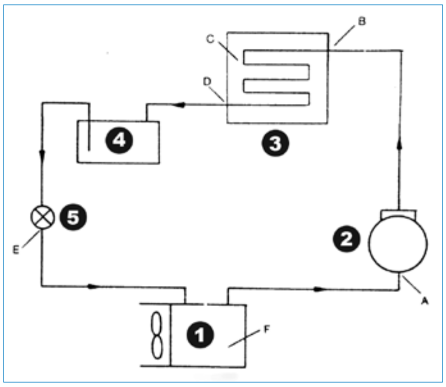



*Figure 1: Vapor Compression Refrigeration System*
1. Evaporator; 2. Compressor; 3. Condenser;
4. Receiver; 5. Throttling Device

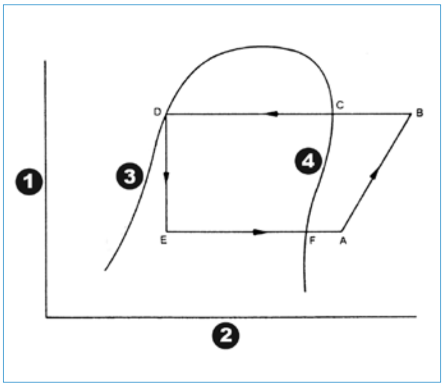



*Figure 2: Pressure Enthalpy Diagram for Compression Refrigeration System*
1. Pressure (N/cm2); 2. Enthalpy (kJ/kg);
3. Saturated Liquid; 4. Saturated Vapor

Refrigerant vapour enters the compressor from the evaporator at a slightly superheated condition (A) and is compressed to the condensing pressure (B). The amount of suction gas superheat (F-A) is a function of the type of the evaporator and the heat absorbed from the atmosphere as the gas travels along the suction line from evaporator to the compressor.

The compressor and further superheated vapor enters the heat rejection device (condenser) at Point B, where the superheat is quickly removed and the saturated vapor state (Point C) is reached. From Point C to Point D, condensation of the refrigerant occurs at constant pressure until the refrigerant reaches a saturated liquid state at Point D.

There may be some subcooling of the liquid refrigerant near the outlet of the evaporative condenser, but this is quickly dissipated in the drain line from the condenser to the receiver, and in the receiver itself. The drain line and the receiver contain both refrigerant liquid and vapor, and where these two phases coexist, it is impossible for the liquid temperature to remain below the saturation temperature. Therefore, the lower heat content of the subcooled liquid condenses some of the refrigerant vapor until an equilibrium condition is reached at a saturated temperature corresponding to the condensing pressure. So, from a practical standpoint, the refrigerant liquid going to the evaporator should be saturated as represented by Point D. The only exception to this is when a separate subcooling device is used to subcool the liquid after it leaves the receiver.
The refrigerant liquid at Point D is passed through a throttling device (orifice, capillary, or valve) where the pressure is reduced at a constant enthalpy to the system suction pressure at Point E. The refrigerant at Point E consists of liquid and vapor, the vapor resulting from the "flashing" of some of the liquid in order to cool the remaining liquid from condensing temperature (Point D) to the evaporation temperature (Point E). The evaporation of the remaining liquid from Point E to Point F represents the useful work of heat pick-up in the evaporation.

## 3. Refrigeration Heat Rejection Systems

*"Once-Through" Condensing System*
Water, because of its seemingly inexhaustible supply, stability, and heat transfer characteristics, has long been the principal medium used for heat rejection from refrigeration and air-conditioning systems.

The simplest heat rejection system is one using city, well or surface water directly through a refrigerant condenser and then dumping that water into the sewer, to the ground, or back to the surface water source (see Figure 3). The heat removed in the condenser is dependent upon the temperature rise and the flow rate of the water. For an average heat rejection of 12,5 kW per 10 kW of refrigeration and a water temperature rise of 11°C in the condenser, approximately 0,27 l/s of water per 10 kW must be supplied to and wasted from the refrigerant condenser.

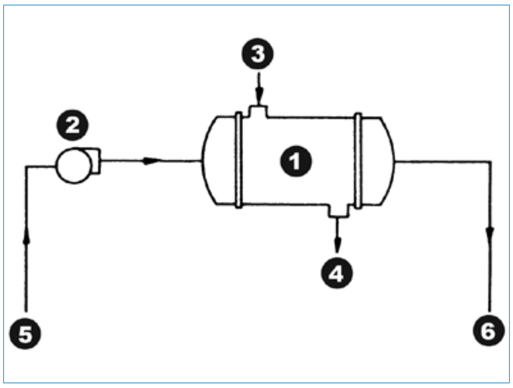



*Figure 3: "Once-Through" Condensing Systems*
1. Refrigerant Condenser; 2. Pump; 3. Refrigerant Vapor In; 4. Refrigerant Liquid Out; 5. City, Well or Surface Water 16°C (0.027l/s / 1kW); 6. Hot Water to Sewer 27°C

This "once-through" type of system at one time was used almost universally for refrigerant condensing. However, the increasing cost of water, high sewerage charges, and restrictions on thermal pollution have made this type of system uneconomical and obsolete.

*Refrigerant Condenser and Cooling Tower*
One of the early modifications to the "once-through" system was the addition of a cooling tower to permit recirculation of the cooling water and thus conserve water. In a cooling tower, the heated water from the condenser is brought in contact with air, and a small portion of the water is evaporated into the airstream. For each kg of water evaporated, approximately 0,65 kWh are removed from the remainder of the recirculated water. Therefore, only 4,3 x 103 l/s water is used per 10 kW of refrigeration, a theoretical savings of 98% of the water required by the "once-through" system. In actual practice, however, the savings is approximately 95%, because a small amount of water must be "bled-off" from the system in order to control the concentration of impurities in the recirculated water.

The temperature of the water leaving the cooling tower is determined by the ambient air wet bulb temperature. In most areas, design wet bulb temperatures are such that the temperature of the water leaving the cooling tower is substantially higher than well or surface water temperatures. Therefore, to compensate for the higher cooling water temperature, and the additional step of heat exchange introduced by

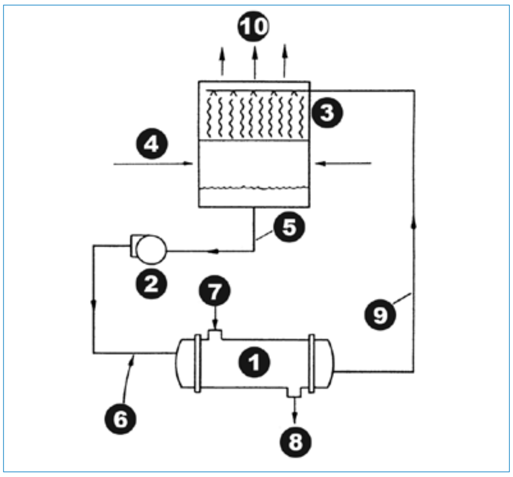



*Figure 4: Refrigerant Condenser with Cooling Tower*
1. Refrigerant Condenser; 2. Pump; 3. Cooling Tower; 4. Wet Bulb 25°C (30 l/s / 1kW); 5. 30°C; 6. Water Recirculated at 0.08 l/s / 1kW (High pumping head); 7. Refrigerant Vapor In; 8. Refrigerant Liquid Out 38°C; 9. 33°C; 10. Air Discharge

the cooling tower, the condenser water circulation rate and the design condensing temperature often must be increased in comparison to a "once-through" system.

Figure 4 shows a typical arrangement for a cooling tower/refrigerant condenser system. The recirculated water flow rate of 0,08 l/s per 1 kW of refrigeration and the 3°C water temperature increase are representative of those existing in an ammonia refrigeration system. The 38°C condensing temperature is about the practical minimum that could be obtained at a 25°C design wet bulb temperature. Since the pump must circulate water through the refrigerant condenser, cooling tower, and interconnecting piping, a relatively high pumping head is required.
Halocarbon refrigerant systems may be and usually are designed for somewhat higher condensing temperatures than ammonia systems. This permits a higher water temperature rise through the condenser, but increases the compressor power. Water circulation is normally 0,048 l/s per 1 kW versus 0,08 l/s through 0,096 l/s per 1 kW required for an ammonia system.

*Air-Cooled Condensers*
The air cooled condenser is another type of heat rejection device used for refrigeration and air-conditioning systems.

Figure 5 shows a typical air-cooled condenser. Since it does not utilize the evaporative principle, the amount of cooling in the air-cooled condenser is a function of the ambient dry bulb temperature. Design dry bulb temperatures are normally 8°C to 10°C higher than design wet bulb temperatures, so condensing temperatures using air-cooled equipment will be at least that much higher than condensing temperatures using evaporative cooling, resulting in increased compressor horsepower.

Air-cooled condensers reject heat from the refrigerant by sensible heating of the ambient air that flows through them.

The low specific heat of air results in a large volume flow rate of air required (approximately four times that of evaporative cooling equipment) with corresponding high fan horsepower and large condenser plan area.

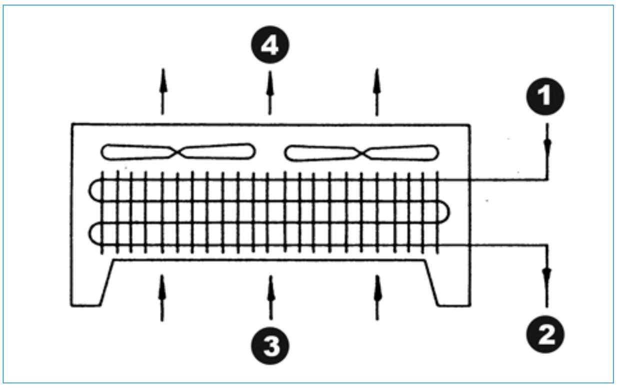


*Figure 5: Air-Cooled Condenser*
1. Refrigerant Vapor In; 2. Refrigerant Liquid Out 45°C; 3. D.B. Inlet Air 35°C (130 l/s : 1kW); 4. Air Discharge

The net result of the use of an air-cooled condenser is a savings of water, but at the expense of increased power consumption by the compressor and the condenser.

*Evaporative Condensers*
Evaporative condensers reject heat from refrigerant and air-conditioning systems while using minimum quantities of energy and water. As shown in Figure 6, water is pumped from the pan section and is distributed over the exterior of the condensing coil by a series of distribution troughs or spray nozzles. The flow rate of water needs only be enough to thoroughly wet the condensing coil to provide uniform water distribution and prevent accumulation of scale. Therefore, minimum pumping head is required.

A fan system forces air through the falling water and over the coil surface. A small portion of the water is evaporated, removing heat from the refrigerant, and condensing it inside the coil. Therefore, like the cooling tower, all of the heat rejection is by evaporation, thus saving about 95% of the water normally required by a "once-through" system.
**The evaporative condenser essentially combines a cooling tower and a refrigerant condenser in one piece of equipment.** It eliminates the sensible heat transfer step of the condenser water which is required in the cooling tower/refrigerant condenser system. This permits a condensing temperature substantially closer to design wet bulb temperature, and consequently, minimum compressor energy input.

The temperatures and water flow rate shown in Figure 6, are typical of an evaporative condenser applied to a refrigeration or air-conditioning system at the designated design wet bulb temperature with either ammonia or a halocarbon refrigerant. These conditions would result in a lower condensing temperature and lower compressor energy input could be obtained with a larger condenser at this same wet bulb temperature.

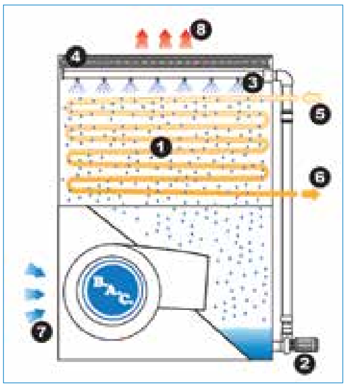


*Figure 6: Evaporative Condenser*
1. Condensing Coil; 2. Pump (Approx. 0.15 l/s / 1kW Low pumping head); 3. Water Dist. System; 4. Eliminators; 5. Refrigerant Vapour In; 6. Refrigerant Liquid Out 35°C; 7. W.B. 25°C (30 l/s / 1kW); 8. Air Discharge

The evaporative condenser offers a number of important advantages over other condensing systems:

- **Low system operating costs**. Condensing temperatures within 8°C of design wet bulb are practical and economical, resulting in a compressor horsepower savings of 10% or more over cooling tower/condenser systems and more than 30% over air-cooled systems. Fan horsepower is comparable to cooling tower/condenser systems and is about one-third that of an equivalent air-cooled unit. Because of the low pumping head and reduced water flow water, pumping horsepower is approximately 25% of that required for the normal cooling tower/condenser installation.
- **Initial cost savings**. The evaporative condenser combines the cooling tower, condenser surface, water circulating pump, and water piping in one assembled piece of equipment. This reduces the cost of handling and installing separate components of the cooling tower/condenser system.
  Since the evaporative condenser utilizes the efficiency of evaporative cooling, less heat transfer surface, fewer fans, and fewer fan motors are required resulting in an initial material cost savings of 30% to 50% over a comparable air-cooled condenser.
- **Space savings.** The evaporative condenser saves valuable space by combining the condensing coil and cooling tower into one piece of equipment, and eliminating the need for large water pumps and piping associated with the cooling tower/condenser system. Evaporative condensers require only about 50% of the plan area of a comparable sized air-cooled installation.

## 4. Evaporative Condenser Operation and Installation Recommendations

### A. Condenser Piping - Single Condensers

Figure 7 indicates the recommended piping for one or more compressors discharging into a single evaporative condenser. The compressor discharge line should be sized to reflect the design pressure drop allowance between the compressor and condenser. Normally, a pressure drop per 30,5 m corresponding to a 0,5°C condensing temperature penalty is considered acceptable design. This 0,5°C penalty is the basis for the pipe capacity tables in the pipe sizing chapter in the ASHRAE Handbook of Fundamentals. That chapter also provides data for calculating pipe sizes for other design pressure drops and for determing total line loss for a specific system.

For close coupled systems, the pipe size selection based on the 0,5°C penalty results in a negligible pressure differential between the pressure at the compressor discharge and that at the condenser inlet. However, if the discharge lines are long and/or sized for a larger design pressure drop, then allowance must be made in the compressor or condenser selection for the actual pressure loss. For example, an ammonia system designed for 1276 kPa discharge pressure at the compressor, and with a total discharge line pressure drop of 41 kPa, would require a condenser selected for a condensing temperature of 35°C (1234 kPa) instead of 1276 kPa.

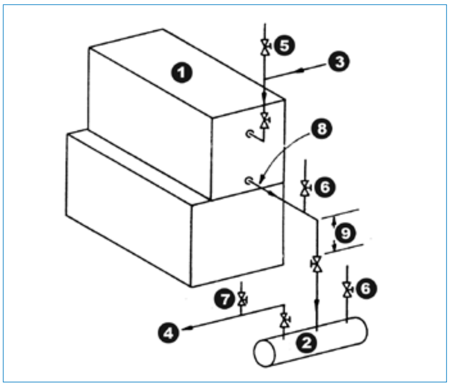



*Figure 7: Single Evaporative Condenser with Top Inlet Receiver*
1. Evaporative Condenser; 2. Receiver; 3. Compressor Discharge Line; 4. Liquid Line to Evaporator; 5. Alternate Purge Valve when Unit Shut Down; 6. Purge Valve; 7. Charging Valve; 8. Slope 22 mm/m toward Receiver; 9. 300 mm minimum.

Discharge line losses are particularly important in the case of centrifugal compressor systems with evaporative condensers. Centrifugal compressors have critical head characteristics and discharge line pressure drop must be considered carefully in either the compressor or condenser selection.

The Table below shows capacity in kW for discharge lines based on a line friction pressure drop per 30,5 m equivalent pipe length corresponding to a 0,5°C change in saturation temperature.

**Condenser Discharge Line Condenser Inlet Capacity in kW (1)**

| Steel Pipe (Sch. 40) | |
|---|---|
| **ND** | **R717** |
| 25 | 91 |
| 32 | 180 |
| 40 | 268 |
| 50 | 523 |
| 65 | 823 |
| 80 | 1486 |
| 100 | 2971 |

*Notes:*
*(1) Tables based on 35°C condensing, 6°C suction for R-717 (Ammonia).*
*Maximum tons for inlets based on a line friction pressure drop per 30,5 m equivalent pipe length corresponding to a 0,5°C change in saturation temperature.*
*Equivalent pressure drop per 30,5m for each refrigerant is: R-717: 22,7 kPa*

All the following piping recommendations include a high-pressure receiver. The receiver provides surge capacity to accommodate fluctuations in refrigerant charge in both the high and low sides as the system capacity varies. The condenser coil is permitted to drain freely and there is no loss of condenser capacity due to refrigerant back-up in the condenser coil.

The receiver must be equalized to some part of the system high side so that the condenser coil can drain freely. This equalization can be accomplished either through the refrigerant drain line itself or through an external equalizer.

When equalization is through the refrigerant drain line, as shown in Figure 7 (Single Evaporative Condenser with Top Inlet Receiver) this line must not be trapped and should be sized for a maximum liquid refrigerant velocity of 0,5 m/s. This line should also be sloped toward the receiver, at least 20 mm per m, so that all liquid in the line drains to the receiver on shutdown.

If a bottom inlet receiver is used, the liquid drain line will be trapped and an external equalizer must be used as shown on Figure 8. Since the liquid drain line will carry only refrigerant liquid, the trapped line may be sized on the basis of 0,76 m/s refrigerant velocity.

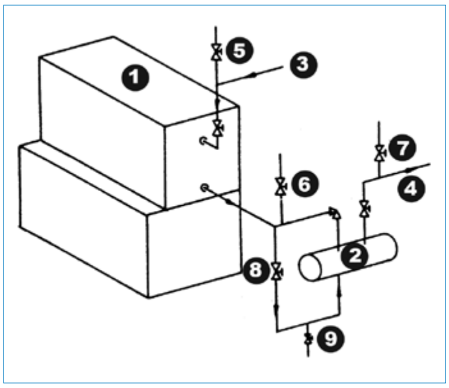



*Figure 8: Single Evaporative Condenser with Bottom Inlet Receiver*
1. Evaporative Condenser; 2. Receiver; 3. Compressor Discharge Line; 4. Liquid Line to Evaporator; 5. Alternate Purge Valve when Unit Shut Down; 6. Purge Valve; 7. Charging Valve; 8. Liquid Drain Line; 9. Pump Out Valve

The Table below shows the refrigerant capacity in kW for liquid lines between condenser and receiver for both 0,5 and 0,76 m/s for most of the common refrigerants.

**Condenser Liquid Drain Line Capacity in kW (Steel Pipe)**

| ND mm | R717 0,5 m/s | R717 0,76 m/s |
|---|---|---|
| 25 | 225 | 338 |
| 32 | 391 | 587 |
| 40 | 532 | 798 |
| 50 | 850 | 1276 |
| 65 | 1213 | 1820 |
| 80 | 1868 | 2800 |
| 100 | 3235 | 4853 |

Evaporative condensers are frequently provided with liquid outlet connections that are oversized for the design load and refrigerant. It is permissible to reduce the drain line size in the connecting piping, provided that the liquid velocity at design load does not exceed 0,5 or 0,76 m/s, depending on the type of receiver inlet. However, **all reductions in liquid drain line size must be made in the vertical portion of the piping.**

The equalizer line does not lend itself to a positive method of sizing. This line equalizes the pressure between the receiver and condenser coil outlet, permitting a free flow of liquid refrigerant from the condenser to the receiver through the liquid drain line. The equalizer line carries gas from the receiver to the condenser any time the dry bulb temperature at the receiver is higher than the condensing temperature, causing some flashing of the liquid refrigerant in the receiver. It must carry gas from the condenser to the receiver any time the dry bulb temperature at the receiver is lower than the condensing temperature, causing condensation of vapor inside the receiver. The Table below gives selections for equalizer lines that will be satisfactory for most systems.

**Recommended Equalizer Line Pipe Size**

| | | 19 mm | 25 mm | 32 mm | 40 mm | 50 mm |
|---|---|---|---|---|---|---|
| Max. system cap. (kW) | R717 | 1538 | 2642 | 4264 | 5800 | 9580 |

## B. Condenser Piping - Multiple Condensers

The requirements for multiple evaporative condensers connected in parallel to a single receiver are extremely important if maximum efficiency is to be obtained under all operating conditions. All figures below indicate recommended piping practices for two or more evaporative condensers operating in parallel.
Comments regarding the compressor discharge line are the same as previously covered, except that the discharge piping for the multiple condensers should be as symmetrical as possible in order to equalize the gas line pressure drop to each individual condenser.

The most significant piping change is in the liquid line connections between the condensers and the receiver. With multiple condensers, it is essential to use trapped vertical liquid legs from each coil outlet to equalize any difference in coil outlet pressures. If for any reason there is a greater pressure drop in one coil than in another, resulting in different coil outlet pressures, liquid refrigerant would back up in the coil with the greatest pressure drop (lowest outlet pressure) until the liquid head was sufficient to overcome the pressure differential. Different coil pressure drops might result from use of condensers of different sizes, variations in piping, or variable load conditions. One condensing coil might be shut down completely and therefore have essentially zero pressure drop. With the trapped liquid legs, differences in coil outlet pressures are corrected with varying liquid levels in the vertical drop legs without backing up liquid into the condensing coil and reducing its operating efficiency.

Similarly, because of possible variations in coil outlet pressures, the receiver must not be equalized with the coil outlets. This would again result in refrigerant back up in the coils with low coil outlet pressures. Instead, the receiver is equalized with the gas inlet to the condensers. The point at which the equalizer is tied to the compressor discharge should be, as nearly as possible, equidistant from each of the condensers.
For standard BAC evaporative condensers, the height of the vertical liquid leg "H" should be at least 1 m for ammonia (R-717) and 2,5 m for halocarbon refrigerants. These dimensions are minimum and increased heights are desirable wherever possible in order to take care of wet bulb temperatures. The minimum liquid leg heights should also be increased to account for the pressure drop of any stop valves at the condenser inlet and outlet. Figure 9 shows recommended piping for a bottom inlet receiver. With this arrangement, the drop legs and the liquid header may be selected for liquid velocities of 0,76 m/s maximum.

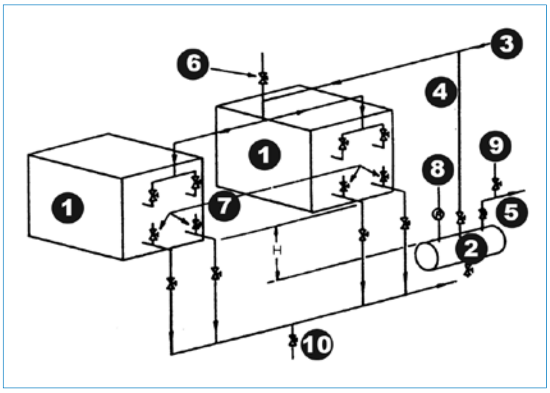



*Figure 9: Parallel Evaporative Condensers with Bottom Inlet Receiver*
1. Condenser; 2. Receiver; 3. Discharge Line from Compressor; 4. Equalizing line; 5. Liquid Line to Evaporator; 6. Alternate Purge Valve when Unit Shut Down (See Purging); 7. Purge Valves (See Purging); 8. Relief Valve; 9. Charging Valve; 10. Pump Out Valve

Figures 10 and 11(Parallel Evaporative Condensers with Common Liquid Header above Receiver Level: Alternate 1 and Alternate 2) show two recommended piping methods for multiple condensers with top inlet receivers. These two methods are equally acceptable and will give the same results.

In Figure 10, the individual drop legs are trapped into a common liquid header above the receiver. The traps may be as short as piping practice will permit; there is no advantage to a long trap. The drop legs and the trapped liquid header may be sized for a maximum liquid velocity of 0,76 m/s. The liquid header must also act as liquid reservoir for the drop legs, and it should have a volume equivalent to the volume of liquid in the drop legs. The vertical drain line from the common liquid header to the receiver must be sized for a maximum liquid velocity of 0,5 m/s. The trapped liquid header is connected to the equalizing line to prevent a siphoning effect from the liquid header to the receiver.

It is desirable, but not essential, to trap the liquid header as shown in Figure 10. Trapping the header will insure a stable operating condition for the condensers.

If the liquid header is not trapped, there may be times, particularly at initial plant start-up, where there will be erratic condenser operation until all liquid leg seals are stabilized. Also, if the header is trapped, it need not be sloped toward the receiver. This may be advantageous on large jobs with several condensers where sloping the liquid header might require increased elevation of the condensers. Untrapped liquid headers must be sized for 0,5 m/s drain velocities, and should be sloped a minimum of 20 mm/m toward the receiver.

Figure 11 indicates an alternate method of trapping the main liquid header using a vertical trap. The volume of the vertical trap between the bottom inlet connection and the top outlet connection must be equal to the combined volume of the liquid in all of the drop legs.

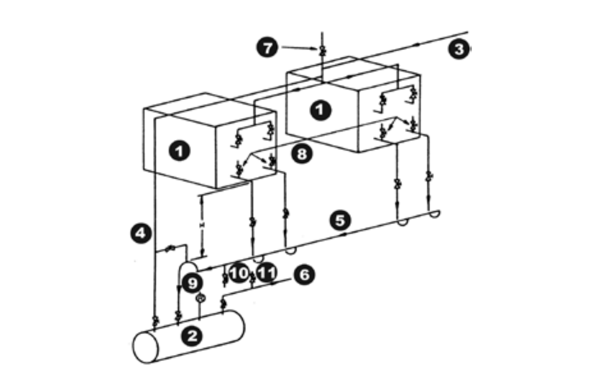



*Figure 10: Parallel Evaporative Condensers with Common Liquid Header Above Receiver Level: Alternate 1*
1. Condenser; 2. Receiver; 3. Discharge Line from Compressor; 4. Equalizing line; 5. Common Liquid Header; 6. Liquid Line to Evaporator; 7. Alternate Purge Valve when Unit Shut Down (See Purging); 8. Purge Valves (See Purging); 9. Relief Valve; 10. Pump Out Valve; 11. Charging Valve

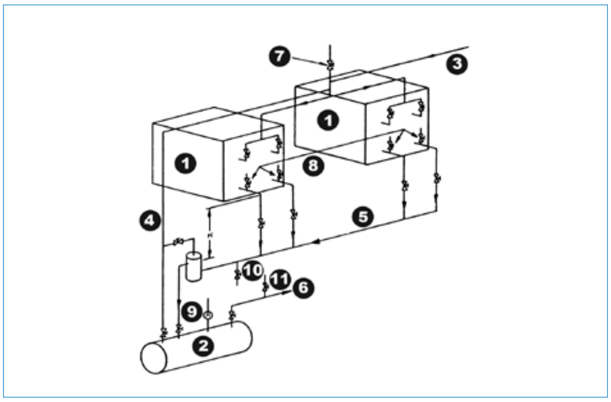



*Figure 11: Parallel Evaporative Condensers with Common Liquid Header Above Receiver Level: Alternate 2*
1. Condenser; 2. Receiver; 3. Discharge Line from Compressor; 4. Equalizing line; 5. Common Liquid Header; 6. Liquid Line to Evaporator; 7. Alternate Purge Valve when Unit Shut Down (See Purging); 8. Purge Valves (See Purging); 9. Relief Valve; 10. Pump Out Valve; 11. Charging Valve

The top of the vertical trap must be connected to the equalizing line to prevent a siphoning effect from the liquid header to the receiver. There is no need to trap the individual drop legs when a vertical trap is used. The drop legs and the common liquid header should be sized for a maximum liquid velocity of 0,76 m/s. The vertical drain line from the trap to the receiver should be sized for a maximum liquid velocity of 0,5 m/s.

*Evaporative Condensers in Parallel with Shell-and-Tube Condensers*

Many times evaporative condensers are added to existing systems having shell-and-tube condensers. The recommended piping for operating the two in parallel is shown in Figure 12. The refrigerant pressure drop through the shell-and-tube condenser is very small and requires only that the condenser be located above the receiver to obtain liquid flow.

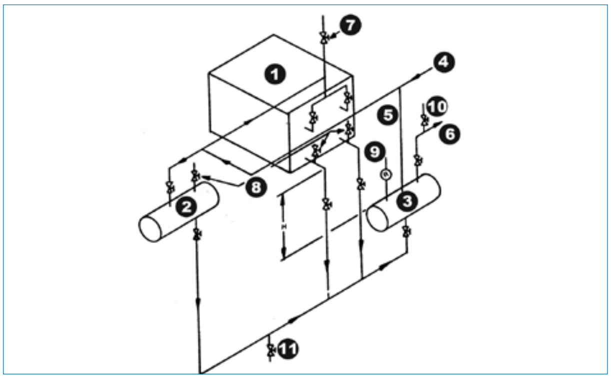



*Figure 12: Paralleling an Evaporative Condenser and a Shell & Tube Condenser*
1. Evaporative Condenser; 2. Shell & Tube Condenser; 3. Receiver; 4. Discharge Line from Compressor; 5. Equalizing line; 6. Liquid Line to Evaporator; 7. Alternate Purge Valve when Unit Shut Down (See Purging); 8. Purge Valves (See Purging); 9. Relief Valve; 10. Charging Valve; 11. Pump Out Valve

*Miscellaneous Condenser Piping Guidelines*

- Consider and allow for future expansion in the initial installation.
- Design the piping with some flexibility to allow for vibration, expansion, and contraction. A piping system should never be completely rigid.
- When two or more parallel ammonia compressors are used with any number of condensers, cross connect the discharge line at the compressor and use a single line to the condensers. However, on halocarbon systems it may be desirable to isolate each compressor circuit to facilitate oil return to the compressor. If multiple halocarbon circuits are not isolated, then an oil return system must be provided to return oil to each compressor in the proper amount.
- Locate any valve or reducer in the refrigerant drain line from the condenser in a vertical section of piping. Avoid any restriction to flow in the horizontal run leaving the condenser.
- Any refrigerant valves in a horizontal pipe run must be installed with the valve system in the horizontal position.

## C. Purge and Purge Piping

*Source of Non-Condensables*

Air and other non-condensable gases collect in refrigeration systems from several sources:
- Poor evacuation of a new system low side if operation is at pressures below atmospheric.
- Failure to evacuate completely after part of a system has been open for repair.
- Chemical breakdown of oil and/or refrigerant.

If permitted to accumulate, non-condensables in the system cause high condensing pressures and, therefore increased power input to the compressors.

*Checking the System for Non-Condensables*

To check the system for non-condensable gases, first close the valve in the liquid line running from the receiver to the evaporator (king valve), then pump down the system slightly, enough to assure that if any non-condensables are present they are pumped over to the high side.

Immediately after pump-down, close the discharge valve on the compressor. Operate the evaporative condenser for at least two hours or until the water temperature in the pan or remote sump is the same as the entering wet bulb temperature. Then the temperature corresponding to the pressure in the evaporative condenser should correspond, or nearly so, to the wet bulb temperature of the entering air. If this temperature is higher than the wet bulb temperature by more than 1°C the system has an excessive amount of non-condensables. (Be sure that all gauges are accurate when checking for non-condensables).

*Purge Connections*

The several recommended piping arrangements each show purge valves at two different locations, i.e., at the high point of the system and at each condensing coil outlet. Purging at the high point of the system can only be effective when the system is down. During normal operation the non-condensables are dispersed throughout the high velocity refrigerant vapour and too much refrigerant would be lost when purging from this high point.

However, purging at the condenser coil outlet can be effectively accomplished during system operation.
The non-condensables will carry through the condenser coil with the refrigerant liquid and vapor and tend to accumulate in the condensing coil outlet header and connection where the temperature and velocity are relatively low.
In the BAC condenser coil design, the refrigerant outlet connection is tangent to the top of the coil header so non-condensables cannot trap in the header. A 12 or 18 mm purge connection should be cut into the top of the liquid outlet along the horizontal run. Each connection must be valved so that each coil can be purged separately.

*Purge Piping*

All of the purge connections on the condenser coils plus the purge connection in the receiver may be cross connected to a single purge line, connected to an automatic purger. However, only one purge valve should be open at a time. Opening two or more valves tied together equalizes the coil outlet pressures and the effect of the vertical drop legs is lost.

## 5. Special Applications

*Desuperheaters*

A desuperheater is an air-cooled finned coil usually installed in the discharge air stream of an evaporative condenser. Figure 13 shows a typical arrangement. Its primary function is to increase the condenser capacity by removing some of the superheat from the discharge vapour before the vapour enters the wetted condensing coil. The amount of superheat removed is a function of the desuperheater surface, condenser airflow, and the temperature difference between refrigerant temperature and the temperature of the air leaving the condenser. Practically, the application of a desuperheater is limited where discharge temperatures are relatively high (120°C to 150°C).

It is economically impractical to provide a desuperheater on an evaporative condenser with enough heat transfer surface to remove all of the superheat in the ammonia refrigerant. Therefore, complete superheat removal is never attained under design conditions of load and ambient wet bulb temperature with the standard desuperheater coils furnished by evaporative condenser manufacturers. The anticipated capacity increase on an ammonia condenser with standard desuperheater is in the area of 10% rather than the 16% theoretically possible.

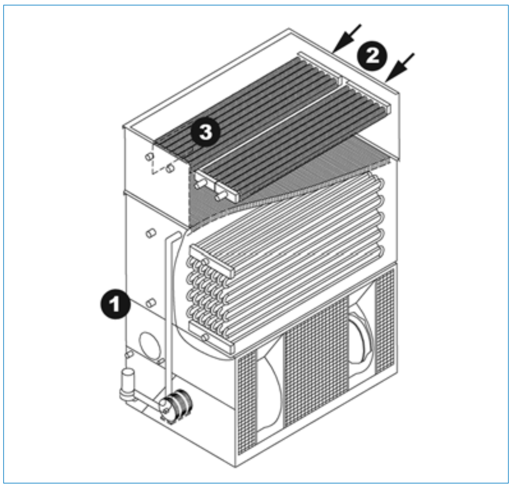



*Figure 13: Evaporative Condenser with Desuperheater Coil*
1. Liquid Outlet; 2. Hot Gas from Compressor; 3. Desuperheater Coil

Occasionally, where condenser space is limited, the addition of a desuperheater may permit a smaller plan area unit. However, with the numerous size increments available in today's evaporative condensers, such instances are rare. The air-cooled desuperheater is not as efficient as a wetted condenser surface, so it is more economical to select a condenser with additional wetted surface to achieve greater capacity.

Desuperheaters have been recommended by some manufacturers to assist in oil removal from the ammonia vapor and also to minimize scaling of the upper tubes of the wetted condensing coil by reducing entering refrigerant gas temperatures to the wetted coil.

For oil removal, an oil separator is installed between the desuperheater coil and the wetted condenser coil. The theory is that cooling of the hot discharge refrigerant vapor will promote condensation of the oil vapor from the refrigerant-oil mixture and separation of the oil from the refrigerant in the oil separator. This claim has merit. However, there is normally no control over the amount of heat removed from the refrigerant vapor in the desuperheater coil. At less than design load or wet bulb temperature, the desuperheater coil often becomes a condensing coil, and when liquid refrigerant mixes with liquid oil, separation becomes quite difficult.

Today there are many oil separators with high efficiencies for removing oil from the hot discharge vapour as it leaves the compressors. The oil separator can be located in the engine room where it can be monitored by the operating engineer and where it is not exposed to the ambient temperatures that would cause refrigerant condensation.

From the scaling standpoint, the presence or absence of a desuperheater is immaterial. The primary factor that determines the tendency to form scale on the wetted coil of an evaporative condenser is the external surface temperature of the coil. At the inlet of the wetted coil where only hot refrigerant vapor exists, the internal heat transfer coefficient is quite low. Despite the high vapor temperature at the inlet (120°C to 150°C) the low internal coefficient reduces the rate of heat transfer through the coil tubes at that point. The resulting coil surface temperature at the inlet is not appreciably different from the coil surface temperature in the condensing portion of the coil. Therefore, scaling in an evaporative condenser becomes primarily a function of adequate water distribution over the coil, proper bleed-off to prevent concentration of solids, and proper water treatment where water conditions are particularly bad.

The increasing use of screw compressors for industrial refrigeration systems further obsoletes the use of a desuperheater. The screw compressor is an oil seal, oil cooled unit, with the cooled oil injected into the compressor in contact with the refrigerant vapor. Larger, efficient, de-mister type oil traps furnished as part of the screw compressor package minimize problems of oil carryover. Because the cooled oil is in direct contact with the refrigerant vapour, discharge temperatures are relatively low on water-cooled screw compressors (71 to 88°C), and even lower on refrigerant liquid injected screw compressors (approximately 49°C). Consequently, any capacity gain of a desuperheater used on a screw compressor installation is negligible.

*Refrigerant Liquid Subcooling (Halocarbon Refrigerants)*

In the case of air-conditioning or refrigeration systems, the pressure at the expansion device feeding the evaporator(s) can be substantially lower than the receiver pressure due to liquid line pressure losses. If the evaporator is above the receiver, the static head at the evaporator is less than at the receiver, which further reduces the pressures at the expansion device.

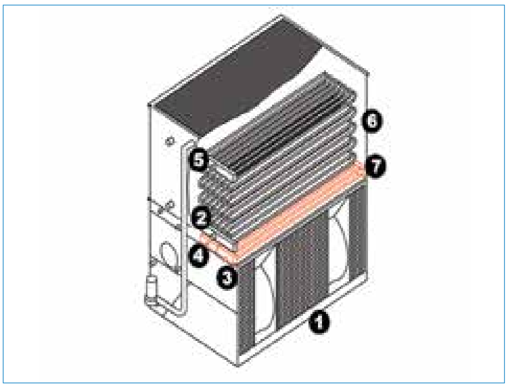


*Figure 14: Evaporative Condenser with Liquid Subcooling Coil*
1. Evaporative Condenser; 2. Refrigerant Liquid Outlet to Receiver; 3. Inlet Subcooling Coil coming from Receiver; 4. Subcooled Liquid from Subcooling Coil to Expansion Valve; 5. Compressor Discharge; 6. Condensing Coil; 7. Subcooling Coil.

A refrigerant remains in liquid form only as long as the liquid pressure is at or higher than the saturation pressure corresponding to its temperature. Any pressure reduction in the liquid line between the receiver and the expansion device causes flashing or vaporization of some of the liquid. The presence of this flash gas will cause erratic operation of the thermal expansion valve and reduce the valve capacity, sometimes to the point of starving the evaporation.

To avoid liquid line flashing where the above conditions exist, it is necessary to subcool the liquid refrigerant after it leaves the receiver. The minimum amount of subcooling required is determined by the temperature and the saturation temperature corresponding to the pressure at the expansion valve. To determine the degree of subcooling required, it is necessary to calculate the liquid line pressure drop including valves, ells, tees, strainers, etc., and add to it the pressure drop equivalent to the static head loss between the receiver and the thermal valve at the evaporator, if the evaporator is located above the receiver.

Some compressor manufacturers publish their compressor ratings based on a fixed amount of subcooling at the thermal expansion valve. Subcooled liquid at the expansion valve of the evaporator does increase system capacity since it increases the refrigeration effect per pound of refrigerant circulated. But the increase is relatively small and seldom justifies the cost of the subcooling device and piping for this reason alone. However, **where compressor ratings based on subcooled liquid are used, the specified amount of subcooling must be added to that required for liquid line pressure drop and static head loss.**

One method commonly used for supplying subcooled liquid for halocarbon systems is to provide a subcooling coil section in the evaporative condenser, located below the condensing coil (see Figure 14). Depending upon the subcooling coil surface, these sections will normally furnish 5,5°C to 8,5°C of liquid cooling. However, to be effective the subcooling must be piped between the receiver and evaporator as shown in Figure 14.

*Increasing the evaporative condenser size over the capacity required for the system will not produce liquid subcooling. The increased condenser capacity will result only in lower operating condensing temperatures. The same result will occur if the condensing coil is piped directly to the subcooling coil.*

Low temperature, multistage ammonia refrigeration systems often use liquid subcooling between stages for more economical operation. However, subcooling coils in an evaporative condenser are seldom, if ever, used with an ammonia refrigeration system for several reasons:

- Design condensing temperatures are generally lower with ammonia, thus limiting the amount of subcooling that can be obtained.
- The density of ammonia liquid is approximately 592,67 kg/$m^3$, less than half that of the normally used halocarbons, and static head losses are proportionally less.
- The expansion devices and system designs normally used for ammonia systems are less sensitive to small amounts of flash gas.
- The high latent heat of ammonia (approximately 1110 kJ/kg) results in comparatively small amounts of flash gas with a liquid line properly sized for low pressure drop.

### *Multiple Circuit Condenser Coils*

The coil in a single condenser can be split in sections to provide a number of individual circuits. A multiple circuit coil is used primarily with the common halocarbon refrigerants on small air-conditioning or refrigeration systems with two or more reciprocating compressors. The reason for this is that proper oil return to the compressors can be a problem on these systems, and it is good design practice to isolate each compressor.

In general, the halocarbon refrigerants are highly miscible with oil, the degree of miscibility being a function of the refrigerant, the type of oil, the pressure and temperature of the mixture. During normal operation, some oil is lost from the crankcase of the reciprocating compressor and this oil travels around the refrigerant circuit with the refrigerant. It is essential that the oil lost from the compressor be returned to it.

In order to avoid oil return problems, it is common practice on the smaller (870 kW and below) halocarbon refrigeration and air-conditioning systems to design independent refrigerant circuits where two or more reciprocating compressor systems are involved. In order to use a single evaporative condenser, the condenser coil can be split internally to accommodate the capacity of the individual systems.

This practice is not followed with R717 (ammonia) systems. Oil and ammonia are practically immiscible so that most of the oil carried over from the oil separators in the discharge line is returned either directly to the individual compressor crankcase or to an oil receiver and then to the compressor crankcase.

If multiple compressor halocarbon systems are not designed with isolated circuits, an oil return system must be provided to return oil to each compressor crankcase in the proper amount.

### *Auxiliary Cooling using Condenser Pan Water*

During normal evaporative condenser operation, the recirculated spray water is maintained at a temperature some point higher than the inlet air wet bulb temperature and lower than the condensing temperature. The exact recirculated water temperature is determined by these two operating parameters. Therefore, this water can be considered as a source of relatively cool fluid for auxiliary cooling requirements on refrigeration plants, such as jacket cooling for reciprocating and rotary compressors, jacket cooling for air compressors and vacuum pumps, and oil cooling for screw compressors.

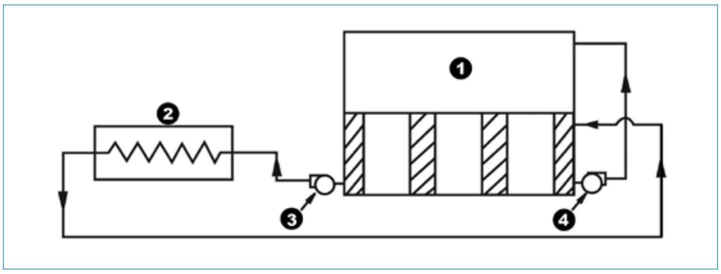



*Figure 15: Auxiliary Cooling using Condenser Pan Water*
1. Evaporative Condenser; 2. Cooling Load; 3. Auxiliary Pump; 4. Standard Condenser Pump

Water is taken from the pan of the condenser or the remote sump and is pumped to the source of heat, usually by a separate pump (see Figure 15). In most cases only a fraction of the evaporative condenser flow rate is required for cooling purposes. The water flows through the heat source, increases in temperature, and is then returned to the condenser pan or remote sump. The heated water then mixes with the pan water producing a mixture temperature somewhat higher than the normal recirculated water temperature. An increase in temperature of the recirculated water by virtue of an external cooling load has the effect of reducing condensing capacity, but the penalty is relatively small. Consult your local BAC representative for specific evaporative condenser performance data on systems utilizing pan water for auxiliary cooling.

Using a portion of the recirculated spray water for external cooling purposes is an effective and simple concept. However, there is a significant drawback to this cooling system that does not always make it desirable. An evaporative condenser characteristically behaves as an air washer, stripping dirt and dust particles from the air circulating through it, and holding them in suspension in the recirculated water. Consequently this can create serious clogging of compressor jackets or heat exchanger or sophisticated filtering equipment is usually required.

*Closed Circuit Fluid Cooling*

To eliminate the problem of system contamination associated with using spray water for auxiliary cooling, BAC recommends to use a closed system for that cooling whenever possible. A separate closed circuit evaporative cooler, or a split circuit coil in the evaporative condenser, with one circuit for condensing the refrigerant and the other for cooling the liquid, are two good solutions.

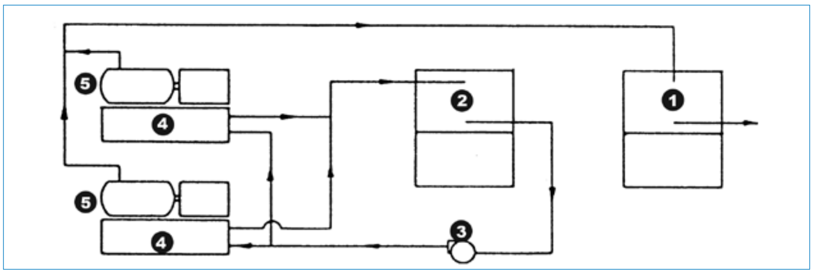



*Figure 16: Evaporative Condenser with Closed Circuit Evaporative Cooler for Fluid Cooling: Cooling Oil for Refrigeration Screw Compressors*
1. Evaporative Condenser; 2. Closed Circuit Evaporative Cooler; 3. Pump; 4. Oil Cooler; 5. Screw Compressor

As an example, a closed circuit evaporative cooler could be used to cool water or an ethylene glycol solution for oil coolers of refrigeration screw compressors. Figure 16 shows a typical arrangement. This is the ideal cooling system because it provides the following important advantages:

- ♦ Provides closed loop cooling, which precludes the contamination of system fluid.
- ♦ Provides independent control of the condensing and water-cooling systems for separating these two functions into two or more units.
- ♦ Permits the evaporative condenser to be operated as an air-cooled condenser in cold weather, thus minimizing freeze-up problems.

It is important to note that if the closed circuit evaporative cooler is installed in a freezing climate, an antifreeze (ethylene glycol) solution must be used instead of water. If a closed circuit evaporative cooler coil containing water is not provided with a supplementary heat load after shut-down, and is exposed to an ambient temperature below 0°C the water could freeze and rupture the coil. Other winterizing precautions similar to those described earlier in this manual for evaporative condensers apply equally to closed circuit evaporative coolers.

A separate closed circuit evaporative cooler for fluid cooling cannot always be justified, particularly on smaller installations. For instance, on refrigerated plants involving only one or two water-cooled screw compressors, it may be more economical to furnish an evaporative condenser with a split circuit coil, with one circuit for condensing refrigerant and the other isolated for fluid cooling. This approach lacks one of the features of the separate unit arrangement, i.e., the fluid cooling and condensing functions cannot be controlled independently. Both functions are handled within the same unit, but the heat rejection capacity of the unit must be controlled by either the condensing pressure or the leaving fluid temperature. Consequently it is necessary to sacrifice close control of one of these parameters, usually the leaving fluid temperature.

Using an evaporative condenser for both condensing and fluid cooling also limits the permissible inlet and outlet fluid temperatures on the fluid cooling circuit. Careful engineering analysis is required to establish satisfactory temperature criteria and properly select the evaporative condenser. Consult your local BAC representative for specific recommendations on split circuit evaporative condensers.

14

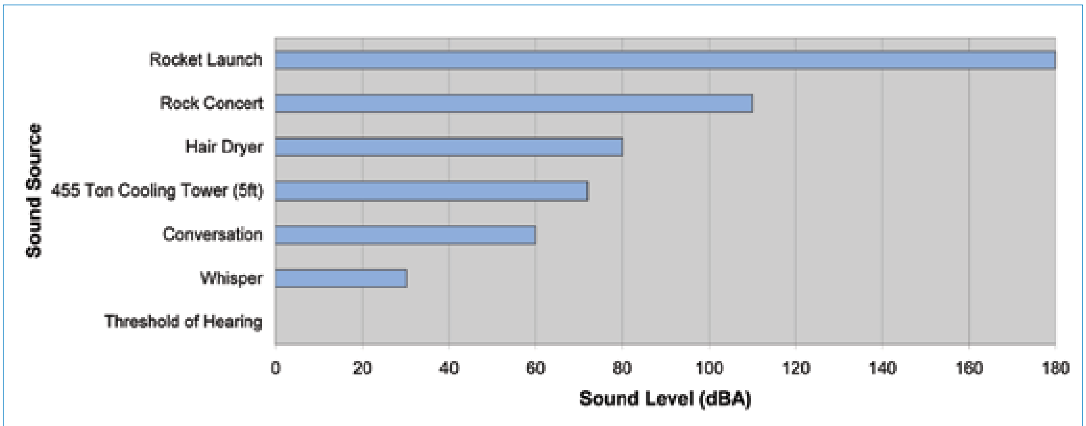
# Fundamentals of Sound

## 1. Introduction

Sound is an important consideration in the selection of mechanical equipment. The purpose of this article is to present a procedure for evaluating the sound levels created by cooling equipment to determine if these levels will be acceptable to the neighbours* who live or work near the installation. In addition, sound levels must comply with local code requirements. While most often these levels are found to be acceptable, certain situations may call for sound levels lower than those produced by the equipment. It is then the task of the manufacturer, engineer, and owner to determine the best way to decrease the sound levels for the particular installation. This article presents a means for assessing the impact of the evaporative cooling equipment's sound on a neighbour and possible means to reduce that impact should it be a potential problem.

The procedure consists of three steps, followed by a fourth step if necessary:

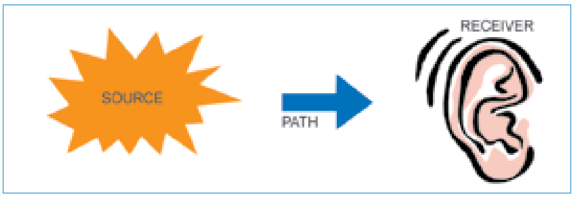
- Establish the noise criterion for the equipment: i.e., determine the sound levels that will be considered acceptable by the neighbours who will be exposed to them. Also consult local codes for appropriate sound levels. For a general idea of how sound levels produced by a cooling tower compare to sound from other common sound sources, see the graph below.




- Estimate the sound levels that will be produced by the equipment, taking into account the effects of equipment geometry, the installation, and the distance from the equipment to the neighbour.*
  ** In this article, the term "neighbour" is used to denote the person or group of persons to be protected against excessive sound levels created by the evaporative cooling equipment. It is intended that this include not only the occupants of other buildings, but also the occupants of the building served by the equipment.*
- Compare the noise criterion with the expected sound levels to determine if the sound levels from the equipment will be acceptable.

- In the event that the equipment sound levels are excessive for the particular site conditions, a method should be determined to modify the neighbour's perception of the sound. There are three ways to change the effects that any undesirable sound has on the receiver of that sound:
  * Modify the source of the sound
  * Control the path of the sound
  * Adjust the receiver's expectation or satisfaction, keeping in mind that sound can be very subjective and is highly dependent on perception.

Some ways that sound from BAC equipment can be adjusted for a more favorable impact on the receiver include:




- Modify equipment location or position
- If possible, simply do not run the equipment at the critical time (at night for residential areas and during the day for office parks)
- Install a second motor, two-speed motor, or VFD so that the unit can run at lower speeds when the full capacity is not required
- Use a low sound fan
- Oversize the equipment and run the fan at lower speed and power level
- Construct sound barriers (sound walls, etc.) or use existing barriers (trees, other buildings, etc.) when planning the location of the equipment
- Install sound attenuation (available on the air intake and air discharge of the equipment)

The article also includes several appendices to lend assistance in understanding and performing some aspects of a sound analysis. Contact your local BAC Balticare Representative with questions on sound analysis or sound issues specific to your installation.

## 2. Sound Levels

Sound rating data are available for all BAC models. When calculating the sound levels generated by a unit, the designer must take into account the effects of the geometry of the tower as well as the distance and direction from the unit to noise-sensitive areas. Whisper Quiet fans and intake and discharge sound attenuation can be supplied on certain models to provide reduced sound characteristics.The Baltiguard® Fan System, two-speed motors, or variable frequency drives can also be used to reduce sound during periods of non-peak thermal loads. For more information on sound and how it relates to evaporative cooling equipment, see Section "Sound Levels for Cooling Equipment". For detailed low sound selections, please consult your local BAC Balticare Representative.

## 3. Terminology and Units of Measurement

The following terms and units of measure are used in this article, in accordance with accepted European Standards:
**Decibel (dB)** – the unit of measurement used in sound control (dimensionless, used to express logarithmically the ratio of a sound level to a reference level).
**dB(A)** – the A-weighted sound pressure level.
**Cooling equipment** – used in this article to represent all BAC product lines in the sound analysis
**Frequency** – the number of repetitions per unit time (the unit for frequency is the Hertz (1 cycle/s)).
**Hertz** – abbreviated Hz, is the unit of frequency, defined as "cycles per second."
**Noise** – unwanted sound.
**Noise Criteria** – the maximum allowable sound pressure level(s) (Lp) at a specific location. Criteria may be expressed as a single overall value or in individual octave bands. The NC values and curves are further explained in the next table.
**Octave Band** – a range of sound frequencies with an upper limit twice its lower limit. The bands are identified by their center frequencies ("identifying frequencies"), which is the square root of the product of the upper and lower cutoff frequencies of a pass band. These center frequencies and band widths are shown in the next table. In some sound data tables, these eight octave bands are also called by their "Band Numbers;" hence, the Band Numbers are also listed as such in this article, in addition to the BAC Selection Software.
**Sound** – the sensation of hearing; rapid, small fluctuations to which our ears are more or less sensitive; small perturbation of the ambient state of a medium (ambient air in most cases) that propagate at a speed characteristic of the medium.
**Sound Pressure Level (Lp) in dB** – a ratio of a sound pressure to a reference pressure and is defined as:
Lp = 20LogP/0.0002(dB), reference 0.0002 microbar.
The reference pressure used in this article is the long-used and accepted value of 0.0002 microbar. Another way to describe the same value, which may be used in other publications, is the value of $20 \times 10^{-6}$ Pascals ($N/m^2$).
**Sound Power Level (Lw) in dB** – the measure of the total acoustic power radiated by a given source and is defined by:
Lw = 10Log ($W/10^{-12}$ )dB, reference $10^{-12}$ . The standard reference power used in the BAC literature is $10^{-12}$ watt.

To eliminate any possible confusion, the reference power should always be quoted, as in "a sound power level of 94 dB reference $10^{-12}$ watt."
**Unit** – a single cell of cooling equipment.

## 4. Establishing the Noise Criterion

*Introduction*
At the beginning of any sound analysis, it is necessary to establish the sound level at a particular site that would be considered acceptable by those who might be affected. This acceptable sound level is called the "noise criterion" for that situation, and it is important to realize that it may vary widely for different situations.
The procedure for developing the noise criterion involves consideration of the following:

- The type of activity of those people in the vicinity of the evaporative cooling equipment who will be affected
- The amount of attenuation from acoustic barriers or walls that lie between the equipment and the people who may hear it
- The outdoor background noise that might help mask the sound from the equipment

From these factors, we can arrive at the final noise criterion for the particular installation.

The noise that humans hear covers a frequency range of about 20 Hz to about 20.000 Hz. Of course, there are exceptions to this, but this range has come to be accepted for most practical purposes. Furthermore, for most engineering applications, most of this audio range is subdivided into eight frequency bands called "octave bands" which cover the range of frequency somewhat as the octaves on a piano cover the range of pitch. The eight octave bands used in this article have the following identifying center frequencies and ranges:

| Band number | Identifying Frequency (Hz) | Approx. Frequency Range (Hz) |
|---|---|---|
| 1 | 63 | 44-88 |
| 2 | 125 | 88-176 |
| 3 | 250 | 176-353 |
| 4 | 500 | 353-707 |
| 5 | 1000 | 707-1414 |
| 6 | 2000 | 1414-2828 |
| 7 | 4000 | 2828-5656 |
| 8 | 8000 | 5656-11312 |

When sound levels are plotted on a graph, they are most often divided into these eight octave bands. In this way it is possible to observe the variation of a sound level with change in frequency. This variation is important in any situation since humans display a different sensitivity and a different response to low frequency sounds as compared with high frequency sounds. In addition, engineering solutions for low frequency sound issues differ markedly from those for high frequency sound issues.

*Indoor Neighbour Activity*
From earlier studies of real-life situations where people have judged sounds all the way from "comfortable" to "acceptable" to "disturbing" and even to "unacceptable" for various indoor working or living activities, a series of "Noise Criterion Curves" ("NC" curves) has been developed. Figure 1 is a graph of these "NC" curves. Each curve represents an acceptable balance of low frequency to high frequency sound levels for particular situations, and is keyed into the listening conditions associated with the sound. The lower NC curves describe sound levels that are quiet enough for resting or sleeping or for excellent listening conditions, while the upper NC curves describe rather noisy work areas when even conversation becomes difficult and restricted. These curves may be used to set desired sound level goals for almost all typical indoor functional areas where some acoustic need must be served.

Note that the curves of the following figure have as their x-axis the eight octave frequency bands; and as their y-axis, sound pressure levels given in decibels (dB) relative to the standard reference pressure of 0.0002 microbar. For convenience, the following table lists the sound pressure levels at each octave band center frequency, for each Noise Criterion.

**Table A: Octave Band Sound Pressure Levels (dB re 0.002 microbar) of Indoor Noise Criterion ('NC') Curves**

| Noise Criterion | Octave Band Center Frequency in Hz | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **63** | **125** | **250** | **500** | **1000** | **2000** | **4000** | **8000** |
| NC-15 | 47 | 36 | 29 | 22 | 17 | 14 | 12 | 11 |
| NC-20 | 51 | 40 | 33 | 26 | 22 | 19 | 17 | 16 |
| NC-25 | 54 | 44 | 37 | 31 | 27 | 24 | 22 | 21 |
| NC-30 | 57 | 48 | 41 | 35 | 31 | 29 | 28 | 27 |
| NC-35 | 60 | 52 | 45 | 40 | 36 | 34 | 33 | 32 |
| NC-40 | 64 | 56 | 50 | 45 | 41 | 39 | 38 | 37 |
| NC-45 | 67 | 60 | 54 | 49 | 46 | 44 | 43 | 42 |
| NC-50 | 71 | 64 | 58 | 54 | 51 | 49 | 48 | 47 |
| NC-55 | 74 | 67 | 62 | 58 | 56 | 54 | 53 | 52 |
| NC-60 | 77 | 71 | 67 | 63 | 61 | 59 | 58 | 57 |
| NC-65 | 80 | 75 | 71 | 68 | 66 | 64 | 63 | 62 |

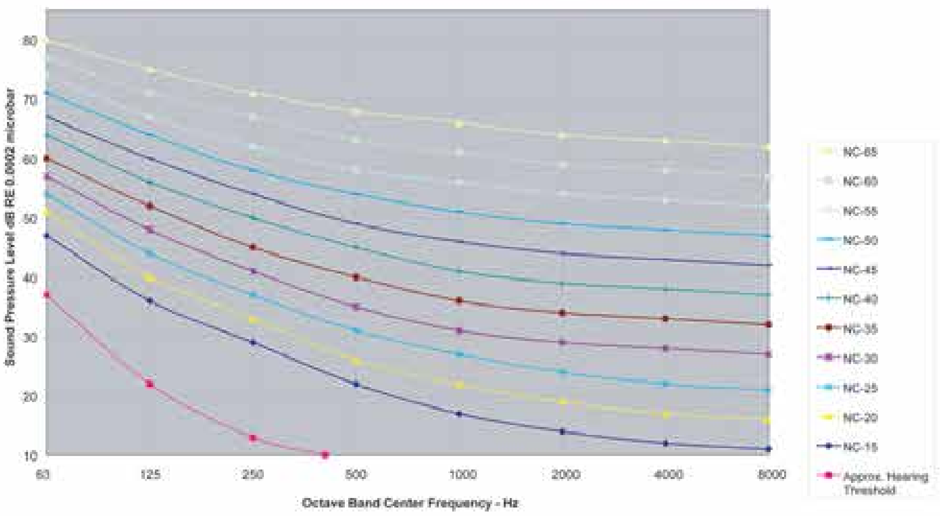



*Figure 1: Noise criterion "NC" curves. The octave band sound pressure levels associated with the noise criterion conditions of Table B.*

Table B is used with the NC curves and lists some typical activities that require indoor background sound levels in range of NC-15 to NC-55. Certain unusual acoustical requirements may not easily fall into one of the groups. It may be necessary to apply specific criteria for those special situations or to assign a criterion based in similarity to one of the criterion given in the table.

**It is emphasized that the NC curves are based on, and should be used only for, indoor activity.**

The first step in the development of the evaporative cooling equipment's noise criterion is to select from Table B the particular activity that best describes what the indoor "neighbours" in the vicinity of the equipment will be doing when the equipment is operating. Where two or more neighbor conditions may be applicable, the one having the lowest NC value should be selected. The corresponding NC values of the above figure or table A give the eight octave band sound pressure levels, in decibels, for that selection. The goal is to keep the sound heard by the neighbour, inside his home or building, at or below these sound pressure levels.

**Table B: Suggested Schedule of Noise Criteria for Indoor Neighbour Activities***

| ACTIVITY | SUGGESTED RANGE OF NOISE CRITERIA |
| --- | --- |
| **Sleeping, Resting, Relaxing** | |
| Homes, apartments, hotels, hospitals, etc.<br>Suburban and rural<br>Urban | <br>NC-20 to NC-25<br>NC-25 to NC-30 |
| **Excellent Listing Conditions Required** | |
| Concert Halls, Recording Studios, etc. | NC-15 tot NC-20 |
| **Very Good Listening Conditions Required** | |
| Auditoriums, theaters<br>Large meeting and conference rooms | NC-20 to NC-25<br>NC-25 to NC-30 |
| **Good Listening Conditions Required** | |
| Private offices, school classrooms, libraries, small conference rooms, radio and television listening in the home, etc. | NC-30 to NC-35 |
| **Fair Listening Conditions Desired** | |
| Large offices, restaurants, retail shops and stores, etc. | NC-35 to NC-40 |
| **Moderately Fair Listening Conditions Acceptable** | |
| Business machine areas, lobbies, cafetarias, laboratory work areas, drafting rooms, satisfactory telephone use, etc. | NC-40 to NC-45 |
| **Acceptable Working Conditions with Minimum Speech Interference** | |
| Light to heavy machinery spaces, industrial areas, commercial areas such as garages, kitchens, laundries, etc. | NC-45 to NC-55 |

** The ASHRAE Guide usually lists a 10 dB range of NC values for each situation leaving it to the option of the user to select the specific NC value for his own need. In the interest of more assuredly achieving satisfactory neighbour conditions, Table B listings are the more conservative lower 5 dB range of the ASHRAE value.*

*Sound Reduction Provided by Building Construction*

Neighbours who are either indoors in their own building or outdoors on their property may hear sound from outdoor equipment. If they are outdoors, they may judge the sound against the more-or-less steady background sounds in the area. If they are indoors, they may tend to judge the sound by whether it is audible or identifiable or intrusive into the surroundings.

When outdoor sound passes into a building, it suffers some reduction, even if the building has open windows. The actual amount of sound reduction depends on building construction, orientation, wall area, window area, open window area, interior acoustic absorption, and possibly some other factors. The approximate sound reduction values provided by several typical building constructions are given in the following table.

For convenience in identification, the listed wall constructions are labeled with letters A through G and are described in the notes under the Table C. Note that A represents no wall, hence no sound reduction, and the use of A indicates that the selected NC curve would actually apply in this special case to an outdoor activity, such as for a screened-in porch, an outdoor restaurant, or an outdoor terrace.

By selecting the wall construction in the following table, which most nearly represents that of the building containing the neighbour activity, and adding the amounts of sound reduction from the Table C to the indoor NC curves, band-by-band, the outdoor sound pressure levels that would yield the desired indoor NC values when the equipment sound passes through the wall and comes inside, are obtained. This second step, then, provides a “tentative outdoor noise criterion” based on hearing the sound indoors in the neighbour’s building.

**Table C: Approximate Sound Reduction (in dB) Provided by Typical Exterior Wall Construction**

| Octave Frequency Band | Wall Type (See Notes Below) | | | | | | |
|---|---|---|---|---|---|---|---|
| (Hz) | A | B | C | D | E | F | G |
| 63 | 0 | 9 | 13 | 19 | 14 | 24 | 32 |
| 125 | 0 | 10 | 14 | 20 | 20 | 25 | 34 |
| 250 | 0 | 11 | 15 | 22 | 26 | 27 | 36 |
| 500 | 0 | 12 | 16 | 24 | 28 | 30 | 38 |
| 1000 | 0 | 13 | 17 | 26 | 29 | 33 | 42 |
| 2000 | 0 | 14 | 18 | 28 | 30 | 38 | 48 |
| 4000 | 0 | 15 | 19 | 30 | 31 | 43 | 53 |
| 8000 | 0 | 16 | 20 | 30 | 33 | 48 | 58 |

A: No wall; outside conditions
B: Any typical wall construction, with open windows covering about 5% of exterior wall area
C: Any typical wall construction, with small open-air vents of about 1% of exterior wall area, all windows closed
D: Any typical wall construction, with closed but operable windows covering about 10%-20% of exterior wall area
E: Sealed glass wall construction, 6 mm thickness over approximately 50% of exterior wall area
F: Approximately 100 $kg/m^2$ solid wall construction with no windows and no cracks or openings
G: Approximately 250 $kg/m^2$ solid wall construction with no windows and no cracks or openings

*Outdoor Background Sound*

In a relative noisy outdoor area, it is possible that the outdoor background sound is even higher than the "tentative outdoor noise criterion." In this case, the steady background sound in the area may mask the sound from the evaporative cooling equipment and take over as the controlling outdoor noise criterion. Determining whether or not this situation does exist is the third step in developing the noise criterion.

The best way to judge this is to take a few sound pressure level measurements to get the average minimum background level during the quietest intervals in which the equipment is expected to operate, or during the intervals when noise complaints are most likely to be caused; for example, at night in residential areas where cooling equipment is operating at night, or during the day in office areas exposed to daytime cooling equipment sound.

In the event that background sound measurements cannot be made, the Tables D and E and Figure 2 may be used to estimate the approximate outdoor background noise. In Table D, the condition should be determined that most nearly describes the community area or the traffic activity in the vicinity of the evaporative cooling equipment during the quietest time that the equipment will operate. For the condition selected, there is a curve in the following figure that gives an estimate of the average minimum outdoor background sound pressure levels. The sound pressure levels of that figure's curves are also listed in the table thereafter.

It is cautioned that these estimates should be used only as approximations of background sounds, and that local conditions can give rise to a wide range of actual sound levels.

**Table D: Estimate of Outdoor Background Sounds Based on General Type of Community Area and Nearby Automotive Traffic Activity**

| CONDITIONS | CURVE No in FIGURE 2 of TABLE E |
|---|---|
| 1. Nighttime, rural; no nearby traffic of concern<br>2. Daytime, rural; no nearby traffic of concern | 1<br>2 |
| 3. Nighttime, suburban; no nearby traffic of concern<br>4. Daytime, suburban; no nearby traffic of concern | 2<br>3 |
| 5. Nighttime, urban; no nearby traffic of concern<br>6. Daytime, urban; no nearby traffic of concern | 3<br>4 |
| 7. Nighttime, business or commercial area<br>8. Daytime, business or commercial area | 4<br>5 |
| 9. Nighttime, industrial or manufacturing area<br>10. Daytime, industrial of manufacturing area | 5<br>6 |
| 11. Within 100 m of intermittent light traffic<br>12. Within 100 m of continuous light traffic | 4<br>5 |
| 13. Within 100 m of continuous medium-density traffic<br>14. Within 100 m of continuous heavy-density traffic | 6<br>7 |

| | |
|---|---|
| 15. 100 to 300 m from intermittent light traffic<br>16. 100 to 300 m from continuous light traffic | 3<br>4 |
| 17. 100 to 300 m from continuous medium-density traffic<br>18. 100 to 300 m from continuous heavy-density traffic | 5<br>6 |
| 19. 300 to 600 m from intermittent light traffic<br>20. 300 to 600 m from continuous light traffic | 2<br>3 |
| 21. 300 to 600 m from continuous medium-density traffic<br>22. 300 to 600 m from continuous heavy-density traffic | 4<br>5 |
| 23. 600 to 1200 m from intermittent light traffic<br>24. 600 to 1200 m from continous light traffic | 1<br>2 |
| 25. 600 tot 1200 m from continuous medium-density traffic | 3 |

(Determine the appropriate conditions that seem to best describe the area in question during the time interval that is most critical, i.e., day or night. Then refer to corresponding Curve No. in Figure 2 or Table E for average minimum background sound levels to be used in sound analysis. Use lowest Curve No. where several conditions are found to be reasonably appropriate.)

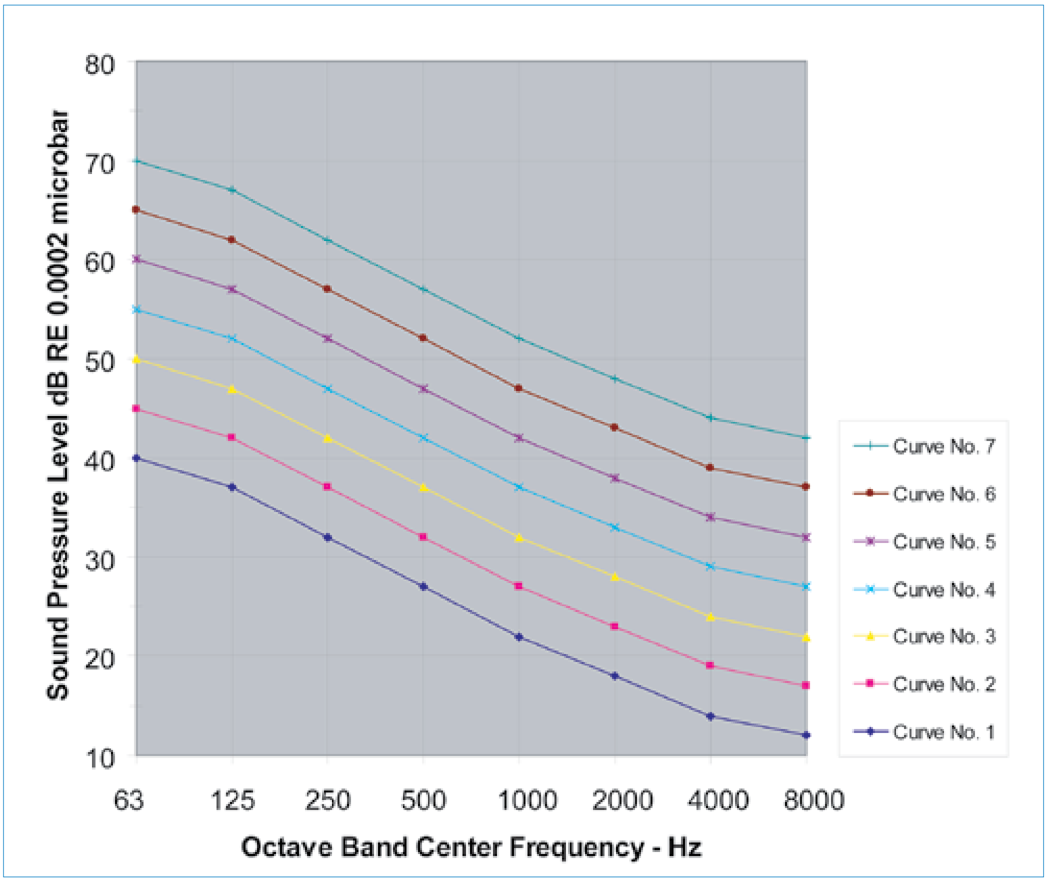



*Figure 2: Approximate average minimum outdoor background sound pressure levels associated with the conditions of table D.*

**Table E: Octave Band Sound Pressure Levels (in dB) of Outdoor Background Noise Curves of above figure**

| Curve No. in Figure 2 | Octave Band Center Frequency in Hz | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 |
| 1 | 40 | 37 | 32 | 27 | 22 | 18 | 14 | 12 |
| 2 | 45 | 42 | 37 | 32 | 27 | 23 | 19 | 17 |
| 3 | 50 | 47 | 42 | 37 | 32 | 28 | 24 | 22 |
| 4 | 55 | 52 | 47 | 42 | 37 | 33 | 29 | 27 |
| 5 | 60 | 57 | 52 | 47 | 42 | 38 | 34 | 32 |
| 6 | 65 | 62 | 57 | 52 | 47 | 43 | 39 | 37 |
| 7 | 70 | 67 | 62 | 57 | 52 | 48 | 44 | 42 |

*Final Noise Criterion*

The measured or estimated average minimum background sound levels should now be compared, band-by-band, with the "tentative outdoor noise criterion" determined previously. The larger of these values, in each frequency band, now becomes the octave band sound pressure levels that comprise the "final outdoor noise criterion" for the equipment installation.

Any new intruding sound is generally judged in comparison with the background sound that was already there. If the new sound stands out loudly above the existing sound, the neighbours will notice it, be disturbed by it, and object to it. On the other hand, if the new sound can hardly be heard in the presence of the old sound, it will pass relatively unnoticed. Therefore, if the sound coming from the equipment is below or just equal to the final noise criterion, it will not be noticed and our objectives will have been satisfied. If there are two or more different criterion for a particular installation, the analysis should be carried out for each situation and the lowest final criterion should be used.

*Municipal Codes and Ordinances*

Where local sound codes or ordinances exist, it is necessary to check the expected sound levels of the unit to be installed, including any sound control treatments, to determine if they comply with the code requirements. Depending on the form and language of the code, it may be necessary to introduce the code sound levels into the noise criterion analysis.

*Example*

To summarize this procedure, consider a cooling tower installation located near the edge of a college campus, approximately 91 m from a classroom building. The college is located within a large city, and two main streets pass by one corner of the campus about 450 m from the classroom building. The cooling tower will be used both day and night during warm weather. The classroom must rely on open windows for air circulation. Determine the noise criterion for the cooling tower.

**The steps for this example are given in the sample Sound Evaluation Work Sheet, included as Appendix D in this article.**

**Step 1** Determine the neighbour activity condition from Table B. For "good listening conditions" inside a typical classroom, select NC-30 as the noise criterion.

**Step 2** In the indicated spaces under Item 2 of the Sound Evaluation Work Sheet, enter the sound pressure levels for the octave frequency bands of the NC-30 curve as taken from Figure 1 or Table A.

**Step 3** Determine the wall condition of Table C that best describes the exterior wall of the classroom. Wall B can be selected for normally open windows during the summer time. Insert the Wall B values in the Item 3 spaces.

**Step 4** Add the values of Steps 2 and 3 together and insert the sums in the Item 4 spaces. This is the "tentative outdoor noise criterion."

**Step 5** In the Item 5 spaces, enter either the measured average minimum background sound pressure levels or the estimated background levels obtained from the use of Figure 2 and Tables D and E. In this example, we estimate that the traffic activity is best represented by "305 m - 610 m from continuous heavy-density traffic." This leads to Curve 5 of Figure 2 and Table E, whose values are then inserted in the Item 5 spaces.

**Step 6** In the Item 6 spaces insert the higher value, in each frequency band, of either the Item 4 or Item 5 values. This is the "final noise criterion."

In this example, note that the Item 4 values are equal to or higher than the Item 5 values in all bands. Thus, the final noise criterion is based essentially on the classroom noise criterion and the wall condition. However, the outdoor background noise estimate equals the "tentative outdoor noise criterion" in the 250 and 500 Hz bands. If they had been higher, in this example, those higher values would have been used in setting the final noise criterion in those bands.

We will attempt to keep all octave band sound pressure levels of the selected cooling tower equal to, or below, the values of Step 6. Should a sound code exist, this would be an appropriate point in the analysis to check agreement between the code and the Step 6 final outdoor noise criterion. If the criterion developed here is lower than the sound code levels at the specified distance, the sound analysis will yield results that will comply with the code.

The remaining steps of this sound evaluation example are explained in later sections of this article as we progress with the entire sound evaluation procedure.

## 5. Sound Levels for Cooling Equipment

*Introduction*

Now that we have established an acceptable noise criterion, the next step is to study the source of the sound and develop equipment sound levels at the neighbour location, in the same sound pressure level terms used to express the noise criterion. It will be the aim of this section to discuss the actual sound pressure levels of BAC evaporative cooling equipment, and to show how these levels can be corrected for various distances and certain geometric arrangements. The orientation of the equipment and distance from the equipment to the most "critical neighbour" will be our primary concern. Where possible, the distance from the equipment to the neighbour should be kept as large as possible, and the equipment should be oriented so that its lowest sound levels are radiated toward the neighbour.

Cooling equipment sound ratings can be stated in terms of both sound pressure levels and sound power levels, and both may be necessary to permit thorough sound analysis in a given situation. However, in any sound evaluation, octave band sound pressure levels for the proposed equipment are essential, and it is important to have a fairly accurate indication of the directivity characteristics of the equipment's sound.

For general use, sound pressure levels measured in the four different horizontal directions (one from each side) of the unit, plus the vertical direction above, will yield the desired directivity data. The primary requirements for obtaining the outdoor equipment's sound levels are:

- Accurate calibrated sound measurement equipment should be used.
- Octave band sound pressure levels are mandatory.
- he sound level data should indicate the true directivity effects of the unit's sound (there should be no nearby buildings or obstructions to distort the true radiation pattern of the unit test).
- The measurement distance should be specified.

Some equipment is rated in terms of the total sound power radiated, expressed as sound power level. Sound power level is a valid index for comparing the sum of sounds radiated by evaporative cooling equipment, but has the serious disadvantage of not revealing the directivity effects of the radiated sounds. Where only sound power level data are given, the resulting conversion to sound pressure level at a particular location will give less accurate results than if directional sound pressure level data are used. Sound generated by evaporative cooling equipment is directional, and sound pressure level ratings are necessary in order to determine the actual sound in any direction around the installation.

*Single Number Rating System*

Many attempts have been made to express the frequency content and pressure level (intensity) of sounds using a single number system. The most common method used is the A-B-C weighting network of sound level meters.

Sound meters with A-B-C weighting networks attempt to simulate the ear's response to sound at different pressure intensities. At a relatively low sound pressure level, the human ear is considerably more sensitive to high frequency than to low frequency sounds. This difference, however, becomes less noticeable at higher sound levels where the ear approaches more nearly equal sensitivity for low frequency and high frequency sounds.

The A-scale weighting network is designed to simulate the ear's response for low pressure sounds (below about 55 dB). The B-scale weighting is designated to simulate the ear's response for medium pressure sounds (about 55 dB to 85 dB). The C-scale weighting tends to provide nearly equal response in all frequencies and is used to approximate the ear's response at higher sound pressure levels (above about 85 dB).

| Octave Frequency Band (Hz) | Correction for A weighting |
|---|---|
| 63 | -26 |
| 125 | -16 |
| 250 | -9 |
| 500 | -3 |
| 1000 | 0 |
| 2000 | +1 |
| 4000 | +1 |
| 8000 | -1 |

A-B-C scale ratings have been used in some sound ordinances and equipment sound ratings because of their simplicity of statement. They may have value in some sound comparison situations, but such data are of little value in making an engineering evaluation of a sound issue caused by evaporative cooling equipment, because no indication of the frequency content of the sound is apparent. For example, two different types of cooling towers could have the same A scale rating, but one could have most of its energy in the low frequency bands while the other could have its energy concentrated in the high frequency bands. A single number rating will give no indication of this and its use could lead to less than optimal and sometimes costly decisions.

*Comparison of Cooling Equipment employing a Centrifugal Fan versus an Axial Fan*

Based on extensive studies of field data from several cooling tower installations, it has been found that overall sound pressure levels of centrifugal fan cooling towers are about 5 to 7 dB lower than those of axial fan cooling towers for the same cooling capacity even though the axial towers use about half the kW. As a comparison, this means that an axial fan cooling tower would have to be twice as far away from the neighbours as a centrifugal fan tower in order to be just as quiet (6 dB reduction for each doubling of distance, see Table F). The frequency distribution and the radiation patterns also differ for these two types of units. For any specific comparison of cooling towers, the manufacturer's actual measured data should be used.

*BAC Sound Ratings*

BAC has measured the sound levels radiated by its products at 1,5 m and 15 m distances for the five principle directions, (four horizontal and one vertical). The sample sound rating data sheet indicates the five principle directions and the type of sound data available for a BAC cooling tower. As the data sheet suggests, the data given in the five blocks pertain to the sound pressure levels measured at 15 m distances from the five principle directions of the cooling tower. Where it might be desired to estimate the sound pressure levels at some intermediate direction, such as halfway between the right end and the air inlet, levels can be averaged or interpolated from the data actually presented.

## Sound Rating

**Sound Pressure Level**

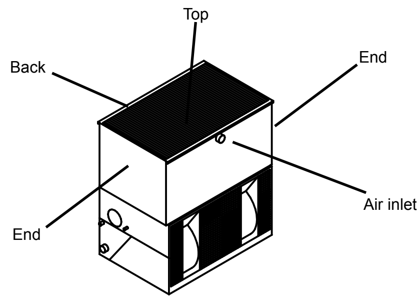
| Hz | Fan End(dB) | Back(dB) | End1(dB) | End2(dB) | Discharge (dB) |
|---|---|---|---|---|---|
| 63 | 66.0 | 60.0 | 64.0 | 64.0 | 58.0 |
| 125 | 64.0 | 58.0 | 61.0 | 61.0 | 60.0 |
| 250 | 61.0 | 54.0 | 56.0 | 56.0 | 58.0 |
| 500 | 58.0 | 54.0 | 54.0 | 54.0 | 57.0 |
| 1000 | 58.0 | 53.0 | 52.0 | 52.0 | 56.0 |
| 2000 | 55.0 | 48.0 | 48.0 | 48.0 | 53.0 |
| 4000 | 52.0 | 43.0 | 42.0 | 42.0 | 49.0 |
| 8000 | 49.0 | 38.0 | 38.0 | 38.0 | 44.0 |
| **dB(A)** | **63.0** | **57.0** | **57.0** | **57.0** | **61.0** |

**Input Options**

| | |
|---|---|
| Model | VXT 185 |
| Sound Attenuation | no attenuation |
| Additional ESP (Pa) | 0 |
| Fan Motor Size (kW) | 1 x 18.5 kW |
| Approximate Fan Speed | 100.0 % |
| Distance (m) | 15.0 |

**Total Sound Power Level**

| Octave Band (Hz) | Total Sound Power Level |
|---|---|
| 63 | 95.0 |
| 125 | 93.0 |
| 250 | 90.0 |
| 500 | 88.0 |
| 1000 | 87.0 |
| 2000 | 83.0 |
| 4000 | 80.0 |
| 8000 | 76.0 |
| dB(A) | 91.0 |




Octave band and A-weighted Sound Pressure Levels (SPL) in dB RE 0.0002 Microbar.
Note: Sound data are free field data valid for unit installation without elevation, not taking into account any reflections

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In addition to the five sets of sound pressure levels at each of the two distances, the data sheets contain the calculated sound power level values for the reference power level $10^{-12}$ watt. Current sound data for all BAC equipment is available from BAC Balticare Representative.

Since sound power levels are being mentioned here, it is appropriate at this point to note that Appendices A, B, and C are given at the end of this article to supply basic information related to sound power levels and to other calculations that may be required from time to time in a sound evaluation. Appendix A describes a simplified method for calculating the sound power level of a unit where the five sets of sound pressure level readings are known. Appendix B gives a procedure for calculating the average sound pressure level at a given distance if the sound power level is known.
Appendix C gives a simple procedure for adding decibel values. This is required, for example, in converting sound pressure levels into sound power levels, or in calculating an overall sound pressure level from the eight individual octave band levels,

or in adding two or more sound sources.

*Effective Distance beyond 15 m*
In any actual situation, it is usually necessary to determine the sound pressure levels of the equipment at some distance other than the 1,5 m and 15 m distances given in the BAC rating sheets. In this section, distance corrections are given for estimating sound pressure levels at distances beyond 15 m.

For distances that are large compared to the dimensions of the unit, the "inverse square law" holds for sound reduction with distance: i.e., for each doubling of distance from the unit, the sound pressure level decreases 6 dB. Thus, for distances beyond 15 m the inverse square law applies and the distance correction is quite straightforward. Table F presents the reduction of sound pressure level for distances from 15 m out to 800 m. The values given in Table F are to be subtracted from the sound pressure levels at the given distance of 15 m in order to arrive at the sound pressure levels at the distance of interest.

For relatively short distances (less than 30 m), the same correction value applies to all eight frequency bands. For the larger distances (greater than 30 m), high frequency sound energy is absorbed in the air and the correction terms have larger values in the high frequency bands. For distances greater than about 150 m, wind and temperature of the air may further influence sound propagation; but because these are variables, they are not considered in this article and the correction figures of Table F represent more or less "average" sound propagation conditions.

If the critical distance falls between the specific distances given in the left-hand column of Table F, interpolate the sound reduction value to the nearest 1 dB. Do not attempt to use fractions of decibels.

**Table F: Reduction of Sound Pressure Level (in dB) for Distances beyond 15 m**

| Distance (m) | Octave Band Center Frequenzy in HZ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **63** | **125** | **250** | **500** | **1000** | **2000** | **4000** | **8000** |
| **15** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **20** | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| **25** | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| **30** | 6 | 6 | 6 | 6 | 6 | 6 | 7 | 7 |
| **37,5** | 8 | 8 | 8 | 8 | 8 | 8 | 9 | 10 |
| **50** | 10 | 10 | 10 | 10 | 10 | 10 | 11 | 12 |
| **60** | 12 | 12 | 12 | 12 | 12 | 13 | 14 | 15 |
| **75** | 14 | 14 | 14 | 14 | 14 | 15 | 16 | 18 |
| **100** | 16 | 16 | 16 | 16 | 16 | 17 | 18 | 21 |
| **120** | 18 | 18 | 18 | 18 | 19 | 19 | 21 | 24 |
| **150** | 20 | 20 | 20 | 20 | 21 | 22 | 24 | 27 |
| **200** | 22 | 22 | 22 | 22 | 23 | 24 | 27 | 31 |
| **240** | 24 | 24 | 24 | 25 | 25 | 26 | 30 | 35 |
| **300** | 26 | 26 | 26 | 27 | 27 | 29 | 34 | 40 |
| **400** | 28 | 28 | 28 | 29 | 30 | 32 | 38 | 46 |
| **480** | 30 | 30 | 30 | 31 | 32 | 35 | 43 | 53 |
| **600** | 32 | 32 | 32 | 33 | 35 | 38 | 47 | 61 |
| **800** | 34 | 34 | 34 | 36 | 38 | 42 | 53 | 70 |

*Effect Distance between 1,5 m and 15 m*
In this section, distance corrections are given for estimating sound pressure levels in the close-in range of 1,5 m to 15 m. When the distance from a sound source is small or comparable to the dimensions of the source, the "inverse square law" does not necessarily hold true for variations of sound level with distance. So, for the relatively short distances of 1,5 m to 15 m, it might be necessary to accept some sound pressure level variations, which do not follow the straightforward trends that hold for distances beyond 15 m. Table G permits us to estimate the sound pressure levels at these close-in distances, provided the 1,5 m and 15 m sound pressure levels are known.

To illustrate the use of Table G, suppose the sound pressure level of a unit in a particular frequency band is 68 dB at 1,5 m and 54 dB at 15 m distance. The difference between these two values is 14 dB. In Table G, we find the column of values under the heading "If the difference between the 1,5 m and 15 m levels is 13 – 15 dB." The numbers in this column are the values (in decibels) to be added to the 15 m sound pressure level of 54 dB to obtain the sound pressure level at some desired shorter distance. If, for instance, we wish to know the "sound pressure level" of this unit at 1,5 m, we find that we must add 8 dB to the 15 m level of 54 dB to get 62 dB as the sound pressure level at the desired distance of 1,5 m.

Now, for these close distances, the difference values between the 1,5 m and 15 m sound pressure levels may not be constant for all frequency bands so it is necessary to follow this procedure for each octave band. For example, in one frequency band the difference may be 12 dB but in another band it may be 15 or 16 dB.

Close-in interpolation of sound pressure levels is inherently somewhat unreliable; so do not be surprised if some oddities or discrepancies in the data begin to appear at very close distances. The method used here at least gives some fairly usable data to work with.

**Table G: Interpolation Terms for Obtaining Sound Pressure Levels (in dB) Between 1,5 m and 15 m**

| Distance at which SPL is desired (m) | If the difference between the 1,5 m and 15 m levels is: | | | | | | |
|---|---|---|---|---|---|---|---|
| | 4-6 dB | 7-9 dB | 10-12 dB | 13-15 dB | 16-18 dB | 19-21 dB* | 22-24 dB |
| | Add the following values to the 15 m sound level to obtain sound level at desired distance: | | | | | | |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13,5 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| 12 | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| 10,5 | 1 | 1 | 2 | 3 | 3 | 3 | 3 |
| 9 | 2 | 2 | 3 | 4 | 4 | 4 | 5 |
| 7,5 | 2 | 3 | 4 | 5 | 5 | 6 | 7 |
| 6 | 2 | 4 | 5 | 6 | 7 | 8 | 9 |
| 4,5 | 3 | 5 | 6 | 8 | 9 | 10 | 12 |
| 3 | 4 | 6 | 8 | 10 | 12 | 14 | 16 |
| 1,5 | 5 | 8 | 11 | 14 | 17 | 20 | 23 |

* This column of values is based on the "Inverse Square Law" variation with distance from 15 m all the way in to 1,5 m.
All other columns represent variations with distances that do not follow the "Inverse Square Law."

### *Reflecting Walls and Enclosures*

Discussion so far has been concerned with what might be considered "simple installations" from an acoustic point of view, where only distance to the neighbour and relative orientation of the unit have been required points of consideration.

Frequently, the geometry of an installation involves some nearby reflecting walls or buildings, which adds to the acoustic complexity of the site. Let us consider this for three typical situations:

- Cases in which reflecting walls modify the radiation pattern of the sound from the unit to the neighbour
- Cases in which close-in walls confine the unit and cause a build-up of close-in sound levels
- Cases in which the unit is located in a well and all the sound radiates from the top of the wall

### Effect of Reflecting Walls

Several factors that influence the amount of reflected sound are the following:

- The sound radiation pattern (directivity) of the equipment
- The radiating area of the equipment
- The orientation of the equipment
- The distance of the unit to the neighbours
- The distance of the equipment to the reflecting wall
- The area of the reflecting wall
- Various angles of incidence and reflection between the equipment, the wall, and the neighbours

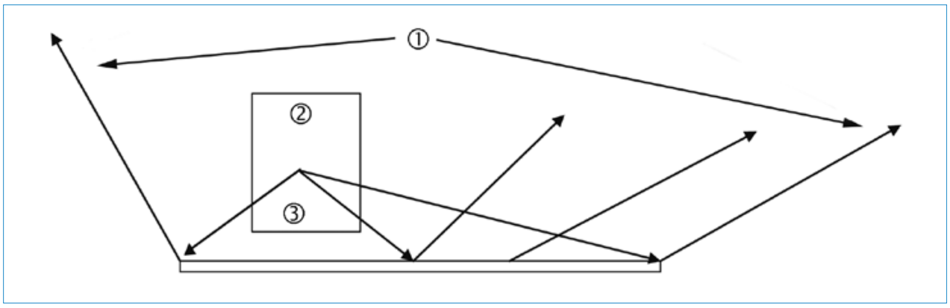
Because so many variables are involved, we will not attempt to develop a rigorous procedure for estimating the influence of a reflecting wall. Rather, we caution that if a large reflecting surface is located near the equipment, it should be considered as a potential reflector of sound. If the equipment is oriented such that its loudest side is already facing toward the neighbour, the influence of the reflecting wall can be ignored!

However, if this is not the case, these conditions must be met for the reflected sound to be of concern:

- The area of the reflecting wall is at least three times the area of the side of the equipment that faces that wall
- The distance from the unit to the reflecting wall is less than half the distance from the equipment to the neighbour

- If a simple optical ray diagram is drawn from the center of each unit to all parts of the reflecting wall and the reflecting rays are then drawn away from the wall, the neighbour is located within the angular range of the reflected rays (see sketch below)

If each of these three conditions is met, then the sound pressure levels at the neighbour may be higher than if the wall were not there.

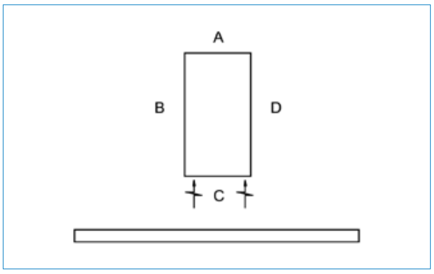



*Neighbour Area Influenced by the Reflecting Wall*
1. Neighbour area influenced by the reflecting wall; 2. Cooling Tower; 3. Air Intake.

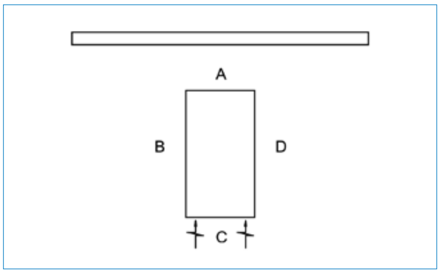
In Figures 3 and 4, a few representative reflecting walls are shown for various orientations, and approximate sound pressure level adjustments are suggested for A, B, C, and D directions away from the equipment. These adjustments should be made using the 15 m levels. Figure 3 applies to units having one air intake, while Figure 4 applies to units having two air intakes.

As an example, for Case 1, if the neighbour is located off the A side of the unit, apply the "A" adjustment to the A side 15 m sound pressure level rating of the unit and then correct as necessary to the neighbour's distance. If the situation is that of Case 9 and the neighbour is located in the direction D, then the "D" adjustment would be utilized to arrive at a 15 m sound pressure level for the unit.

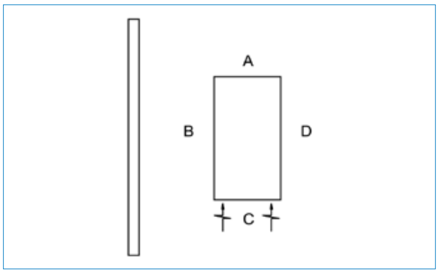
Figure 3: For Single Air Inlet Units



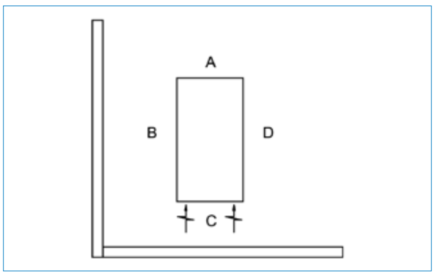

*Case 1*
A. Use Average of A and C Levels, B. Use average of B and C levels, C. Not applicable, D. Use average of D and C levels.



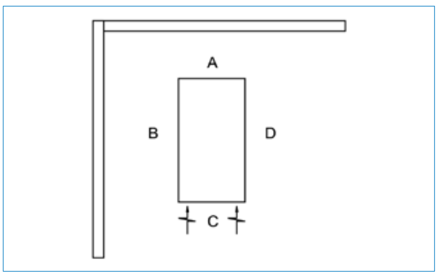

*Case 2*
A. Not applicable, B. Use greater of B level or average of B and A levels, C. No change to C levels, D. Use greater of D level or average of D and A levels.



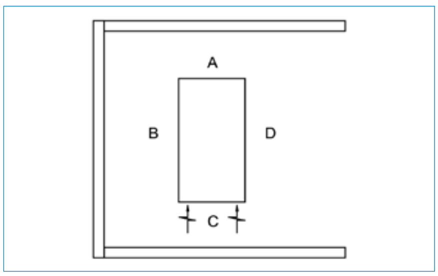

*Case 3*
A. Use greater of A level or average of A and B levels, B. Not applicable, C. No change to C levels, D. Add 2 dB to D levels.




*Case 4*
A. Use average of A and C levels, B. Not applicable, C. Not applicable, D. Use average of D and C levels.

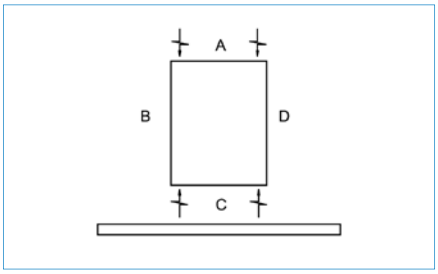



*Case 5*
A. Not applicable, B. Not applicable, C. No change to C levels, D. Use average of A, C, D levels.

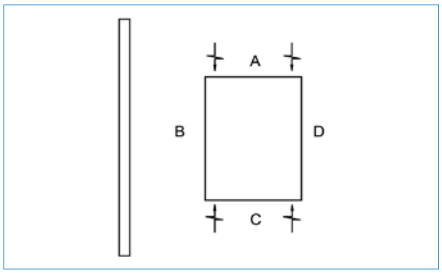



*Case 6*
Four sound levels out the open end of a 3-sided enclosure, add 3 dB to the sound pressure levels of the air intake side of the unit.

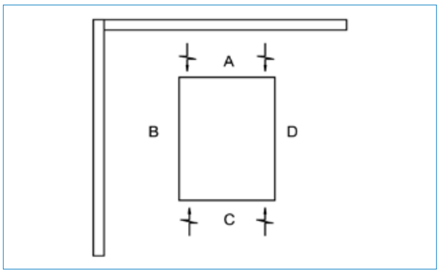
Figure 4: For Dual Air Inlet Units



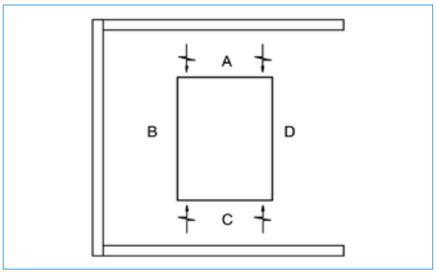

*Case 7*
A. Add 2 dB to A levels, B. Use average of B and C levels, C. Not applicable, D. Use average of C and D levels.




*Case 8*
A. No change to A levels, B. Not applicable, C. No change to C levels, D. Add 3 dB to D levels.




*Case 9*
A. Not applicable, B. Not applicable, C. Add 2 dB to C levels, D. Add 3 dB to D levels.




*Case 10*
For sound levels out the open end of a 3-sided enclosure, add 3 dB to the sound pressure levels of the air intake side(s) of the unit.

These figures and their associated adjustment values are to be used to correct base 15 m sound pressure level ratings in the neighbour direction of the effect of the reflecting surface conditions shown.

## Build-Up of Close-in Sound Levels

Cooling equipment is sometimes located very close to a building wall, inside a "court" formed by two or three surrounding walls, or even in a specially provided room or space in the mechanical equipment area inside a building. In these installations, the principal concern may be the sound in the immediate vicinity (within 1,5 m - 3 m) of the unit(s), rather than the sound levels radiated and reflected away to some neighbour location.
For these situations, we may use Table G to determine approximately the sound pressure levels for the close-in distances of interest, and then add an increment to account for the build-up of sound levels. Here also, the geometry of the layout controls the problem and it is not possible to give a general solution that will cover the multitude of possible layouts. As an approximate acknowledgement of this situation, we suggest that the close-in sound pressure levels be increased by 5 dB, recognizing that the range of increase could be as little as 2 or 3 dB (in a fairly open courtyard) and as much as 10 to 15 dB (in a fairly confined mechanical room enclosure). This adjustment should be applied to all eight-octave band readings.

## Sound Radiation from a Four-Sided Enclosure or "Well"

Cooling equipment is sometimes located inside a four-sided enclosure or "well," where all the sound radiates more-or-less vertically out the top of the well and then "spills over" the sidewalls of the well. A simple generalized solution to this problem is not possible, but a reasonable approximation can be made.

While the sidewalls serve as barrier walls against normal sound radiation in horizontal directions, the four-sided enclosure tends to "average-out" any free-field directional characteristics of the unit and causes an average sound pressure level to be radiated from the top of the well in all directions in which sound is free to radiate per the geometry of the situation. Appendix B provides a procedure for calculating sound pressure levels for a given sound power level, at various distances and with several radiation patterns.

In the typical case illustrated, where the sound from the well radiates over a hemisphere, the sound pressure levels of the unit at a 15 m distance would be determined by subtracting 32 dB from the sound power levels of the unit.

It should be recognized that this method of sound evaluation is an approximation. Actual sound levels may be somewhat lower in the higher frequency bands, and could be slightly lower in the lower frequency range depending upon the neighbour location relative to the equipment. If the sidewall of the well clearly serves as a barrier wall for the radiated sound, barrier wall attenuation values can be applied to the problem in the same manner as the sound evaluation procedure of this article subsequently permits for the non-well type installation.

Example Continued

Let us now summarize Step 2 in the sound evaluation process, looking at the source of sound and correcting it for distance and path. This will yield equipment sound pressure levels for the same point, which the final noise criterion was calculated in the earlier example.

We are now interested in Items 7-11 in the sample Sound Evaluation Work Sheet (see Appendix D) which pertain to the cooling tower sound pressure levels as extrapolated to the 90 m distance. We continue the step-by-step procedure on the Sound Evaluation Work Sheet where we left off earlier.

**Step 7** Decide on the preferred orientation of the cooling tower at the site. From the BAC Sound Rating Data Sheet, determine the sound pressure levels at the 15 m distance for the side of the cooling tower facing the college classroom. Assume one of the end sides here (the "blank-off sides"), since they are the quietest. Insert these sound pressure level values in the Item 7 spaces of the Sound Evaluation Work Sheet.

**Step 8** Insert the distance "90" m in the appropriate space under Item 8 and refer to Table F for the distance correction values corresponding to 90 m. Insert these values in eight spaces of Item 8.

**Step 9** The sound pressure levels at 90 m will be lower than at 15 m, hence subtract the Item 8 values from the Item 7 values and insert the remainder in the Item 9 spaces. These then are the sound pressure levels that will exist just outside the college classroom, 90 m from the cooling tower.

**Step 10** Had there been a sound increase due to the presence of a reflecting wall that met one of the conditions illustrated by Figures 3 or 4, corrections would be inserted now in the Item 10 spaces. Had this been a close-in problem involving a build-up of sound levels due to some nearby enclosing walls around the tower, "+5 dB" would have been inserted in the Item 10 spaces. Since neither of these conditions applied in this example, we insert "0" in each of the Item 10 spaces.

**Step 11** Item 11 is the sum of Items 9 and 10. This is the sound pressure level of the cooling tower at the 90 m distance.

## 6. Comparison of Noise Criteria and Evaporative Cooling Equipment Sound Levels

*Example Continued*

From the material given in the two preceding sections, it is now possible to determine if a particular cooling tower will be satisfactory (from a sound point-of-view) in a given location for a given set of circumstances. The analysis now consists of comparing the estimated cooling tower sound levels with the noise criterion developed for the neighbour situation. The comparison may be made by plotting the sound levels and the noise criterion on a graph, as show in Figure 5, or merely by comparing the two groups of values on a band-by-band basis. We are now interested in Items 12-13.

**Step 12** Merely as a means of simplifying the next step, copy in the Item 12 spaces the values taken from Item 6, which was the "Final Noise Criterion."

**Step 13** By subtracting the Final Noise Criterion (Item 12) from the Resultant Cooling Tower Sound Pressure Levels (Item 11), we determine if there is any excess of coo-ling tower sound above the criterion. Any positive-valued remainder represents sound excess above the criterion. Any negative-valued remainder means that the cooling tower level is below the criterion and no sound reduction is required in the frequency bank; hence, "0" is inserted in that space.

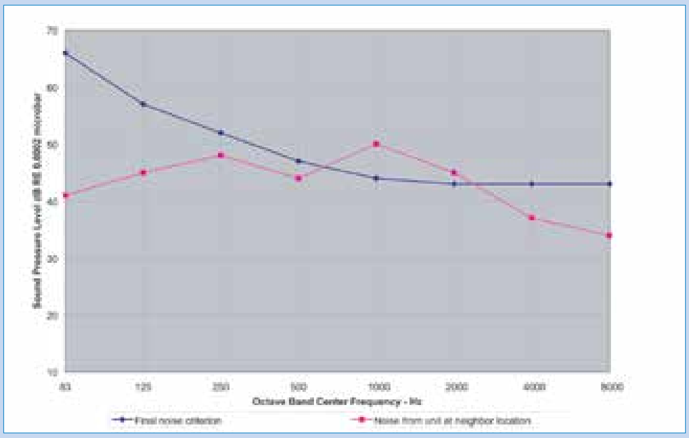



*Figure 5: Comparison of Final Noise Criterion and Equipment Sound Levels*

If the cooling tower levels in all eight octave bands are below the criterion values, there should be no sound problem. If two or three of the cooling tower levels exceed the criterion values by only 1 or 2 or 3 dB, there will probably be no sound problem. If several octave band sound levels exceed the criterion by 5 to 10 dB, or more, a sound problem should be anticipated – the higher the sound excess the more assured is the problem if suitable measures are not taken.

*Judgement Factor*
At this point, some remarks should be made on the overall reliability of this approach, and an opportunity should be provided for inserting a judgment factor. In as much as the original criterion selection was based mostly on lower range NC values for the various environments considered, the derivation presented here may be somewhat conservative. Because of this, decisions based on this approach will usually lead to acceptance of the sound from the equipment. As explained throughout the procedure, several approximations are made (such as for the sound reduction of various general types of walls, and the sound estimates of community or traffic background sounds, and others). These approximations may lead to some variability from one installation to the next, although it is believed that a small amount of variability can be accommodated by the procedure without changing the results unreasonably.

Experience shows that where the criterion is based on sleeping at night, the criterion should not be exceeded, and therefore, the conclusions reached by this procedure should be followed. However, where the criterion is based on somewhat less critical daytime activities, and the background sound frequently ranges considerably above the average minimum conditions used here, then the risk is not too great if the criterion is exceeded by about 5 dB. In such cases the criterion should not be exceeded by more than 5 dB for fear of serious objections. If it is decided to permit the sound to exceed the criterion by as much as 10 dB or more, sound reduction steps should be considered for future addition to the installation, even though they may not be included in the initial installation.

In view of the above, if the equipment's owner, architect or engineer chooses to follow a conservative approach or even to allow for some excess sound on a particular project (that is, permit the equipment's sound to exceed the background sounds slightly and thus be identifiable and possibly disturbing to the neighbors), this opportunity is afforded in Items 14 and 15 of the Sound Evaluation Work Sheet (Appendix D).

**Step 14** Insert the cooling tower owner's Judgement Factor. For a "conservative approach" insert 0 dB in the Item 14 spaces of the Work Sheet. To purposely allow the cooling tower sound to exceed the acceptable levels slightly, insert 5 dB in the Item 14 spaces.

**Step 15** The Final Sound Reduction Requirement for the cooling tower is the difference, in each band, obtained by subtracting Item 14 from Item 13. These are the attenuation values in each octave band necessary to reduce the cooling tower sound to an acceptable level. A brief discussion of sound control for evaporative cooling equipment is given in the next section.

**Step 16** Sound reduction can be accomplished in several ways, and quantitative values for possible sound reduction steps are discussed in the next section. Step 16 of the Sound Evaluation Work Sheet should include the attenuation obtained from the use of two-speed fan motors, Baltiguard drives, VFD, low sound fans, barrier walls, and from any special acoustic treatments to be provided. Other situations that may apply are oversizing the equipment and utilizing strategic layout.

## 7. Cooling Equipment Sound Control

*Introduction*
The sound reduction required for cooling equipment is simply the excess of the equipment's sound pressure levels over the applicable noise criterion levels. This is shown numerically by the dB values found in Item 15 of the Sound Evaluation Work Sheet (Appendix D) when the particular calculation is carried out. The clue as to whether it will be a simple or complex sound reduction problem lies largely in the amount and frequency distribution of the required sound reduction.

Job conditions may allow some quieting to be obtained by strategically positioning the equipment, controlling the fan motor, installing a low sound fan option, or constructing barrier walls located between the equipment and neighbour. Additional sound reduction needs may be met with packaged attenuators or other acoustic treatments, which, in general, can achieve high frequency noise reduction rather easily but usually involve larger weight and space requirements to accomplish low frequency quieting.

*Strategic Positioning*
The first and most economical strategy in reducing sound pressure levels from cooling equipment involves considering the layout of the equipment. "Strategic Positioning" includes two aspects. First, make sure to position the quietest side of the equipment towards the sound sensitive direction. This option should always be a first consideration with single side air inlet products. Next, take advantage of any existing sound barriers that may aid in muffling the sound from the equipment to the neighbour. For example, if a building or shed exists on the job site, position the equipment so that the structure blocks the direct path between the equipment and the neighbour, thus acting as a sound barrier. Trees and bushes are also good examples of barriers that greatly reduce sound exposure at neighbouring properties.

*Fan Motor Control*
Operating the equipment at various speeds by utilizing a VFD, Baltiguard drives or a two-speed motor is a practical option

of sound control if reduced equipment loads can be made to coincide with periods when low sound pressure levels are required. This is a normal nighttime situation for many air conditioning installations.
An 1500-750 rpm fan motor operating at 750 rpm would provide about 60% of full-load capacity on a BAC unit and would give approximately the following octave band dB noise reductions:

| Frequency Band - HZ | | | | | | | |
|---|---|---|---|---|---|---|---|
| 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 |
| 4 | 6 | 8 | 10 | 8 | 8 | 6 | 4 |

In as much as these are average dB reductions that can be anticipated for half-speed operation, these figures can apply to both sound power and sound pressure levels. Also, these approximations are sufficiently accurate to be used for both centrifugal and axial fan towers.

In addition to running the equipment at a lower speed during noise-critical hours, it is beneficial to investigate whether or not the equipment could be turned off completely during these hours. This would completely negate any sound created by the unit; however, the system and its loads must be researched to understand if this option is feasible.

In some cases what people find objectionable is not the steady sound of the equipment, it is the abrupt stopping and starting of the fan system. Properly setting the tower control sequence to avoid excessive cycling of fan motors is important in this regard, as well as to protect the motor from overheating. VFD's solve this issue by allowing for a soft start of the fans, followed by a gentle ramping up and down of the fan speed in line with the load requirement. Simply stated, VFD's allow the fan motor to run at the speed required to meet leaving water temperature requirements rather than running at full speed all the time. Decreasing the motor speed, and therefore the fan rpm, can decrease sound levels significantly. VFD's also minimize harsh sounding on-off cycles by providing a gradual start.

*Figure 6: BAC axial fan cooling tower utilizing the Baltiguard drive.*

*Figure 7: If applicable, turn towers off at night to eliminate sound*

*Figure 8: VFD with Integrated Bypass*

*Figure 9 :Axial Fans*

*Oversizing Equipment*
If space and budget allow, it may be beneficial to oversize the equipment and run the larger capacity equipment at a lower fan speed rated for the specific job. As discussed in the previous section, reducing the motor speed reduces the fan speed and because fan speed is directly proportional to sound, reduces sound.

*Low Sound Fans*

Another option for reducing the sound that the equipment produces is to select a low sound fan. Low sound fans provide greater solidity than regular fans and so are able to move the same amount of air, while operating at a slower speed.

*Barrier Walls*

Barrier walls can be used to provide sound attenuation. In some cases barrier walls may exist due to the architectural treatment of the site, while at other times they are constructed specifically to provide needed sound reduction.

Taking the first case, a wall used to shield a unit from view can also act to reduce the sound radiated by the tower, particularly high frequency sound (broadly considered here as the upper four octave frequency bands). However, such barrier walls must "cover" by line-of-sight the entire sound source as observed from the neighbor's position. Louvered, latticed or slotted openings will render negligible the attenuation abilities of a barrier wall. A solid wall of height equal to a unit and located close to it will provide the following approximate attenuation:

| Frequency Band - Hz | | | | | | | |
|---|---|---|---|---|---|---|---|
| 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 |
| 4 | 5 | 5 | 5 | 5 | 6 | 7 | 8 |

When greater attenuation is required, a larger specially constructed barrier wall may be designed and installed. Care must be taken, though, in locating the wall because of the many geometric and material considerations involved.

As an example, a barrier wall that (1) extends at least 1 to 1,5 m beyond the line-of-sight in both the horizontal and vertical directions, (2) that is located within 1,5 to 2,5 m of the cooling tower and (3) that is made of a solid impervious material having a surface weight of at least 85 $g/m^2$ will have approximately the following attenuation:

| Frequency Band - Hz | | | | | | | |
|---|---|---|---|---|---|---|---|
| 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 |
| 5 | 5 | 6 | 8 | 10 | 12 | 14 | 16 |

A still larger and heavier barrier wall will provide still greater attenuation. To be most effective, however, a barrier wall must be located as close as possible to the sound source and there must be no reflecting surfaces in the area that can reflect sound around the barrier.

*Figure 10: Architectural walls being constructed around Closed Circuit Cooling Towers*

Design details of barrier walls and other acoustic treatment such as custom–engineered plenum chambers and acoustic mufflers are best left to acoustical engineers or consultants and acoustical treatment manufacturers.

*Sound Attenuation*

A significant feature of both axial and centrifugal fan equipment is that its noise, if it is a problem at all, can be treated with relatively simple package attenuation. Figure 11 is a photograph of a BAC Axial Fan Open Cooling Tower, with sound attenuation on both the intake and discharge of the unit. The fan intake attenuator has unique circular acoustical baffles in a staggered arrangement and the discharge attenuator is a lined plenum chamber.

*Figure 11: Intake and discharge sound attenuation on a BAC Axial Fan Open Cooling Tower*

Lined plenum chambers, to be effective, (1) must be fairly large, (2) should contain a thick absorbent lining, and (3) should be arranged such that the sound path through the plenum includes does not allow line-ofsight. Depending on the degree to which the plenum chamber conforms to these three requirements, its sound reduction may range in the order of 5 to 10 dB for low frequency noise up to 10 to 20 dB for high frequency noise.

BAC sound attenuation packages are designed, tested and rated by BAC, hence ensuring single source responsibility. They provide reductions in the horizontal direction up to 25 dB in the mid frequency bands. Many sound attenuation alternatives are available from BAC to optimally and economically meet a large variety of sound requirements. Sound attenuation packages are available for centrifugal and axial fan models. Exact values of the attenuation obtained from these packages are available from your local BAC Balticare representative.

*Effects of Sound Reduction Options on Equipment Performance*
The cost of sound attenuation, including the effect on performance, must be evaluated versus simpler methods such as oversizing the unit(s) to meet the sound criteria for a project. Note that with either low sound fans or "add-on" attenuation, lower sound levels often come at the expense of lower airflow. The system designer must ensure that the manufacturer's ratings are adjusted to account for any decrease in thermal performance from this reduction in airflow.

Another caution is for the use of sound barrier walls. It is necessary for barrier walls to be far enough away from the tower so as to prevent recirculation of the moist discharge air. If this practice is not followed, the warm air can be introduced to the air intake, increasing the wet bulb temperature of the unit, and in turn decreasing the cooling capacity of the tower.

## 8. Summary

This article provides a simple and direct evaluation method for determining whether or not a given cooling equipment installation is producing, or will produce, excess sound. It also offers some general information on methods that can be used to reduce the sound.

BAC can provide reliable sound level data on its open cooling towers, closed-circuit cooling towers, evaporative condensers, dry coolers and dry coolers with adiabatic pre-cooling through their representatives. Consult your local BAC Balticare Representative for specific project applications.

*Acknowledgement: BAC extends its sincere appreciation to Mark E. Schaeffer, P.E. (President of Schaffer Acoustics Inc. of Pacific Palisades, CA) for his contributions to this article.*

## Appendix A: *The Calculation of Sound Power Level (Lw) from Measured Sound Pressure Levels (Lp)*

Sound power is a measure of the total acoustic power radiated by a sound source. “Sound power level” is the sound power, expressed in decibels, relative to the reference power quantity $10^{-12}$ watt.

Sound power is not directly measured as such. Instead, it is a calculated quantity and is obtained from the measurement of sound pressure levels at a suitable number of measurement positions. Even in indoor testing with reverberant or semi-reverberant rooms and a standard reference sound source, sound power level is calculated from sound pressure level measurements. In this discussion, no technical detail is given for the derivation of sound power level; instead, a very simple procedure is provided for establishing the approximate sound power level of evaporative cooling equipment for the case in which the sound pressure level is measured at four horizontal positions (each position at a specific distance from each of the four sides) plus one vertical position above the unit. The measurement positions may be at any distance between 2 and 4 times the unit’s largest dimension, which is usually its length.

The measured sound pressure levels must be obtained with accurate, calibrated equipment, and the sound data must be in the conventional eight octave bands of frequency. The measurements should be made under essentially free-field conditions: i.e., outside in an area free of any nearby reflecting surfaces. The unit is assumed to be located on the ground or on a platform reasonably close to ground level.
The approximate sound power level in each of the eight octave bands is the sum, by decibel addition, of the individual five sound pressure level readings in each octave band plus a correction term (K) which is a function of the number of measurements positions, the measurement distance and the reference power. In equation form, this can be expressed as

$$\mathbf{Lw = \Sigma Lp + K}$$

The decibel summation of a number of sound pressure levels is determined from the material given in Appendix C and the correction terms are given below in Table A for the appropriate conditions. The use of the five measurement positions and the decibel addition of the five readings automatically introduce the directivity characteristics of the unit into the calculated sound power level. No further provision for directivity is required in this simplified method.
To illustrate this procedure, suppose we wish to estimate the sound power level (Lw) in one octave band for the case of the five-position measurements 15 m from a cooling tower. Assume the five sound pressure levels measured in the particular frequency band are 56, 53, 59, 53 and 47 dB (re 0.0002 microbar).

By the decibel addition method shown in Appendix C we find that the decibel sum of these five sound pressure levels is 62 dB. From Table A we then find that for the 15 m measurement distance, the correction term is 25 dB re $10^{-12}$ watt.
For this example,

$$\begin{aligned} \mathbf{Lw} &= \mathbf{\Sigma Lp + K} \\ &= \mathbf{62 + 25} \\ &= \mathbf{87\ dB} \end{aligned}$$

The same procedure could be followed for all octave bands to get the complete Lw of the cooling tower. The procedure given here is for the specific five measurement positions noted and may not be applicable generally to other situations. The procedure is not accurate to less than 1 dB, so fractional values of decibels should not be used or relied upon.

Correction term K to be used in converting Sound Pressure Levels (Lp) into Sound Power Level (Lw) for special five-position procedure given

**Table A**

| Measurement Distance (to Acoustic Center) (m) | Correction Term K for Lw re $10^{-12}$ Watt (dB) |
|---|---|
| 7,5 | 19 |
| 9 | 20 |
| 10,5 | 21 |
| 12 | 23 |
| 13,5 | 24 |
| 15 | 25 |
| 18,5 | 26 |
| 21 | 27 |
| 24 | 29 |
| 27 | 30 |
| 30 | 31 |

## Appendix B: *The Calculation of Average Sound Pressure Level (Lp) for a given Sound Power Level (Lw)*

For comparative purposes it may occasionally be necessary to estimate the approximate average sound pressure level radiated by a unit for which only the sound power level is given. There are also some applications that are best appraised by converting sound power back to average sound pressure levels. The procedure outlined in this Appendix will provide this estimate.

It is important to realize that the resulting value is an average sound pressure level that theoretically would be radiated the same in all directions from the unit. In practice, the unit probably would not radiate the same levels in all directions; but, when only the sound power level is given it is not possible to know the directivity characteristics of the unit.

The average sound pressure level at a desired distance is obtained by subtracting from the sound power level in any given octave frequency band the appropriate correction term (C) from Table B. In equation form, this relationship is expressed as

$$Lp_{Avg.} = Lw - C$$

As an illustration, suppose we wish to know the average sound pressure at a 15 m distance for a cooling tower that is stated to have a sound power level 87 dB re $10^{-12}$ watt. (Note that this is the counterpart of the example given in Appendix A.) From Table B, for a 15 m distance, we see that the correction term is 32 dB.

$$\begin{aligned} Lp_{Avg.} &= Lw - C \\ &= 87 - 32 \\ &= 55 \text{ dB} \end{aligned}$$

By comparing this value with the five levels fed into the illustration in Appendix A, we see that although this is an average value, it actually does not equal any of the levels from the five measured directions. Note again that the average value does not pretend to show the directivity characteristics of the sound source.

If two competitive cooling towers are being compared for a particular site condition, a comparison of the sound power level or the average sound pressure level may be a general clue to the relative sound from the two units, but a more careful comparison should take into account the actual sound levels to be radiated in the particular critical direction(s).

Correction terms C to be used in converting Sound Power Level into average Sound Pressure Level for special five-position procedure given.

**Table B**

| Measurement Distance (to Acoustic Center) (m) | Correction Term C for Lw re $10^{-12}$ Watt (dB) |
|---|---|
| 7,5 | 26 |
| 9 | 27 |
| 10,5 | 28 |
| 12 | 30 |
| 13,5 | 31 |
| 15 | 32 |
| 18,5 | 33 |
| 21 | 34 |
| 24 | 36 |
| 27 | 37 |
| 30 | 38 |

The correction term C is based on the sound radiating uniformly over a hemisphere. This would apply for a typical ground level installation or for a unit located on a large roof. If there are conditions such that the sound will radiate over a large angle, say a 3/4 sphere, add 3 dB to the above C. Subtract 3 dB from the above C for a 1/4 sphere radiation.

For distance beyond 30 m calculate the average Lp for 15 m using the method here; then extrapolate to the desired distance using the Lp reduction values of Table F in section “Effect of Distance beyond 15 m”.

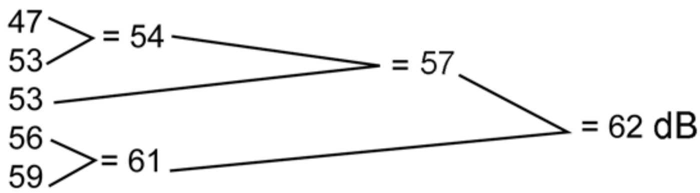
## Appendix C: *Addition of Decibels*

Since decibels are logarithmic values it is not proper to add them by normal algebraic addition. For example, 63 dB plus 63 dB does not equal 126 dB but only 66 dB.

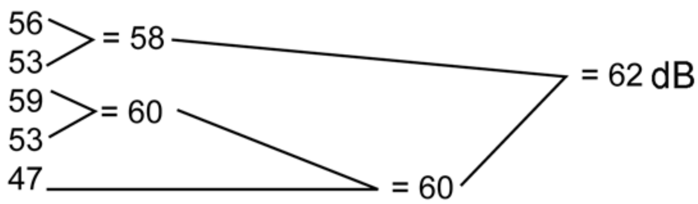
A very simple, but adequate schedule for adding decibels is as follows:

| When two decibel values differ by: | Add the following amount to the higher value: |
|---|---|
| 0 or 1 dB | 3 dB |
| 2 or 3 dB | 2 dB |
| 4 tot 8 dB | 1 dB |
| 9 dB or more | 0 dB |

When several decibel values are to be added, perform the above operation on any two numbers at a time, the order does not matter. Continue the process until only a single value remains. As an illustration let us add the five sound levels used in the example of Appendix B.




Or, suppose we arrange the same numbers in a different order, as in:




Sometimes, using different orders of adding may yield sums that might differ by 1 dB, but this is not too significant a difference in acoustics. In general, the above simplified summation procedure will yield accurate sums to the nearest 1 dB. This degree of accuracy is considered acceptable in the material given in this article.

## APPENDIX D: *BAC Sound Evaluation Worksheet*

Job Name________________________________ Date________________________________

Address ________________________________ Engineer ____________________________

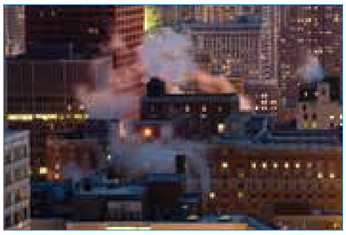
Architect _______________________________ BAC Model___________________________

| Steps | Items | Center Frequency - Hz | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 63 | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 |
| Noise criterion | 1. Determine appropriate "NC" Criterion for neighbour activity from Table B. | | | | | | | | |
| | 2. Insert sound pressure levels (Lp) for selected "NC" Criterion. (Obtain values from Figure 1 or Table A) | | | | | | | | |
| | 3. Tabulate sound reduction provided by wall construction. (Obtain values from Table C) | | | | | | | | |
| | 4. Establish tentative outdoor Noise Criterion from the unit. (Item 2 plus Item 3) | | | | | | | | |
| | 5. List average minimum outdoor background sound levels. (Measured or estimated from Figure 2 or Tables D and E) | | | | | | | | |
| | 6. Set final outdoor background Noise Criterion. (High value, by octave band, of Items 4 and 5) | | | | | | | | |
| Sound Levels | 7. Enter unit sound pressure level rating at 15 m. | | | | | | | | |
| | 8. Insert distance correction to adjust unit ratings to distance of _ m in direction toward critical neighbour. (For distance greater than 15 m use Table F; for distances less than 15m use Table G) | | | | | | | | |
| | 9. Establish outdoor unit Lp at neighbour location. (Item 7 minus Item 8 for distances greater than 15 m. Item 7 plus Item 8 for distances less than 15 m.) | | | | | | | | |
| | 10. Apply reflection adjustments to meet condition existing at unit site. Refer to Figures 3 and 4 for effect of reflecting walls; or add 5 dB for close-in build up noise; 0 dB if no reflection effects. | | | | | | | | |
| | 11. Tabulate resultant unit Lp at critical neighbour location. (Item 9 plus Item 10) | | | | | | | | |
| Comparison, Criteria vs Levels | 12. Copy Item 6 levels from above. This is the outdoor Noise Criterion for the critical neighbour. | | | | | | | | |
| | 13. Ascertain tentative sound reduction required for unit. (Item 11 minus Item 12. Insert "0" for negative values) | | | | | | | | |
| | 14. Apply judgement factor. (For conservative approach, use "0" in all bands. To permit unit noise to exceed background levels slightly, insert "5") | | | | | | | | |
| | 15. Tabulate final sound reduction requirement for the job. (Item 13 minus Item 14) | | | | | | | | |
| | 16. Indicate estimated or rated attenuation of all sound reduction treatment if used. (Should at least equal Item 15) | | | | | | | | |

# Plume Abatement

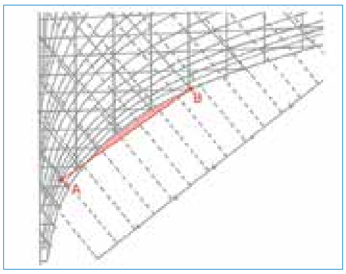
15

## 1. What is Plume?



At the air discharge water droplets can be formed by condensation of warm humid discharge air by contact with the colder ambient air upon leaving the equipment. This type of condensation is the visible plume that often can be seen rising above evaporative cooling equipment during the winter season. The water vapour caused by condensation contains droplets of pure water and is harmless. In some instances visible plumes are considered as a hinder, in which case measures must be taken to minimise or eliminate the occurrence of plume. Consult the BAC Balticare Representative for such requests.

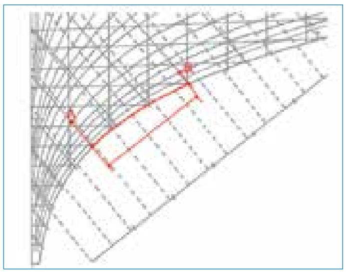
## 2. Evaporative Cooling and Plume



- Air enters at condition A.
- Air picks up heat and water in the evaporative fluid cooler (discharge condition B).
- Ambient air serves as heat sink for the discharge air (line AB).
- Intersection of saturation line leads to visible plume.
- Large intersection area: more plume; small intersection area: less plume.

*Plume is the condensation of water vapour and is harmless to the environment.*

## 3. Condition of the Ambient Air



Temperature and relative humidity of the entering air influence the condition of the discharge air. Depending on the entering air condition the discharge air IS NOT ALWAYS 100 % SATURATED.

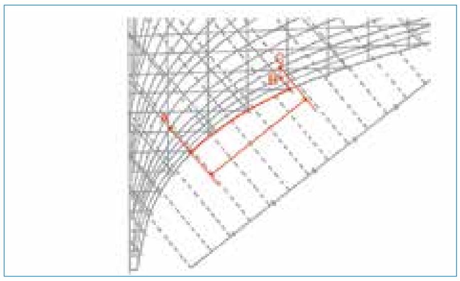
- Dry ambient air: discharge air has low relative humidity and high temperature.
- Wet ambient air: discharge air has high relative humidity and lower temperature.
- Warm ambient air: discharge air has lower relative humidity and higher temperature.
- Cold ambient air: discharge air has higher relative humidity and lower temperature.
- Discharge air of open cooling towers is generally higher saturated than discharge air of evaporative coil products.

*Evaluation of Plume Formation Requires:*
Knowledge of climatic conditions (ambient air) in which the equipment will operate. In depth knowledge of evaporative heat transfer to determine the relative humidity and temperature of discharge air in prevailing climate conditions.

## 4. Plume Influencing Factors

- High humidity of ambient and discharge air enhance plume potential and vice versa.
- Large temperature difference between discharge and ambient air increases plume potential and vice versa.
- High heat load/ air flow ratio provides large temperature difference and high plume potential and vice versa (Typically heat load/ air flow ratio for evaporative coil products is smaller.).
- Next to equipment selection plume formation is a function of the actual heat load and climatic conditions and needs to be evaluated over a wide band of operating conditions. BAC provides the methodology to make such an evaluation.

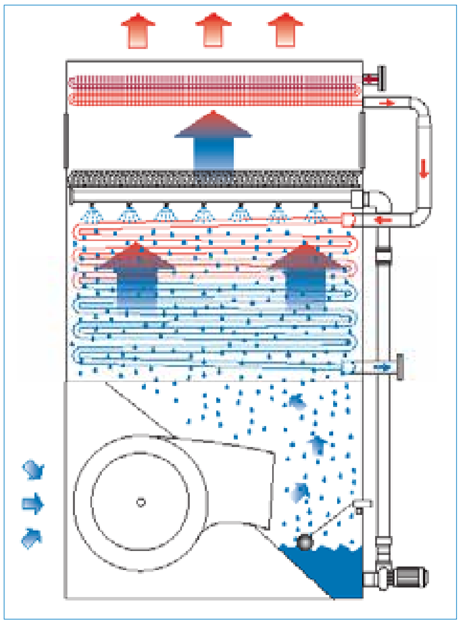
## 5. Plume Abatement Coils



Large surface area plume abatement coils are installed in the air discharge of the evaporative coil products and piped in series with the "wet" coil. To be effective they must have low air and fluid side pressure drops. This results in:

- Significant extension of dry operation capacity.
- Effective increase of discharge air temperature to reduce / eliminate plume during wet operation.
- Additional sensible heat transfer during wet operation which saves water and treatment costs.

Plume abatement coil sizing and performance prediction require a thorough evaluation of thermodynamic and airside behaviour as well as an understanding of climate condition influences. BAC can provide properly sized plume abatement coils and accurate performance data.



*Plume Abatament Coil*

## 6. Capacity Control Strategy

Capacity control of the evaporative cooling equipment has a considerable influence on plume formation.

- No capacity control results in the lowest heat load / air flow ratio and low plume potential.
- Dual drives (BALTIGUARD®) and two speed motors result in higher heat load / air flow ratio; acceptable plume elimination is achieved with plume abatement coils.
- Modulating airside capacity control results in highest heat load / air flow ratio which gives the highest plume potential.

Operating and capacity control strategies are an integral part of the plume evaluation process. Consult your local BAC Balticare Representative for guidance and assistance.

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# Fundamentals of Filtration

## 1. Introduction

BAC recommends that an effective filtration system be installed on all cooling systems. There are several very good reasons for this.

Proper cooling tower filtration:

- ♦ Extends the life of your cooling system and offers a quick return on the investment (payback period usually 12-18 months)
- ♦ Reduces the risk of Legionnaires Disease outbreaks
- ♦ Maintains optimum heat transfer efficiency in heat exchangers
- ♦ Aids in optimization of water treatment equipment
- ♦ Reduces expenses for chemical treatment programs, maintenance and cleaning costs, downtime

The following section on filtration is a brief review of different technologies and approaches to cooling tower filtration, including the advantages and limitations of the most popular filtration systems that are used in both open and closed loop cooling systems.

## 2. The Fundamental Goals of Fluid Filtration

When considering what type of filtration provides the best value for your cooling system it is important to review the fundamental goals of fluid filtration, which include:

- ♦ 1. **WHAT** are the solids you want to filter out of the fluid?
  This is specified in terms of:
  - • Size (measured in microns)
  - • Weight of the particles (measured in specific gravity)
  - • Shape
  - • Volume
- ♦ 2. **WHERE**, or at what point in the system do you want to filter these particles, and what effect will a given filtration technique have on the rate of flow, pressure losses, and other characteristics of the fluid being filtered? Tied in with these considerations is the basic question of which components of the cooling tower system needs the protection that the chosen filtration provides.

It is critical that the fundamentals of filtration are addressed to insure that the expected results are achieved.
Let's start with the solids.

## 3. The Solids

Particle contamination of evaporative cooling loops can be created by a variety of sources, including airborne entry, make-up water, corrosion by-products, and precipitated mineral development. Contamination of closed loops is typically from construction or corrosion by products. For both open and closed loops the particle matter commonly fouls heat exchangers reducing heat transfer efficiency, causing excessive shutdown/ cleaning routines, and posing health and safety concerns. It is important to first identify and define the particle contaminants before applying a filtration technique to effectively remove those contaminants. It is also equally important to select a filtration technique with an understanding of its proper placement, sizing and solution potential.

Particle analysis must include an awareness of not only what type of particles are in the cooling water, but also what particles are most responsible for the fouling and/or lost efficiency of the heat exchanger. An understanding of particle type will greatly determine the proper type of filtration to apply. Understanding the issue of particle size will determine the level of filtration necessary to achieve the desired protection of the heat exchanger, AND address any health and safety issues that may be involved. In essence, it is not always critical to remove the very finest sizes of all types of particle matter in order to assure proper protection, and safe operation of the cooling water system and heat exchangers.

With the knowledge of what contaminants must be filtered to achieve reliable and safe cooling system operation, a review of the popular filtration methods helps identify the proper devices for a given application. Then, using an objective set of selection criteria, the most appropriate filtration system can be determined. Performance and price are obvious issues, but there are several other key factors to consider when the goal is long-term overall savings.

The techniques for filtering cooling water each promise a different level of success as it relates to protecting heat exchangers. Understanding the basic installation scheme for each technique unveils that technique's ability to remove particle contaminants. Over the years, experience and performance have produced a comparative view of various techniques that can help grade the potential solution capability of each technique. An in-depth review of the techniques will identify advantages and limitations.

Settleable solids, such as sand, silt, grit, scale, rust and precipitated minerals are certainly problematic, since they are large enough to clog nozzles and small orifices and heavy enough to settle in tower basins and remote sumps. These solids are routinely present in sufficient concentrations to create problematic conditions throughout a cooling tower system.

Suspended particle matter, such as leaves, grasses, cottonwood seeds, bird feathers, insects and organic matter in excess concentrations can clog nozzles and small orifices shutting of flow in the system. This type of particle is also of concern to tower fill. Since these contaminants typically do not settle, it is unlikely that they will create problems in tower basins or remote sumps, but potentially cause problems downstream at the heat exchangers.

Particle size is an area for debate within the whole process of particle analysis. One view is that contaminants as small as 0,5 microns or less are not only the predominant numerical contaminants in cooling tower water, but also most responsible for the majority of cooling tower problems. The other view is that ultra fine particles (defined as particles smaller that 5 microns – about the size of blood cells) and particles not visible to the naked eye (40 microns – the size of a grain of talcum powder or the end of a human hair) are not the major source of fouling and increased health risks in cooling systems. In determining what filtration system is best for your system, BAC recommends that a common sense approach be utilized and take into consideration:

- Particles that are capable of plugging orifices and restricting flow must be removed.
- On the health and safety side of this issue it is recommended that there be less than 1/16th inch of dirt settling in a cooling tower basin in order for the system's water treatment/biocide to work effectively and come in contact with the bacteria in the system.
- It is recognized that any contaminants below 5 microns in size are most commonly identified as bacteria, a contaminant that is not removed by filtration, but by disinfection.

Particle volume should also be considered. The chart below offers a comparative and hypothetical example, taking a sample of one trillion particles, with given portions of that sample in each of several particle sizes. As can be seen, if 15% of the total numerical count of particles is greater than 10 microns, those 15% represent over 99% of the total volume. In an actual cooling water loop, there may be many times this amount, but the relative ratio is still valid and important to consider in terms of which contaminants to be most concerned about.

This fact should be considered when determining the particles that are capable of fouling a heat exchanger's small orifice, clogging a nozzle or accumulating in a cooling tower's fill, basin or remote sump preventing the system biocide from reaching the bacteria.

**Particle Size vs. Volume**

| Size of Particle (micron) | Quantity of Particles (x million) | Total volume (I) |
|---|---|---|
| 0,45 | 212.500 | 0,1 |
| 1 | 212.500 | 1 |
| 3 | 212.500 | 3 |
| 5 | 212.500 | 15 |
| **Sub-total:** | **850.000** | **18** |
| 10 | 37.500 | 21 |
| 25 | 37.500 | 300 |
| 50 | 37.500 | 2.500 |
| 75 | 37.500 | 8.800 |
| **Sub-totals:** | **150.000** | **11.000** |

The table above, representing a sample of one trillion particles in a range of sizes, shows that even a relatively small number of particles 10-75 microns in size can represent a very large total volume of particles.

## 4. Where will the filtration solution be installed and how it will affect other variables?

At what location in a cooling tower installation should filtration be installed, and what effect will it have on the operation (and maintenance) of the cooling tower? Although often overlooked, this is a very important aspect of cooling tower filtration. The decision of exactly where to install the filtration solution is often dictated by first identifying what equipment/components needing protection from the contaminants, e.g.: the heat exchangers, the cooling tower basin or remote sump, the tower fill and/or the distribution headers/nozzles.

After making that determination, a second step should assess the costs associated with the problem: increased energy and chemical costs, downtime, cleaning, repairs and/or replacements, outside services, and overtime labor and maintenance. The anticipated costs will become important when the cost of the problem is being compared to the cost of the solution.
In general, there are three approaches (designed by “A”, “B”, and “C” below) to answering the question where to install the filtration solution, and each addresses the problem in a different way and has its own distinct value and benefits.

*APPROACH A: Full-stream filtration*
With full-stream filtration, the filter is usually installed at the cooling system pumps/ discharge, prior to the heat exchangers/chillers. The filter is sized according to the full flow of the pump, filtering all the water that passes on to the heat exchangers/chillers – which is the primary value of this approach. It is estimated to increase the operating cycle of the heat exchanger by ten times before servicing requirements appear (based on experiences with users who have kept good before and after records).

This approach does not directly address the problem of basin/ remote sump solids accumulation. Although effective filtration can reduce overall solids concentration, the tower environment itself does attract and create unwanted solids that can settle in the basin and pass on to the heat exchanger. Full flow filtration is most commonly used for new applications where the effect of the filtration system on system head requirements and space can be considered, and not commonly used in retrofit applications.

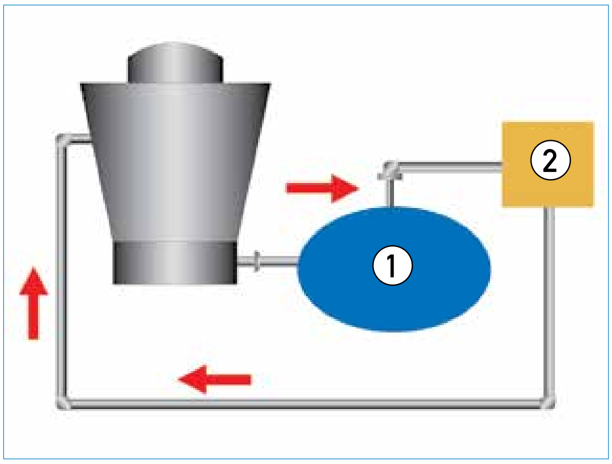



*Figure 1: Full Stream Protection*
1. Filtration solution here; 2. Load or Process.

*APPROACH B: Side stream (or slip stream) filtration*
A typical side stream filtration diverts approximately 5-20% of the full-stream flow through a filter and back into the full-stream flow prior to the heat exchangers/chillers. The logic of this technique is filtering the water at a rate greater than the anticipated input of contaminants and volumetric system turn-over. Lower side stream percentages are occasionally

employed on closed loops, but not usually sufficient on open systems to adequately remove incoming solids. Location (such as near open fields or windy, dusty situations) and seasonal conditions (such as pollen, harvesting or spring blossoming) provide for higher contaminant potential, suggesting a higher percentage of side stream filtration to overcome these conditions.

This approach is estimated to increase the operating cycle of a cooling systems heat exchangers by 3 times before servicing requirements become acute (based on experience with users who have kept good before and after records). This technique is used most often when the full stream flow is extremely high, cau-sing full stream filtration to be financially unfeasible. Like full stream, this technique does not address the problem of solids accumulation in the tower basin or remote sump. Side stream filtration is commonly and effectively applied to both new and existing systems. Care must be utilized when re-directing the side-stream flow back to the pump suction since that reduces the flow to the heat exchangers, or may require an increase in the pump output. With side stream filtration the location of the filtration device is very important to make sure that dirt will get to the filtering system. See Figure 2 for a suggested piping configuration when using the side stream approach.

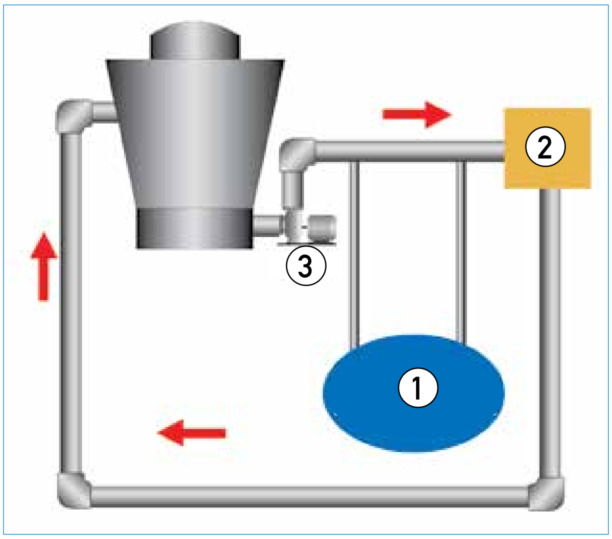



*Figure 2: Side Stream Protection*
1. Filtration solution here; 2. Load or Process; 3. Pump.

By using a full flow "Y" or tee and coming off the bottom of a pipe, the solids are more likely to enter a side stream filter increasing the effectiveness of the filtration in removing the solids from the system and reducing "carryover".

*APPROACH C: Basin Cleaning*

Compared to the previous two approaches, filtration directed specifically at the control of solids accumulation in the cooling tower basin or remote sump is new to the HVAC industry. However because this approach takes control of getting the solids to the filtration system, virtually eliminates solids build up in the tower basin addressing health and safety issues, and is very effective at preventing dirt from reaching the heat exchange surfaces, basin cleaning is among the most popular and effective filtration approaches in use today.

When applying basin cleaning as a means of filtration, water is drawn from the tower basin/sump to the filter package and directly back to the tower basin/sump via a pattern of specialized nozzles (See Figure 4) to create a directed turbulence of flow designed to influence any settleable particles toward the basin cleaning package's pump intake. The size of a basin sweeping filtration package is based on the planned area of the cooling tower's basin or remote sump.

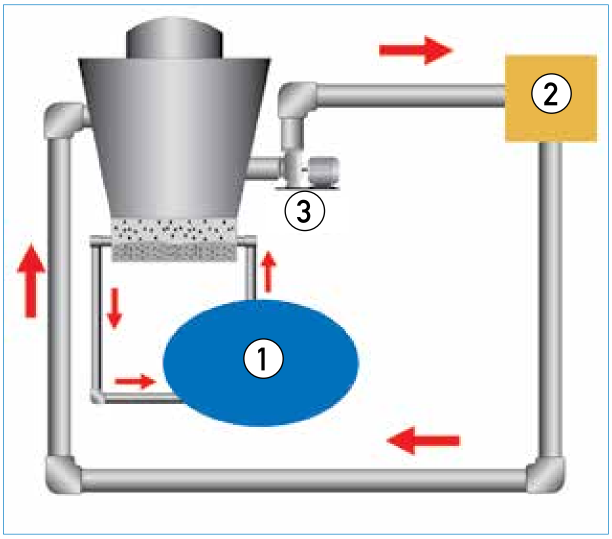



*Figure 3: Basin Cleaning Protection*
1. Filtration solution here; 2. Load or Process; 3. Pump.

**A simple rule of thumb is:**

| **Water Depths** | **$m^3$/hr Filtration Required** |
|---|---|
| Less than 0,9 meters | 0,2 $m^3$/hr per 0,1 $m^2$ |
| Greater than 0,9 meters | 0,3 $m^3$/hr per 0,1 $m^2$ |

This technique, despite concentrating its effort to the prevention of basin or remote sump build-up and not directly protecting the heat exchanger, is very effective at keeping dirt from entering the cooling system and expected to increase the operating cycle of a heat exchanger by eight times before servicing requirements become necessary (based on experiences with users who have kept good before and after records).

Unlike the previously mentioned techniques, basin cleaning does directly address basin/sump accumulation. Basin cleaning does require the appropriate use of a venturi-like nozzle system to increase the total flow activity without the need for a high volume pump, thereby keeping equipment and pump energy costs to a minimum. These nozzles and/or eductors increase the flow that passes through them by a factor of 5-6 times, enabling the filter package to use a smaller filter and pump, while still achieving the flow activity necessary to sweep the settleable solids across the basin/sump to the filter package's pump intake.

An important element to making this approach work effectively is adhering to the flow and pressure requirements (1,4 bar minimum) of the chosen eductors in order to achieve the necessary flow to sweep the solids in the basin/sump and prevent troublesome accumulation. Inadequate flow/pressure to these eductors dramatically reduces their effectiveness and the ability of the system to direct solids toward the pump intake and into the filter. In essence, inadequate flow/pressure results in the same effectiveness as that of a side stream filter.

*Sump Sweeper Piping*

*Features*

Factory or site installed sump sweeper piping comprises a number of eductor nozzles fitted into pipe work located in the cooling tower basin. The eductors generate higher flow volume and hence increased water circulation and agitation inside the cooling tower basin. Eductors are manufactured from fiberglass reinforced polypropylene that will not corrode. The pipe work is laid out on the bottom of the basin so that the eductors 'sweep' the sump water towards the spaced holes in the suction pipe.

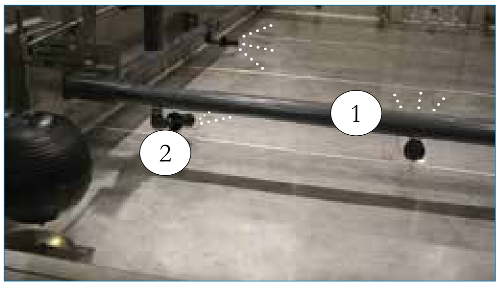



*Figure 4: Sump Sweeper Piping*
1. Pressure Pipe; 2. Eductor.

*Application*

BAC sump sweeper piping is designed for use in combination with a filtration system. An appropriate filtration system with sump sweeper piping provides an effective method of preventing sediment from collecting in the cold water basin of the cooling towers.


*Figure 5: Eductor*
1. Sweeping: Circulate four Litres of Sump Water; 2. One Litre of Filtered Water from Pressure Line; 3. Eductor; 4. Five Litres Circulated

*Benefits*

- Specifically designed and sized for BAC evaporative cooling equipment in combination with BAC filtration systems.
- Factory installed or alternatively retrofitted at the site.
- Sump sweeper piping with eductors improves the performance of the filtration system.
- Improved system hygiene all year round.
- Reduced down time of equipment and less cleaning required.
- Extended life expectancy of the tower materials of construction by preventing under deposit corrosion.

*Typical Arrangement:*

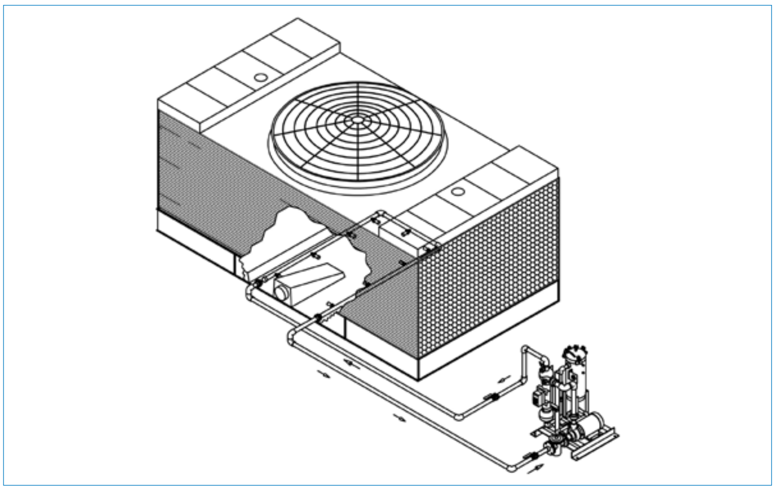


*Figure 6: Filtration System with Sump Sweeper Piping*

## 5. Popular Filtration Equipment

The advantages and limitations of each of the types of equipment are given in each section. Please See Table – Advantages and Limitations of Popular Filtration Equipment for a quick comparison.

*Sand Filters*

Widely known, sand filters direct fluid into the top of their tank(s) and onto the surface of a bed of specified sand or other media. As the fluid passes through the bed of sand media, the contaminants are captured within the upper layer of media. The fluid ultimately makes its way downward, passing into some form of underdrain at the bottom of the filter tank and discharging through an outlet pipe or manifold. The cleaning procedure reverses flow upward from the outlet/manifold (either from other filter tanks in the system or from the main system flow), fluidizing the sand media and backwashing the contaminants through the tank's inlet to a backwash line for disposal discharge. Sand filters are most commonly installed in side stream applications. Care must be taken must be taken before installing in a full flow or basin sweeping configuration because of the potential for interrupted flow during backwash or fouling of the media.

**Solids removal** – This type of device is most appropriate for lightweight solids, organics and other floating contaminants. Though capable of removing heavier solids, the cleaning/backwash procedure makes it very difficult to rid the sand filter of these solids…which may result in a residual build-up and an increasing pressure differential across the filter or excessive backwashing frequency. When specified for removing very fine solids, sand filters must either be oversized to reduce the flow rate per-square-foot or the sand media must be upgraded, adding both cost and higher pressure loss through the filter.

**Flow range** – The total surface area of a sand filter's media bed and the specified flow rate per-square-meters (14 $l/s/m^2$ is typical) dictate the size (diameter) and/or quantity of tanks in a sand filter system. Through some makers use only one large tank, others use multiple smaller diameter tanks. Unlimited flow range capability is offset by the logistics of the size and/or configuration of the overall sand filter system.

**Pressure loss** – Pressure loss varies from low (7 kPa typical) to high (76 kPa). A very low pressure loss through a clean sand filter can be rapidly lost in high solids loading applications.

**Liquid loss** – It is not uncommon to lose hundred or even thousands of gallons of fluid during a backwash cycle. Significant make-up water may also require significant chemical treatment. As a general rule, some sand media is also regularly lost during backwashing, resulting in periodic media replacement.

Solids handling – Solids handling is usually automated as the solids are carried away in the backwash water. Due to the high liquid content during a backwash cycle, solids concentration is not usually practical.

**Replacement parts** – Typical parts manuals for sand filters number eight or more pages. The moving parts and electro-mechanical hardware for automatic backwashing account for most of this requirement. Sand media must be monitored and periodically disposed and replaced. Improper backwashing can also lead to contaminant build-up in the sand bed, providing the opportunity for troublesome bacteria to breed and/or accumulate. If oils or grease are present in the system, frequent sand media replacement will be necessary… and may be designated as hazardous waste, complicating disposal procedures.

**Maintenance requirements** – Backwashing can be manually initiated or automatic. Manual operation creates the risk that pressure differential may become excessive and disruptive to the system if not performed regularly and at appropriate intervals. Additionally, infrequent backwashing drives the contaminants deeper into the sand bed, making it more difficult to completely backwash the sand filter and resulting in residual build-up, which increases the frequency of backwashing/liquid loss. Periodically, even when properly monitored, it is necessary to shutdown the system and dispose and replace the sand media. In high calcium (hard water) content waters it is also not unusual for mineral build-up to induce the sand media to become a hardened cake, incapable of backwashing. Inspection monthly is usually recommended in order to sustain proper operating conditions.

**Space requirement** – Expect sand filters to demand 10 to 20 times more space than other types of filtration for a given flow rate. Sand filter configurations are also limited for specific ceiling or piping restrictions.

**Advantages:** Sand filters remove fine and light particles; Improved water clarity; Easily automated; Requires no solids handling; Wide range of particles removed; Effective over a wide range of flows and pressures.
**Disadvantages:** Prone to changing, or interrupted flow with solids collection; Handling of backwash water volume; Can be maintenance intensive; Heavy, or precipitated solids pack into sand requiring frequent changing of the sand; Space can become an issue; Backwash water volume can be excessive in high solids loading applications.

*Separators*

Separators use centrifugal action to remove solids that are heavier than water by use of a tangential inlet that starts the centrifugal action. More efficient designs utilize internal accelerating slots to increase the velocity, and then allow for settling in a low flow area necessary for the removal of the separable solids. Separated particle matter spirals downward along the perimeter of the inner separation barrel and into the solids collection chamber, located below the vortex deflector plate. Solids removal performance varies widely depending on the design.

**Solids removal** – Separators are proven capable of 5-75 micron performance for particles that are heavier than water. Since the tested performance of centrifugal action separators varies widely among different manufacturers, we encourage third party testing to confirm actual performance at flow rates representing particular site requirements.

**Flow range –** Separators feature individual units for 0,7 $m^2$/hr up to 2895 $m^2$/hr. Easily mainfolded for even higher (or variable) flow rates.
**Pressure loss** – Separators operate continuously (no fluctuations) at a steady pressure loss of only 0,2-0,8 bar. Compare to screens and barrier filters, which build-up to very high pressure losses.
**Liquid loss** – Separators require no backwashing. Low-flow periodic purging or a controlled bleed technique can achieve zero liquid loss. Selected solids collection options ensure minimum liquid waste and easy disposal/recovery of solids collected.
**Solids handling –** Evacuation of separated solids should be accomplished automatically by the use of an electrically-actuated valve programmed at appropriate intervals and duration in order to efficiently and regularly purge solids from the separator's collection chamber. Solids can also be concentrated by the use of a solids recovery vessel. In a solids recovery vessel, separated solids are continuously purged under controlled flow into a vessel equipped with one (or three, depending on the separator size needed) 1 to 50-micron fiber-felt solids collection bag(s). The bags are then manually removed and cleaned or discarded.
**Replacement parts** – Separators have no moving parts, and no filter elements or sand media to clean or replace. The purge options (bag filter or motorized ball valve) for the separator may have replacement parts.
**Maintenance requirements –** Separators may be purged of separated solids without system interruption. Easily automated for no maintenance routine. No filter cleaning. No duplicate equipment needed.
**Space requirements –** Separators are compact. Larger models may be specified at low or vertical profile and/or with alternate inlet/outlet configurations to accommodate limited space or piping needs.

**Advantages:** Removes a wide range of particles; No moving parts; Very minimal to no maintenance requirements; Constant pressure drop is better for basin sweeping applications; Can be installed full flow with low risk for interrupting flow to the main heat exchangers; can be automated.
**Disadvantages:** Primarily removes only solids that are heavier than water.

**Advantages and Limitations of Popular Filtration Equipment**

| | Particle Size Removal | Pressure Loss | Maintenance Requirements | Liquid Loss |
|---|---|---|---|---|
| **Sand Filters** | Best for fine particles; avoid heavy coarse particle applications | Low, variable | Back washing; periodic inspection; sand replacement, electro-mechanical parts | Potentially excessive |
| **Separators** | Fine to coarse in organics only | Low and steady | Purge comments only; periodic inspection / servicing | None to minimal |

# The Value of Maintaining Evaporative Cooling Equipment

17

## 1. Cooling Tower Maintenance and Upgrades... What's in it for You? How about Savings in Time, Money, Energy and Longer Life?

An evaporative heat rejection device enables building owners and operators to take advantage of the operating cost savings inherent in water-cooled systems. A well-maintained tower enables the entire cooling system toperform at optimum efficiency by conserving both energy and water.

A cooling tower is selected to provide a fluid (usually water) to a system at a specific design temperature and specific flow rate (l/s). If the delivered temperature of the fluid to the system is higher than desired, system performance suffers.

Owners gain operating cost benefits when they implement a regular, comprehensive cooling tower maintenance program. Today's building owners are constantly challenged to keep operating costs down and are anxious to learn ways to get the most out of their systems with the least expense. Therefore, owners are motivated to purchase system equipment that is energy-efficient, reliable, and maintenance-friendly. When properly maintained, water-cooled systems meet these objectives.

The cooling tower is often the forgotten component of the system when it comes to maintenance. It's a good example of the phrase "out of sight, out of mind". A newly installed cooling tower reliably delivers the design fluid temperature and flow rate. However, since its heat transfer operation creates a "hurricane-like" environment and is a natural "air-washer", the cooling tower needs routine inspection and maintenance to continue performing as designed.

## 2. A Cost-Saving Opportunity

Owners and operators who have a working knowledge of cooling tower preventive maintenance and upgrade technology will get the most out of their cooling towers.

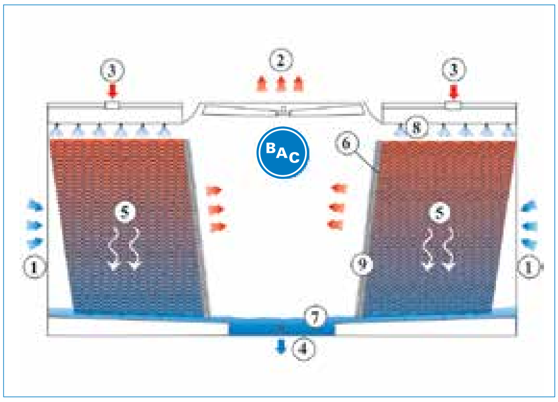
Their efforts can yield beneficial results, including:

- ♦ keeping them running smoothly and reliably
- ♦ increasing cooling tower life expectancy
- ♦ maintaining and potentially improving performance

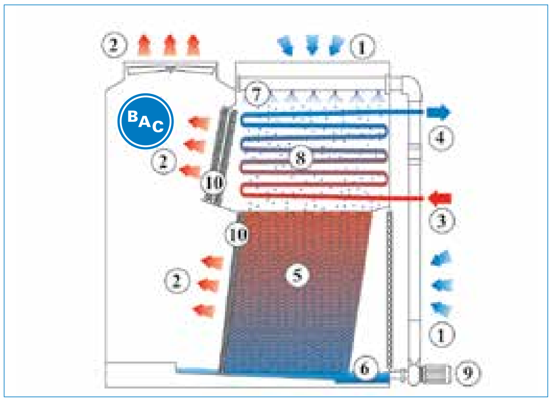
This article will take a look at routine maintenance and suggest ways to improve cooling tower performance.

## 3. Cooling Tower Basics

In an open circuit cooling tower, warm water from the heat source is evenly distributed via a gravity or pressurized nozzle system directly over a heat transfer surface called "fill" or "wet deck", while air is simultaneously forced or drawn through the tower, causing a small percentage of the water to evaporate. The evaporation process removes heat and cools the remaining water, which is collected in the tower's cold water basin and returned to the heat source (typically a water-cooled condenser or other heat exchanger).



*Open Cooling Tower*
1. Air in; 2. Air out; 3. Hot Water in; 4. Cooled Water out; 5. Water; 6. Wet Deck Surface; 7. Cold Water Basin; 8. Water Distribution system; 9. Eliminators



*Closed Circuit Cooling Tower*
1.Air in; 2. Air out; 3. Fluid in; 4. Fluid out; 5. Wet Deck Surface; 6. Cold Water Basin; 7. Water Distribution System; 8. Coil; 9. Spray Water Pump; 10. Eliminators.

Similarly, in a closed circuit cooling tower or evaporative condenser, the heat is rejected indirectly from a fluid or vapour flowing through the coil section by spraying re-circulated water over the coil section, again evaporating a small percentage of the water in the process.
The temperature at which the cooled fluid is returned to the system measures tower performance. This temperature can vary depending upon the actual cooling load, water flow, airflow, and the entering air conditions.

## 4. Preventive Maintenance

Performing routine preventive maintenance is paramount for consistently achieving the desired temperature and flow rate, and plays an important role in maximizing cooling tower operating life. Today, those manufacturers conscious of the importance of maintenance offer many features which simplify these procedures, saving time and money. To perform properly, all tower components must be kept clean and free of obstructions. The following sections describe standard maintenance procedures for optimized operation. These procedures can prevent loss of efficiency in the heat transfer section by maintaining proper water and air flow, as well as preventing corrosion in the cooling tower.
Maintenance frequency will depend largely upon the condition of the circulating water, the cleanliness of the ambient air used by the tower, and the environment in which the tower is operating. More detailed information is provided by BAC's Operating and Maintenance Manual.

## 5. Strainer

Fundamentally important to the performance of a cooling tower is a method to minimize contact between air and waterborne debris and the system components. This is accomplished with strainers. Strainers in the tower provide a means

*Inspecting Cold Water Basin Strainer*

*Hot Water Basin Strainer Cleaning*

of keeping debris out of the condenser water loop. Strainers in the cold water basin outlet prevent debris from reaching the pump. Some towers feature low-pressure drop pre-strainers upstream of the hot water basin to prevent clogging of distribution nozzles. This added feature eliminates the need to access the distribution nozzles. Both strainers should be routinely inspected and cleaned as necessary. Some tower designs allow external access to the strainers, which enables maintenance to take place without the need to turn off the unit.

## 6. Water Distribution

The water distribution system should evenly distribute water over the fill section or coil section via either a gravity distribution system or a pressurized spray system. If the water distribution is found to be uneven, the nozzles need to be checked. Clogged nozzles should be cleaned in accordance with the manufacturer's recommendations.
In a gravity distribution system, the nozzles can be externally accessed, visually inspected and cleaned by removing the hot water basin covers on the fan deck. Most pressurized spray distribution systems use nozzles and branches held in place by snap-in rubber grommets, which allow easy removal to clean and flush debris.

*Pressurized Spray Water Distribution*

*Hot Water Basin with Gravity Water Distribution*

## 7. Cold Water Basin

Since some debris will eventually make its way into the cooling tower, the unit design should facilitate debris removal. A well-designed cold water basin is sloped toward the strainer to keep dirt (which can accelerate corrosion) from accumulating throughout the cold water basin. The basin should be kept clean by occasionally flushing the dirt out of the system through the tower drain. Another way to accomplish this is to install **basin sweeper piping** in conjunction with **water filtration or separator devices**. Water filtration saves maintenance costs by reducing the dirt in the cooling water system, which in turn reduces the time required to clean the cold water basins.
It also reduces water treatment cost, as water treatment chemicals tend to work more effectively in clean water. Foreign particles in dirty water can absorb treatment chemicals, thus requiring the distribution of even more chemicals to properly treat the tower water. For more information refer to Chapter 14: Fundamentals of Filtration.

*Cold Water Basin with Sweeper Piping*

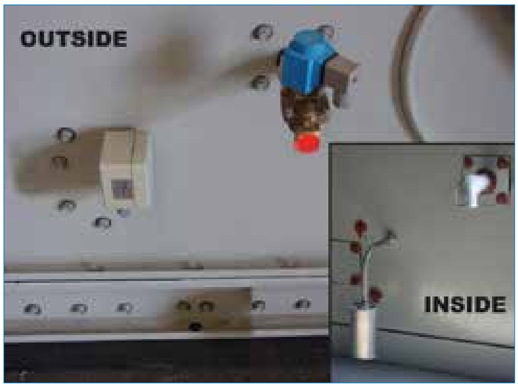
## 8. Make-Up

Though most of the water in the system is recirculated, some water must be added to replace what is lost by evaporation and bleed. Bleed is the defined as the water that is discharged to prevent the accumulation of solids in the recirculated water. The make-up water system provides the means to replace the water via a mechanical float ball and valve assembly or an electronic water level probe assembly (with solenoid valve), which measures water depth in the cold water basin.

The make-up water supply pressure should typically be maintained between 1 bar and 3,5 to ensure proper valve shut-off and avoid "chatter". If the supply pressure is higher than 3,5 bar, install a pressure reducing valve.

The operating water level of the cooling tower will vary with system thermal load (evaporation rate), the bleed rate employed, and the make-up water supply pressure. Some tower designs offer access to the make-up assembly external to the

Mechanical Water Level Control




Electronic Water Level Control

cooling tower, which allows easy basin water depth inspection and adjustment without the need to turn off the unit. The tower water level should be set in accordance with the BAC's recommendations to ensure no air enters the pump suction, but not so high that water is wasted through the overflow when the tower is shut down.

## 9. Bleed

To prevent the accumulation of solids in the recirculating water, the tower should be equipped with a bleed line (including a metering connection and globe valve) connected to a nearby drain. In a closed circuit cooling tower or evaporative condenser with a circulating pump, a metering valve to control the bleed rate should be provided at the pump discharge. While a manually adjusted bleed valve is the simplest system, getting the proper bleed rate can be a problem, as cooling tower loads vary throughout the day. A conductivity meter connected to a solenoid valve solves this problem by maintaining the proper cycles of concentration at all times. Also, it is recommended that a separate meter is installed to measure bleed volume, since less water is discharged to drain than supplied to the cooling tower. This can reduce sewer water charges.

The bleed rate should be adjusted to prevent an excessive build-up of impurities in the re-circulating water. This is largely dependent upon the local water quality and the evaporation rate. Constant bleed and replacement with fresh water will prevent the accumulation of impurities. To obtain specific recommendations, contact a competent water treatment professional for your area.

## 10. Mechanical Drive System

The mechanical fan drive system has several components, which should be checked regularly. Many of these components operate at high speed. Follow proper lock-out/tag-out procedures, including locking out all motor disconnect switches before working on the mechanical system.

Mechanical Belt Drive System

Cooling tower fans are typically driven by belt or gear drive systems. Both require routine maintenance to ensure reliable, trouble-free performance. Belt drive systems are popular, yet reliable, offer single point adjustment, and have no limit on turndown capabilities for variable speed applications. If a problem does occur, a simple change of the belt is usually all that is required, and replacement components are readily available.

Gear drives provide reliable operation, when properly maintained. If a problem occurs, resolution may be more involved if a gear box rebuild or replacement is required. Some manufacturers offer both systems to meet user needs or preferences. To ensure proper operation of a belt drive system, tighten drive belts to manufacturer's specifications. In gear drive systems, the oil level and quality, as well as shaft alignment should be checked regularly in accordance with the manufacturer's recommendations.

When starting up a new unit, lubrication for the fan shaft bearings is typically not necessary, since most units leave the factory already greased. However, for seasonal start-up, purge the fan shaft bearings with new grease (per manufacturer's recommendations). Fan shaft bearings should be lubricated after every 2,000 hours of operation or every three months (whichever occurs sooner). Motor bearings should be lubricated as recommended by the manufacturer's instructions. For maximum life, it is best to install motors with a "cooling tower duty" rating.

## 11. The Importance of Clean Operation

Cooling tower components must be kept clean and free of obstructions. Neglecting the cooling tower will lead to higher than desired return water temperatures to the system, which will result in higher energy usage from two perspectives. First, the system (chiller) will consume more energy because it must operate at a higher than necessary condensing pressure (head) to satisfy the load. Due to the higher fluid temperatures provided by the cooling tower. As little as 1°C higher temperature can result in 6% more energy being consumed by the chiller. Second, the tower must operate longer at higher fan horsepower while trying to attain the design cold water temperature.

## 12. Common Problems: Causes, Effects and Solutions

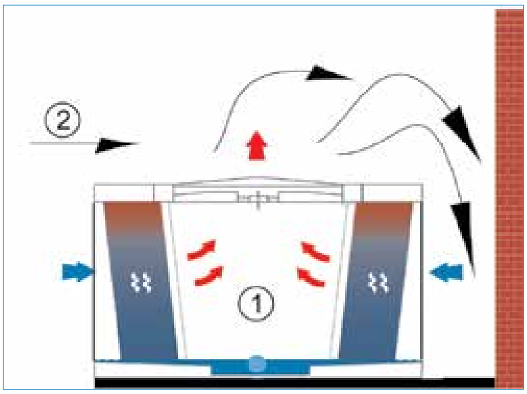
Regardless of how often routine maintenance is performed, like any other mechanical component, problems with cooling towers may sometimes materialize unexpectedly. These include elevated leaving water temperatures, drift, and corrosion. Should any of these problems occur, follow the actions listed and contact the cooling tower manufacturer's representative or water treatment supplier for assistance.

**Check Cooling Load:** If the actual cooling load exceeds the design load for which the tower was selected the leaving water temperature will exceed the design specification.

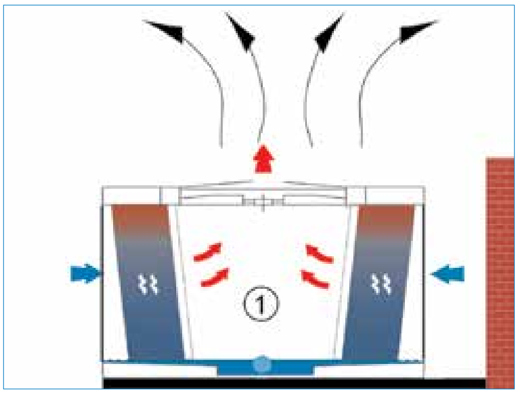
**Check Water Flow and Distribution:** Visually inspect the water distribution system to ensure the spray distribution nozzles are clean and correctly installed and are distributing a uniform spray pattern over the fill. In counterflow towers, measure the pressure at the cooling tower inlet connection and compare it to the design pressure provided by BAC. For towers with a gravity distribution system, the operating level in the hot water basin (typically between 5 cm and 13 cm) can be correlated to a specific flow rate.

*Inspecting Spray Distribution Nozzles*

**Check Air Flow:** Cooling towers should be located where an unimpeded supply of fresh air is available to the air inlets. The cooling tower air discharge should also be at least as high as any surrounding walls to reduce the possibility of hot, moist discharge air being recirculated into the air inlets, creating artificially elevated entering wet-bulb and leaving water temperatures. For more information refer to Chapter 11: Layout Guidelines. To insure full design air flow, the cooling tower drive system must be adjusted according to the BAC's Operating and Maintenance Manual.




*Incorrect Orientation of Tower and Neighbouring Walls*
1. Induced Draft Cooling tower; 2. Prevailing Wind




*Proper Orientation of Tower and Neighbouring Walls*
1. Induced Draft Cooling Tower

The cooling tower and surrounding area should be examined for air flow restrictions which may cause blockage of the air inlets. Check for clogging or improper distribution of water across the tower fill and check for proper operation of capacity control dampers in centrifugal fan towers to ensure proper air flow. The dampers, airfoil blades located in the discharge of the fan housing, help achieve tight temperature control and energy savings by matching cooling tower airflow to actual load requirements.

Though you may encounter dampers in older existing units, today's towers tend to take advantage of variable frequency drive technology (VFD's) to control capacity. VFD's help save energy, do a better job of following the load, and help reduce wear and tear on the drive system.

**Check Ambient Conditions:** Cooling towers are selected to produce the required leaving water temperature at the design cooling load and entering wet-bulb temperature. Whenever the actual entering wet-bulb temperature is higher than design conditions, the leaving water temperature will also be higher. The result is decreased energy efficiency.

Drift occurs as air flows through the cooling tower and carries water droplets out of the tower. Drift eliminators are installed in the discharge stream to remove water droplets from the air. In a properly maintained system, efficient eliminators will reduce drift loss to a negligible percentage of the design flow rate.

If excess drift occurs, check drift eliminators for proper installation, spacing, and overall condition. Examine the fill for even spacing, to insure there is no clogging or blockage, and check water and air flow as described above. Repair or replace eliminators as necessary.

*Inspecting Coil*

*Inspecting Drift Eliminator*

Corrosion is always a concern with cooling towers because of their ability to wash the air of impurities. These impurities cause scale, corrosion, and eventually damage to system components after long-term exposure.

If a constant bleed of the system is ineffective to combat scale or corrosion, chemical treatment may be necessary. A successful chemical or water treatment program should satisfy the specific guidelines set by the manufacturer, provide effective microbiological control, and be compatible with the system's materials of construction as an integral part of the total water treatment program.

Potential airborne impurities and biological contamination (such as Legionella) should be controlled through the use of biocides, and such treatment should be initiated at system start-up and continued regularly. ASHRAE has taken proactive steps to understand and deal with Legionella through its popular publication, ASHRAE Guideline 12 – 2000, entitled "Minimizing the Risk of Legionellosis Associated with Building Water Systems". Contact ASHRAE to secure a copy of this important document. In some European countries health and safety regulations require specific control and maintenance, see Chapter 21: Application Guidelines.

## 13. Performance Improvements

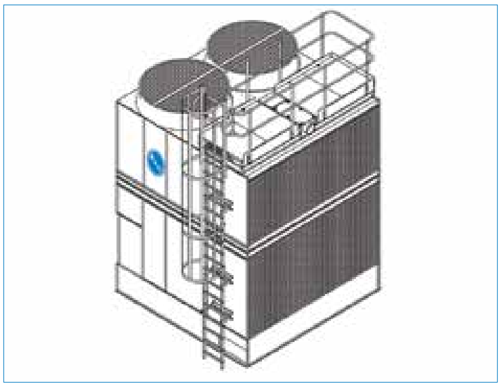
Older, structurally sound cooling towers can be retrofitted with upgrade kits to:

- conserve energy
- restore or improve performance
- facilitate maintenance

To conserve energy, two-speed motors or variable frequency drives (VFD's) or the BALTIGUARD® Fan System can be added to the mechanical drive system. VFD's offer a wide range of speeds to closely parallel operating requirements, and pony motors provide the added benefit of redundancy in the event of a motor failure. A popular energy conservation approach employs a pony motor system with a VFD controlling the lower horsepower motor.

To improve performance on water distribution systems, kits are available to replace older, smaller nozzles or troughs with large-orifice, clog-free design. Retrofit fill kits now exist that easily replace the original fill that may be clogged with scale or airborne debris. Access platforms can also be added to existing cooling towers to facilitate maintenance.

*Installing Retrofit Kit*



*Access Platforms and Ladder*

## 14. Conclusion

Paying regular attention to the forgotten system component, the cooling tower, through a regular, comprehensive maintenance program can save time, money and energy while increasing the tower's life expectancy. A well-maintained tower is a candidate for retrofit kits designed to enhance performance and lengthen its life. Owners and operators save money through preventative maintenance technology. If you are not regularly performing routine maintenance on your cooling tower, implement a comprehensive maintenance program today.

For more information on how to get started, contact your local BAC Balticare Representative.

# Replacement Parts

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To ensure proper operation of your cooling system, replacement components need to be original Baltimore Aircoil spare parts. Many wearing components requiring replacement on a scheduled basis **have a major influence on the thermal performance of the equipment.** Replacing these components with non-authorised spare parts could lead to a sharp reduction in performance and the risk of premature failure. Genuine BAC spare parts are vital in maintaining safe operation. They give you maximum confidence in reliability of your cooling system.

BAC stocks most common repair and retrofit parts in our Central Parts Distribution Center and can ship other parts, often overnight, from any of two manufacturing facilities strategically located in Europe. Even with this fast delivery capability, it is still recommended that certain essential, emergency repair parts be maintained in your local inventory, to minimize any potential downtime.

## 1. Basic Recommended Spare Parts:

- Bearing set
- Float valve or repair kit
- Float ball
- Solenoid valve (if unit equipped with electronic water level control)
- Powerband or set of belts
- Spray nozzle kit with grommets
- Sump heater and low water cut-out
- Door gasket
- Strainer (inlet and suction)
- Fan and drive bushings

## 2. Parts to Consider if Extended Downtime is a Concern:

- Spray pump for coil products
- Fan or fan wheels
- Fan shaft
- Drive sheaves
- Fan motor

# Application Guidelines

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## 1. Introduction

The satisfactory performance of cooling equipment is dependent on correct selection and proper attention to overall system design, installation, water care and maintenance. The purpose of this document is to highlight the major points, which should be considered when designing a system with BAC evaporative cooling equipment.

## 2. Safety

Adequate precautions, appropriate for the installation and location of these products, should be taken to safeguard the public from possible injury and the equipment and the premises from damage. Operation, maintenance and repair of this equipment should be undertaken only by personnel qualified to do so. Proper care, procedures and tools must be used in handling, lifting, installing, operating, maintaining, and repairing this equipment to prevent personal injury and/or property damage.

## 3. Thermal duty

The selection of a particular model is based on a thermal duty and the wet bulb temperature. Thermal ratings are based on the wet bulb temperature of the air entering the equipment and do not take into account any recirculation of warm and humid discharge air, which may occur under certain weather and wind conditions. Verification of ratings assumes a test according to a recognised test standard and the application of tolerances as recorded during the test and applied to the test results.

## 4. Operating Conditions

| | Open Cooling Towers | | Closed Circuit Cooling Towers | | Evaporative Condensers | |
|---|---|---|---|---|---|---|
| | Counterflow | Crossflow | Counterflow | Combined flow | Counterflow | Combined flow |
| Design Pressure std. coil (bar) | NA | NA | 10 | 10 | 22 | 22 |
| Design Pressure high press. coil (kPa) | NA | NA | NA | NA | 28 | 28 |
| Spray Pressure, max. at inlet (kPa) | 50 | NA | 14 | 14 | 14 | 14 |
| Fill Spacing std. (mm) (1) | 14 | 19 | NA | 19 | NA | 19 |
| Inlet temperature, max. (°C) (2) | 55 | 50 | 80 | 60 | 120 | 120 |
| Inlet temperarure CPVC. max. (°C) | 65 | 58 | NA | NA | NA | NA |
| Inlet temperature, PP, max. (°C) (3) | 80 | NA | NA | NA | NA | NA |
| Outlet temperature, min. (°C) | 5 | 5 | 10 | 10 | -20 | -20 |
| Make-Up Pressure mechanical valve (kPa) (4) | 100-500 | 100-500 | 100-500 | 100-500 | 100-500 | 100-500 |

(1) BACount® (PVC or CPVC) fill has spacing of 14 mm and is generally used on all counterflow cooling towers. For specific cooling tower lines, consult your BAC Balticare Representative.
(2) For pultruded material of construction and FRP, maximum inlet temperature is 60°C.
(3) High temperature 80°C application requires special high temperature execution of tower.
(4) It must be ensured that adequate make up water supply is available for proper operation of the equipment within the supply pressure range suitable for the make up valve. Alternative valve selections are available for such cases.

## 5. Fluid Compatibility

The fluid to be cooled must be compatible with the coil material. Fluids not compatible with coil materials can lead to corrosion and tube failure. Certain fluids may require occasional pressure cleaning or mechanical cleaning of the inside of coil tubes. In such cases the coil must be designed to provide this capability.

## 6. Open-Closed System

The standard galvanised steel serpentine and coils (prime surface) are carbon steel, hot-dip galvanised on the outside only, and are intended for application on closed, pressurised systems which are not open to the atmosphere. Stainless steel coils or cleanable coil units (with tubes hot-dip galvanized inside and out) are available to cool corrosive fluids or water and ethylene/propylene glycol solutions in systems open to the atmosphere.

## 7. Code Requirement for Evaporative Condensers

All evaporative condenser coils supplied from Europe, including desuperheater coils, are certified according to the European Pressure Equipment Directive. Since November 1999 this Pressure Equipment Directive has been adopted by the national legislation of all EU and EFTA member states. The PED specifies the design, manufacturing, quality and documentation requirements for pressure vessels and replaces previous national code requirements. BAC evaporative condenser coils fall under Category IV of the PED reglementation and require a CE Declaration of Conformity which is supplied by BAC at time of shipment.

*Standard PED Coil design (hot-dip galvanised)*
All BAC evaporative condenser coils, including bare serpentine coils, split circuit coils, extended surface coils and desuperheater coils are designed as standard for a maximum operating pressure of 23 bar (minimum -1 bar). Design temperatures are minimum: -20°C and maximum +120°C. All standard PED coils are pneumatically tested at 34 bar after fabrication.

*Optional High pressure PED coil design (hot dip galvanised)*
For specific refrigerants or applications requiring higher operating pressures (> 23 bar), the high pressure coil option is available for all hot-dip galvanised condenser coil types (see above under standard PED coil design). The high pressure coils are designed for a maximum operating pressure of 28 bar (min. -1 bar) and are pneumatically tested at 40 bar. Design temperatures are minimum -20°C and maximum +120°C.

*Optional Stainless Steel PED coil design*
Bare serpentine coils only (with or without split) are available in stainless steel AISI 304 or AISI 316 execution. All stainless steel coils are designed for a maximum operating pressure of 23 bar (min. -1 bar) and are pneumatically tested at 34 bar. Design temperature limits are minimum -20°C and maximum +120°C.

## 8. Construction Materials Compatibility

*Cooling Towers Fill Packing*
The heat transfer surface is of the film type and compatible with water found in most cooling tower applications. For cooling applications, where the water is contaminated by solids of large size, oil or grease or organic contaminants, alternative heat transfer surfaces with larger spacing must be considered.

*Closed Circuit Cooling Towers and Condenser Coils*
The standard coil is all prime surface continuous serpentine steel tubing. It is designed for low pressure drop with sloping tubes for free drainage. The coil is encased in a steel framework and the entire assembly is hot dip galvanised after fabrication. Fluids circulated through the inside of the coils must be compatible with the coil construction material, i.e.

- black steel, for std. hot dip galvanised coils
- stainless steel AISI 304L or 316L (option)
- galvanised steel for cleanable coil option (not available for all coil product lines)

Standard coils may contain certain contaminants, such as carbon iron oxide or welding particles. The interior condition of the coil including humid air must be considered, when using halocarbon (or HFC) refrigerants and sensitive system components, such as electronic expansion devices or semi-hermetic compressors.
The installer must take the necessary precautions on site, including complete clean up and evacuation and the installation of filter/dryers to safeguard the operation of these components in conjunction with the condenser coils. It is not uncommon that in the first year of operation filter cartridges have to be replaced more frequently.

## 9. Vibration Cutout Switches

Vibration cut-out switches are recommended on all axial fan installations. Vibration cut-out switches are designed to interrupt power to the fan motor and/or provide an alarm to the operator in the event of excessive vibration. Both electronic and mechanical vibration cut-out switches are available.

## 10. Water Quality

Evaporative cooling is accomplished by the evaporation of a small portion of water. As water evaporates, the dissolved solids originally present in the water remain in the system. The concentration of dissolved solids increases rapidly and can reach unacceptable levels. In addition, airborne impurities and biological contaminants are often introduced into the recirculating water, since the evaporative cooler is washing the air.
If impurities and contaminants are not effectively controlled, they can cause scaling, corrosion, sludge or biological fouling, which reduce heat transfer efficiency and increase system operating costs. For optimal heat transfer efficiency and maximum equipment life, the quality of the make-up and recirculating water should be maintained within the limitations listed below.

*Make-Up Water*
Make-up water to the evaporative unit should have minimum 30 ppm hardness as $CaCO_3$. BAC discourages the use of fully softenend water as make-up to BAC equipment.
Where softening is required,a blend with the raw water supply is imperative to give a recommended residual hardness in the make-up of 30-70 mg/l as $CaCO_3$. This will counter the corrosive tendency of fully softened water, assist the effectiveness of most modern corrosion and scale inhibitors and reduce the use of inhibitors in order to protect the environment.
Maintaining a minimum hardness in the make-up water offsets the corrosive properties of totally softened water and reduces the reliance on corrosion inhibitors to protect the system.

*Circulating Water Quality (Cycles of Concentration)*
The quality of the recirculating water is related to the make-up water by the cycles of concentration.
For example: If a given make-up water had 45 ppm of Chlorides, it would be possible to run the system at 150 / 45 equals 3,33 cycles of concentration without exceeding the 150 ppm of Chlorides allowed for a galvanised steel/Zinc Aluminium or Baltiplus unit. Note that this calculation process needs to be repeated for all of the Guideline parameters (Sulphates, Alkalinity, etc), and the lowest resultant Cycles of Concentration used.

## Circulated Water Quality Guidelines for Baltiplus Protection

| | Baltiplus Protection |
|---|---|
| pH | 6.5 to 9.0 |
| pH during initial passivation | below 8.2 |
| Total hardness (as $CaCO_3$) | 50 to 600 mg/l |
| Total alkalinity (as $CaCO_3$) | 500 mg/l max. |
| Total dissolved solids | 1500 mg/l max. |
| Conductivity | 2400 µS/cm |
| Chlorides | 250 mg/l max. |
| Sulfates* | 250 mg/l max.* |
| Total suspended solids | 25 mg/l max. |
| Chlorination (as free chlorine): continuous | 1 mg/l max. |
| Chlorination (as free chlorine): batch dosing for cleaning & disinfection | 5-15 mg/l max. for 6 hours max.<br>25 mg/l max. for 2 hours max.<br>50 mg/l max. for 1 hour max. |

## Circulated Water Quality Guidelines for Baltibond Hybrid Coating

| | Baltibond® and SST 304 |
|---|---|
| pH | 6.5 to 9.2 |
| pH during initial passivation | below 8.2 (for units with HDG coil only) |
| Total hardness (as $CaCO_3$) | 50 to 750 mg/l |
| Total alkalinity (as $CaCO_3$) | 600 mg/l max. |
| Total dissolved solids | 2050 mg/l max. |
| Conductivity | 3300 µS/cm |
| Chlorides | 300 mg/l max. |
| Sulfates* | 350 mg/l max.* |
| Total suspended solids | 25 mg/l max. |
| Chlorination (as free chlorine): continuous | 1.5 mg/l max. |
| Chlorination (as free chlorine): batch dosing for cleaning & disinfection | 5-15 mg/l max. for 6 hours max.<br>25 mg/l max. for 2 hours max.<br>50 mg/l max. for 1 hour max. |

## Circulated Water Quality Guidelines for Pultruded Composite

| | Pultruded Composite |
|---|---|
| pH | 6.5 to 9.5 |
| pH during initial passivation | not applicable |
| Total hardness (as $CaCO_3$) | 750 mg/l max. |
| Total alkalinity (as $CaCO_3$) | 600 mg/l max. |
| Total dissolved solids | 2500 mg/l max. |
| Conductivity | 4000 µS/cm |
| Chlorides | 750 mg/l max. |
| Sulfates* | 750 mg/l max.* |
| Total suspended solids | 25 mg/l max. |
| Chlorination (as free chlorine): continuous | 2 mg/l max. |
| Chlorination (as free chlorine): batch dosing for cleaning & disinfection | 5-15 mg/l max. for 6 hours max.<br>25 mg/l max. for 2 hours max.<br>50 mg/l max. for 1 hour max. |

## Circulated Water Quality Guidelines for Stainless Steel

| | SST 304 and SST 316 with HDG coil | SST 316 (with SST 316 coil) |
|---|---|---|
| pH | 6.5 to 9.2 | 6.5 to 9.5 |
| pH during initial passivation | below 8.2 (for units with HDG coil) | not applicable |
| Total hardness (as $CaCO_3$) | 50 to 750 mg/l | 750 mg/l max. |
| Total alkalinity (as $CaCO_3$) | 600 mg/l max. | 600 mg/l max. |
| Total dissolved solids | 2050 mg/l max. | 2500 mg/l max. |
| Conductivity | 3300 µS/cm | 4000 µS/cm |
| Chlorides | 300 mg/l max. | 750 mg/l max. |
| Sulfates* | 350 mg/l max.* | 750 mg/l max.* |
| Total suspended solids | 25 mg/l max. | 25 mg/l max. |
| Chlorination (as free chlorine): continuous | 1.5 mg/l max. | 2 mg/l max. |
| Chlorination (as free chlorine): batch dosing for cleaning & disinfection | 5-15 mg/l max. for 6 hours max.<br>25 mg/l max. for 2 hours max.<br>50 mg/l max. for 1 hour max. | 5-15 mg/l max. for 6 hours max.<br>25 mg/l max. for 2 hours max.<br>50 mg/l max. for 1 hour max. |

** Higher concentrations of sulfates allowed provided the sum of chlorides + sulfates parameters does not exceed 500 mg/l for Baltiplus, 650 mg/l for Baltibond/SST 304 and 1500 mg/l for SST 316/Pultruded*
*Note: For Ozone water treatment applications, stainless Steel 316 execution is required.*

*Blow Down*

To prevent an excessive build-up of impurities in the recirculating water, a small amount of water must be bled from the recirculating water. In many localities, this constant bleed and replacement with fresh make-up water will keep the concentration of impurities in the system at an acceptable level.

The **bleed rate** will depend on the cycles of concentration required to maintain recirculating water quality and the **evaporation rate**.

After the cycles of concentration have been determined, the bleed rate can be calculated using the following equation:

$$B = E / (N - 1)$$

Where:
B = bleed rate in l/s;
E = evaporation rate in l/s;
N = number of cycles of concentration.

The maximum evaporation rate can be determined by one of the following methods:

- Method n° 1: The evaporation rate is approximately 1,8 litres per 1000 kcal of heat rejection.
- Method n° 2: The evaporation rate is approximately 1,8 litres per 4180 kJ of heat rejection.
- Method n° 3: evaporation rate = water flow rate (l/s) x range (°C) x 0,0018
- Method n° 4: evaporation rate = total heat rejection kW / 2322 = l/s

*Examples:*

**Method n° 2:** At a flow rate of 10 l/s and a cooling range of 10 °C the evaporation rate is 0,18 l/s
(10 l/s x 10 °C x 0,0018 = 0,18 l/s)

**Method n° 4:** Duty calculates to 418kW, therefore the evaporation rate is 0.18 l/s (418 / 2322 = 0,18 l/s)

*Note: The calculation method described above should not be used to determine the water consumption of evaporative cooling equipment. Next to heat load and water quality the water consumption depends on climatic conditions, the capacity control strategy and the equipment configuration. Water consumption calculations are therefore complex and should not be based on the maximum evaporation rate, which occurs at dry ambient conditions. The above mentioned calculation methods are only suitable for the purpose of sizing a proper blow down.*

*Total Water Make-Up Rate*

**Water make-up rate = evaporation rate + bleed rate + drift loss**

The evaporation and bleed rates are calculated as above. Provided the equipment is correctly fitted with well maintained high efficiency drift eliminators (as per standard Baltimore Aircoil supply), the drift loss can be considered as insignificant when compared with the evaporation and bleed rates.
Note that if other system components require adherence to more stringent recirculating water quality guidelines, the more stringent guidelines must be followed.

*Water Treatment*

The above guidelines do not themselves guarantee portection of the cooling system. The water treatment program must be able to achieve control of corrosion, scaling, microbiological growth and fouling with the BAC equipment and the cooling system it serves. The water treatment regime must also comply with the specific local requirement in term of legionella control. The final choice of the water treatmen program and its follow-up remain the sole and entire responsibility of the water treatment company or the equipment owner.

The water treatment guidelines below should be followed:

- Water treatment chemicals or non-chemical systems need to be compatible with the materials of construction used in the cooling system including the evaporative cooling equipment itself.
- In case of chemical water treatment, chemicals should be added to the recirculating water by an automatic feed system. This will prevent localised high concentrations of chemicals, which may cause corrosion. Preferably the water treatment chemicals should be fed into the cooling system at the discharge of the recirculation pump. The chemicals should not be fed in concentrated form, nor batch fed directly into the cold water sump of the evaporative cooling equipment.
- BAC specifically discourages acid dosing as means of scale controls (unless under certain strict circumstances for open circuit cooling towers with very large volume and remote sump, or constructed from stainless steel.

- A competent water treatment company should be consulted for the specific water treatment programme to be applied. Next to the supply of dosing and control equipment and chemicals, the programme should include regular monthly monitoring of the circulating and make up water quality.
- If it is proposed to operate a treament program outside the BAC Water Quality Control Guidelines, the BAC factory warranty may be invalidatd if the water quality is persistently outside the control guidelines, unless specific prior written BAC approvel (some parameters may be exceeded under certain strict circumstances).

*Passivation*

When new systems are first commissioned, special measures should be taken to ensure that galvanized steel surfaces are properly passivated to provide maximum protection from corrosion. Passivation is the formation of a protective, passive, oxide layer on galvanized steel surfaces. To ensure the galvanized steel surfaces are passivated, the pH of circulating water should be kept between 7.0 and 8.2 and calcium hardness between 100 and 300 ppm (as $CaCO_3$) for four to eight weeks after start-up, or until new zinc surfaces turn dull gray in color. If white deposits form on galvanized steel surfaces after the pH is returned to normal service levels, it may be necessary to repeat the passivation process.
*Note: Stainless steel units and units protected by the Baltibond Hybrid Coating, without galvanized coil, do not require passivation.*

In case you can't keep the pH below 8.2, a secondary approach is to conduct a chemical passivation using inorganic phosphate or film-forming passivation agents. COnsult your water treatment specialist for specific recommendation.

## 11. Control of Biological Contamination and Water Treatment

The growth of algae, slimes and other micro-organisms, if uncontrolled, will reduce heat transfer efficiency and may contribute to the growth of potentially harmful micro-organisms, such as Legionella, in the recirculating water. Accordingly a treatment programme specifically designed to address biological control should be initiated when the system is first filled with water and administered on a regular base thereafter in accordance with any regulations (national, regional) that may exist or in accordance with accepted codes of good practice, such as EUROVENT 9 - 5 & 6.

It is strongly recommended to monitor the bacteriological contamination of the recirculating water on a regular base (for example TAB test with dip slides on a weekly base) and record all results. (TAB = Total Aerobic Bacteria)

In addition to the control of biological contamination, which must be done at all times, it may be necessary to install a water treatment regime to prevent the formation of scale or corrosion. To ensure recognition of any risk and the implementation of protective measures, it is recommended to conduct a risk analysis by a specialised risk assessor. It is also recommended to develop an operations plan for the cooling system.

*Algae*

Algae are plants, which, like all plants, require sunlight and nutrients to grow. In evaporative cooling equipment algae are aesthetically undesirable and may promote other microbial growth. However, unless the algae interfere with the thermal performance of the unit, e.g. by blocking fill or plugging nozzles, it is of itself relatively benign. A biologically active system is one with an active slime layer and high plank tonic bacteria count. Such a system is at risk for poor thermal performance, microbial influenced corrosion, and pathogens.

Algae growth, combined with high total bacteria count , can be a warning sign of a biologically active system. Algae growth combined with low Total Bacteria Count (TBC) is NOT a warning sign for a biologically active system. Consistently low total bacteria counts are a sign of a biologically INACTIVE system regardless of the presence or absence of algae.

Algae growth may be particularly noticeable during the spring and summer. As previously noted, algae requires sunlight to grow; therefore, open cooling systems and systems that receive direct sunlight are more prone to algae growth. Blown-in dirt and nutrients also promote algae growth.

The use of filtration systems to relieve the system of blown-in and precipitated solids can reduce the area for algae to thrive. Effective filtration will not remove existing algae but should prevent future blooms.

## 12. Location

Each cooling tower, evaporative cooler or condenser should be located and positioned to prevent the introduction of the discharge air and the associated drift, which may contain contaminants, such as Legionella, into the ventilation systems or open windows of buildings. To yield full thermal performance, equipment location must be chosen in a way that there is unimpeded supply of air to the entire air intake surface. In addition access to all maintenance and inspection points must be safeguarded. Located in enclosures or close to adjoining building walls, the top of the equipment must be level with or higher than the top of the adjacent walls in order to reduce the possibility of recirculating warm and humid discharge air back to the air intake(s).

To accomplish this, in some cases the equipment needs to be installed elevated or equipped with discharge hoods or ductwork. In case of elevated locations (more than 300 mm above surface), it is necessary to equip counterflow forced draft equipment with a solid bottom panel, to provide protection from moving parts and ensure that the air is drawn horizontally into the cooling tower and not from the bottom (bottom air entry can be considered but requires reduction of nominal fan speed to avoid fan motor overload).

For indoor locations with forced draught centrifugal fan equipment it is common practice to apply ductwork to air entry and discharge. Such ductwork must be designed for even air distribution and minimum pressure drop and access doors must be foreseen to allow access to the interior of the duct and from there to the equipment itself. In some cases the equipment room may be used as an intake plenum, in which case only discharge ductwork is needed. In such cases measures need be taken to prevent erratic air distribution when switching fans and/or cells, for example by the sue of positive closure discharge dampers.

## 13. Piping

*General*

Piping should be sized and installed in accordance with rules of good practice. Dead legs and stagnant water conditions in the piping should be avoided. If more than one inlet connection is required, balancing valves should be installed to properly balance the flow to each inlet. Depending on the design of the hydraulic circuit, it may also be necessary to install balancing valves at the suction connections of the towers. The use of shut off valves is dictated by the necessity to (automatically or manually) isolate cells or towers for capacity control or servicing. If the equipment is installed on vibration rails, compensators must be installed in the connecting piping.

*Open Cooling Towers*

Piping must be sized and installed in accordance with good piping practice. All piping should be supported by pipe hangers or other supports, not by the unit. On open systems, in order to prevent basin overflow at shutdown and to ensure satisfactory pump operation at start-up, all heat exchangers and as much piping as possible should be installed below the operating level of the cooling tower.

Some units may require flow balancing valves (supplied by others) at the hot water and coil inlets to balance the flow to individual inlets and cells. External shutoff valves (supplied by others) may also be required if the system design necessitates the isolation of individual cells.

When multiple cells are used on a common system equalizing lines should be installed between the cold water basins to ensure balanced water level in all cells. It is good engineering practice to valve the inlet and outlet of each tower separately for servicing. The shut-off valves can be used, if necessary, to adjust any minor unbalanced condition in water flow to or from the units.

Although equalizing lines can be used to balance water levels between multi-cell closed circuit cooling towers, the spray water for each cell must be treated separately, and a separate make-up must be provided for each cell. Note that a common remote sump for multi-cell installations can simplify make-up and water treatment. See the appropriate Operating and Maintenance Instruction Manual for more information on water treatment.

Since the sump capacity of any cooling tower is limited, it can only accumulate a certain amount of water draining from the system into the tower, when the circulating water pump stops. Therefore install all heat exchangers and as much tower piping as possible below the operating level of the tower. The BAC Balticare Representative can advise the available sump capacity for system drainage for a given model and operating conditions.

When multiple cooling towers are used on a common system, install equalising lines between the sumps of the towers to ensure a balanced water level. Standard equalising lines are designed for a maximum water level differential (between sumps) of 25 mm and an equalising flow of 15% of the circulating water flow for the largest tower in the system based on the cooling towers being located in close proximity to each other. The connecting pipework (by others) should maintain the same diameter along their length for proper operation. If hydraulical isolation of individual cells is desired a shut off valve in the equalising piping is needed.

*Closed Circuit Cooling Towers*

Fluid piping should allow flexibility for expansion and contraction between component parts of the system. All fluid piping should be supported separately from the equipment by pipe hangers or supports. In a completely closed system, an expansion tank should be installed for purging air from the system and to allow for fluid expansion.

A vacuum breaker or air vent at the high point and a drain at the low point should be installed in the piping system to permit complete drainage of coils.

*For Refrigerent Piping*

Piping should be adequately sized according to standard refrigeration practice and arranged to allow flexibility for expansion and contraction between component parts of the system. Suitably sized equalising lines must be installed between the condenser and high pressure receiver to prevent gas binding and refrigerant backup in the condenser. Service valves should be installed so that the component parts may be easily serviced.

On multiple evaporative condenser installations, evaporative condensers in parallel with shell-and-tube condensers, or single condensers with multiple coils, refrigerant outlet connections must be trapped into the main liquid refrigerant header. The height of the trapped liquid legs must be sufficient to balance the effect of the unequal coil pressures without backing up liquid refrigerant into the condensing coil. This type of liquid line piping permits independent operation of any one of the parallel circuits without manually closing inlet and outlet valves.

Although equalising lines can be used to balance water levels between multi-cell evaporative condensers, the spray water for each cell must be treated separately, and a separate make-up must be provided for each cell. Note that a common remote sump for multi-cell installations can simplify make-up and water treatment. See the appropriate Operating and Maintenance Instruction Manual for more information on water treatment.

*Weld Byproduct Cleaning*
The installation and manufacturing processes commonly used for field assembly of steel-piped systems may leave weld byproducts inside coils and connecting piping (especially in refrigeration systems). It is common practice to install filters and/or strainers that remove contaminants during initial system operation. Shortly after system startup, the filters and/or strainers should be cleaned or replaced.

For installations with high pressure float valves, ensure that liquid piping from condenser outlet to valve(s) is sized for low refrigerant velocity (0,5 m/s) so that valve operation is not disturbed by flash gas and that an equalising line is properly installed. For systems with thermosyphon oil cooling ensure adequate equalising and sufficient height difference between condenser(s) and receiver.

Standard condenser coils are manufactured from black steel and hot dip galvanised after fabrication and may contain certain contaminants, such as carbon, iron oxyde or welding particles. The interior condition of the coil, including humid air must be considered, when using halocarbon (or HFC) refrigerants and sensitive system components, such as electronic expansion devices or semi hermetic compressors. The installer must take the necessary precautions on site to safeguard the operation of these components in conjunction with the condenser coils.

## 14. Capacity Control

*General*
Most cooling systems are subject to substantial changes in heat load and ambient temperature conditions during the operating season. The capacity of evaporative cooling equipment varies greatly as the wet bulb temperature changes. To prevent freezing inside the equipment at subfreezing ambient conditions and/or when a reasonably constant temperature of the cooling water is desired, some form of capacity control is required. The preferred control method is to reduce the airflow through the equipment to adapt to heat load and ambient conditions. It is not recommended to modulate the water (fluid) flow for capacity control reasons. Regardless the type of capacity control chosen, it is necessary to start the circulating pump first and the fan motor(s) thereafter. At the same time prolonged operation of circulating pump(s) only without fan(s) running should be avoided during subfreezing conditions.

*Fan Cycling*
Fan cycling is the simplest method of capacity control, suitable for multiple cell installations. The number of control steps available for fan cycling is generally determined by the number of fan motors, however on certain models two fan motors must be cycled simultaneously to prevent erratic air distribution. Consult your BAC Balticare Representative for more details. The more steps for fan cycling are available the better the control of the cooling water temperature is. Rapid on-off cycling can cause the fan motor to overheat. It is recommended that controls be set to allow a maximum of 6 on-off starts per hour. The number of steps of capacity control can be increased using the Baltiguard® Fan System*, the independent fan motor* option, or two-speed fan motors in conjunction with fan cycling. These options provide substantial energy savings when compared to simple fan cycling.
** Only available for some BAC-products*

On ammonia systems, most evaporators are fed by high pressure or low pressure float valves or float switches which are less sensitive to variations in head pressure. On this type of system, fan cycling of the evaporative condenser will usually provide satisfactory capacity control on the high side of the system, where the evaporative condenser may have several fan motors which can be cycled in steps.

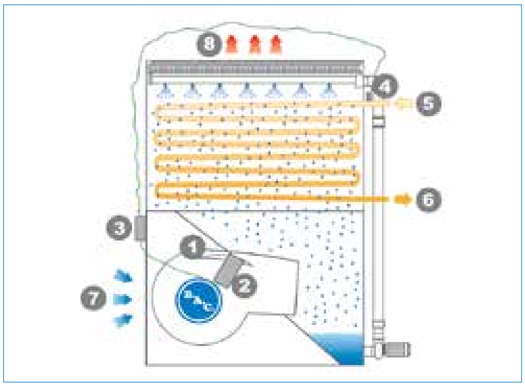
Halocarbon systems generally utilize evaporators controlled by thermal expansion valves. A reasonably constant pressure differential across the thermal expansion valve is required for its proper operation. Therefore, this type of system requires a closer degree of evaporative condenser capacity control than can be obtained with fan.

*Note for Closed Circuit Cooling Towers and Evaporative Condensers: Spray water pump cycling should not be used for capacity control. This method of control often results in short cycling of the pump motor as capacity changes substantially with pump cycling. In addition, alternate wetting and drying of the coil promotes scaling of the heat exchanger coil surface.*

*Multi-Speed Drives*

The number of steps available for fan cycling can be increased by using multi-speed drives. These can either be accomplished by the installation of multi-speed motors (Dahlander/Two speed separate windings) or the Baltiguard® Drive system.

At half of the nominal fan speed (Dahlander/two speed, separate windings) the nominal capacity of the tower will be appr. 60%; at 2/3 of nominal fan speed (Baltiguard®) the nominal capacity of the tower will be appr. 70%. When switching from high to low speed a time interval of min. 15 s must be foreseen, before the low speed drive can be activated to allow the fan(s) to slow down.



*Evaporative Condenser with Modulating Fan Discharge Dampers (Single Coil Circuit Unit)*
1. Modulating Fan Discharge Damper; 2. Fan Damper Actuator; 3. Terminal Box; 4. Sensing Element; 5. Vapour In; 6. Liquid Out; 7. Inlet Air; 8. Air Discharge

*Modulating Capacity Control*

Modulating capacity control is recommended when a closer control of the cooling water temperature or condensing pressure is desired and in particular if free cooling at subfreezing ambient conditions is anticipated. Modulating capacity control can be accomplished with modulating fan discharge dampers (only for centrifugal fan models). Fan discharge dampers vary the airflow to match tower capacity to system heat load and ambient condition. The damper motors switch to low speed and shut off the fan motor(s) when the dampers reach minimum position.
Modulating dampers also affect a reduction in fan motor kW which is approximately proportional to the reduction in air flow as the dampers move toward the closed position. Modulating discharge dampers are also available on centrifugal fan condensers.

- **Single Coil Circuit Units**

Damper control is recommended for any system using evaporators controlled by thermal expansion valves. On a single circuit condenser, a condensing pressure sensing element is located in the compressor discharge line or in the receiver (see Figure aside). The pressure controller is electrically connected to the damper motor, and when the condensing pressure changes, a signal is sent to the damper motors to reposition the dampers and provide more or less airflow as required.

- **Multiple Coil Circuit Units**

On multiple circuit condensers where it is necessary to
control condensing pressures for two or more circuits, a spray water temperature sensing controller, located in the pan, is substituted for the condensing pressures on the
multiple condenser circuits. Even with a very light load on one circuit, the condensing temperature in that circuit can not fall below the spray water temperature.
*Note: This system will not provide control if the pan is drained for dry condenser operation in winter.*

Alternatively to modulating fan dampers variable speed control devices can be installed. In such cases steps must be taken to avoid operating at or near the fan's "critical speed". Consult with the BAC representative or BAC Balticare of any application utilising variable speed control to determine whether any critical speed may be encountered and whether the anticipated fan motor selection is suitable for this application. Fan motors must be equipped with PTC Thermistors for these applications to facilitate protection against motor overheating. Where isolation rails are used in conjunction with variable fan speed controls, the isolation springing should be high deflection, and the minimum continuous running fan speed limited to avoid resonant frequencies with the springing.

Modulating capacity control is the best way to closely control cooling water temperatures, however even with modulating control some variation of the cooling water temperature or condensing pressure will occur, in particular at light heat load or start-up conditions. In applications with open or closed circuit cooling towers where such variations cannot be tolerated (start-up of absorption chiller) an additional bypass to stabilise temperatures must be foreseen.

*Variable Frequency Drives*

Installations which are to be controlled by Variable Frequency Drives (VFD) require the use of an inverter duty motor as designed IEC 34.1, which recognizes the increased stresses placed on motors by these drive systems. Inverter duty motors must be furnished on VFD applications in order to maintain the motor warranty. Fan motors must be furnished with thermal protection (either PTC sensors or coil thermostats normally open, or normally closed). The motor protection consists of temperature sensitive cutout devices embedded in the motor windings (minimum 3 per motor).

The minimum fan motor speed during normal operation should not be below 30% of the speed indicated on the motor nameplate. This corresponds with 15 Hz for a 50 Hz supply and 18 Hz for a 60 Hz supply.
When the fan speed is to be changed from the factory-set speed, including through the use of a variable speed control device, steps must be taken to avoid operating at or near fan speeds that cause a resonance with the unit or its supporting structure. At start-up, the variable frequency drive should be cycled slowly between zero and full speed and any speeds that cause a noticeable resonance in the unit should be "locked out" by the variable speed drive.

## 15. Dry Operation (Coil Products only)

During winter operation, when the load may be reduced and the ambient temperature is far below the design conditions, the equipment may be operated dry, i.e., without recirculated water flow. This reduces the capacity of the unit to more nearly match the reduced load.

Dry operation of an evaporative product is intended to be a seasonal process. Water pump cycling should not be used for capacity control. Capacity changes greatly with and without spray water, so that this method of control often results in short cycling of the recirculating pump. In addition, alternate wetting and drying of the coil promotes formation of scale on the condensing surface.

Evaporative cooling products should not be operated dry in sub-freezing ambient temperatures while the recirculated water is stored in the pan of the unit. The flow of cold air through the unit may freeze the water, even if electric heaters or steam coils have been provided for freeze protection. These heaters are designated to prevent freezing only when the pumps and fan are idle. Furthermore, air turbulence created by the fans will blow water throughout the interior of the unit, and cause icing on the cold surfaces. It is recommended that the equipment be completely drained of water when dry operation is desired.

## 16. Winter Safety

*General*
When a unit is shut down in freezing weather, the basin water must be protected by draining to an indoor auxiliary remote sump tank or by providing supplementary heat to the cold water basin. Supplementary heat can be provided by electric immersion heaters or in some cases, hot water, steam coils, or steam injectors. All exposed water piping, make-up lines, and spray pumps (if applicable) that do not drain at shutdown should be traced with electric heater tape and insulated. When dry operation is planned for low ambient conditions, centrifugal fan units should be supplied with oversized fan motors to prevent motor overload when the spray water is not operating. For remote sump applications, the spray water pump must be selected for the required flow at a total head which includes the vertical lift, pipe friction (in supply and suction lines) plus the required pressure at the inlet header of the water distribution system (14 kPa). A valve should always be installed in the discharge line from the pump to permit adjusting flow to the unit requirement. Inlet water pressure should be measured by a pressure gauge installed in the water supply riser at the spray water inlet, and adjusted to the specified inlet pressure.

Unless the system is shut down and drained during winter, measures must be taken to protect the system from freezing during the winter, during operation and standstill. Freeze protection during operation is achieved by selecting an adequate method of capacity control. For reasonably constant loads and cooling water or condensing temperatures above 15°C step control is usually adequate. For variable loads, in particular when combined with free cooling modulating controls are recommended.

When the equipment is shut down in freezing weather the sump water must be protected. This can be accomplished by the installation of electrical sump heaters. The standard electric heaters are sized to maintain +4°C sump water when the ambient temperature drops to - 18°C.

All sump heaters have six power terminals and one earth terminal. Heaters with six terminals can be wired in Star for 400 Volt; 3 phase supply; or in Delta for 230 Volt, 3 phase supply. All heaters can alternatively be used with a 230 Volt single-phase supply, if the terminals are wired in parallel. Sump heaters need to be sized to maintain a sump water temperature of 4°C at an applicable ambient temperature (for example: - 18°C). They are installed together with a heater thermostat and a low level cut out switch to prevent heater operation, when the sump is drained.

Draining the sump water into a separate tank installed in an area protected from freezing, is an alternative to auxiliary heating of the integral sump. Remote sump sizing must include the water draining from external piping, the tower water distribution system, water suspended in the fill pack or coil and sump as well as water needed to prevent vortexing inside the remote sump.

In addition to the sump all exposed water piping, pumps and make up lines, including mechanical or electrical valves that do not drain at shutdown should be traced with electrical heater tape and insulated.

*Coil Protection for Closed Circuit Cooling Towers, Dry Coolers and Dry Coolers with Adiabatic Pre-Cooling*
At below freezing ambient conditions, the unit can experience heat loss even without the recirculating spray water pump and fans in operation. Without a heat load on the circulating fluid, coil freezing can occur even at full flow. Protective means are readily available to avoid potential freeze problems. Where the system will permit, the best protection against coil freeze-up is the use of an industrially inhibited anti-freeze solution.
When this is not possible, the system must be designed to meet both of the following conditions:

- Maintain minimum recommended flow through the coil at all times.
- Maintain a heat load on the circulating fluid so that the temperature of the fluid leaving the coil will not be below 7ºC.

If the process load is extremely light, or if the process is periodically shut off entirely, then an auxiliary heat load must be applied to the circulating fluid when below freezing ambient temperatures exist to prevent damage to the coil. Refer to the Heat Loss Data for the auxiliary heat load requirement. The amount of auxiliary heat necessary to prevent coil freezing can be further reduced by the use of a positive closure damper hood and insulation.
Draining the coil is not recommended as a normal method of freeze protection. However, draining is acceptable as an emergency method of freeze protection. Frequent draining can promote corrosion inside the coil tubes. If the coil is not protected by an industrially inhibited anti-freeze solution, an automatic drain valve and air vent is recommended to drain the coil if flow stops or fluid temperature drops below 7ºC when the ambient temperature is below freezing. Note that cold water basin heaters will not provide freeze protection for the coil.

The coil of dry coolers can never drain completely. If a minimum heat load can not be guaranteed on the dry coil during the winter period, then the use of an anti-freeze solution is the only available protection against coil freezing.

Draining of the coil(s) is not recommended as a normal method of freeze protection unless the coil(s) are constructed from stainless steel or are of the cleanable type. For standard hot dip galvanised coils draining is acceptable as an emergency method of freeze protection. For this purpose an automatic drain valve and air vent needs to be installed to drain the coil(s) if flow stops or the fluid temperature drops below 10°C when the ambient temperature is below freezing.

## 17. Plume and Plume Abatement

At the air discharge water droplets can be formed by condensation of warm humid discharge air by contact with the colder ambient air upon leaving the equipment. This type of condensation is the visible plume that often can be seen rising above evaporative cooling equipment during the winter season. The water vapour caused by condensation contains droplets of pure water and is harmless. In some instances visible plumes are considered as a hinder, in which case measures must be taken to minimise or eliminate the occurrence of plume. Consult the BAC Balticare Representative for such requests.

## 18. Electrical Wiring and Controls

Wiring to electrical components should be via suitable weatherproof cable glands. Unused electrical entries should be plugged with a weatherproof plug.
Where motors are supplied with PTC Thermistors they should be incorporated into the control circuit as means of motor overheat protection. Also the use of anti condensing heaters is strongly recommended.

## 19. Starting of Fan Motors

Fan motors up to 5,5 kW nameplate rating can normally be started direct on line (DOL). Above these ratings the motor should be started using star delta starter and not DOL. DOL starting requires high starting currents and imposes a large starting torque on the fan drives. Alternatively a soft starter or a variable speed frequency drive may be used instead of star delta starting, according to the project requirements. In all cases, precautions should be incorporated into the control circuitry to protect against motor overloading.

## 20. Sound

BAC provides sound data as sound pressure levels in 5 directions, in 1,5 m and 15 m from the equipment as well as overall sound power levels. Data are available for equipment with and without sound attenuation and should be the base of any acoustical specification and guarantee for outdoor locations. For indoor locations it is preferable to specify partial sound power levels for the air intake and discharge areas. For sound pressure specifications relating to indoor locations, consult the BAC Balticare Representative.

## 21. Maintenance

Regular maintenance in accordance with the appropriate BAC Operating and Maintenance instructions and with prevailing local regulations and Codes is essential for the efficient and safe operation of a cooling tower, evaporative cooler or condenser. A programme of regular maintenance and inspections needs to be set up, executed and documented. For proper execution of maintenance and inspections and depending on site conditions ladders, safety cages, stairways, access platforms with handrails and toe-boards must be installed as appropriate for the safety and convenience of authorised service and maintenance personnel. (See also Chapter 17: The Value of Maintaining Evaporative Cooling Equipment.)

## 22. Safety information

For safe operation of unshielded equipment exposed to wind speeds above 120 km/h installed at a height above 30 m from the ground, contact your local BAC Balticare Representative. For safe operation of equipment installed in moderate and high hazard areas contact your local BAC Balticare Representative.

# Recommendation for Safe Operation of Evaporative Cooling Equipment

20

*Source: Eurovent*

## 1. Introduction

Evaporative cooling is an efficient and cost effective means of removing heat from air conditioning, refrigeration and industrial process cooling systems, based on a natural principle by making use of adiabatic cooling with or without latent heat transfer.

Evaporative cooling combines high thermal efficiency and cost effectiveness by achieving low cooling temperatures with minimum energy and water usage. Low cooling temperatures are essential for many processes to achieve high system efficiency.

## 2. Scope

Purpose of this standard is to describe the measures that should be undertaken to achieve efficient operation of evaporative cooling installations and to control the risk of Legionnaires Disease outbreaks. The measures described here apply to system designers, installers and operators as well as to the manufacturers of evaporative cooling equipment. Evaporative cooling installations are installations in which water is exposed to an air stream with the aim to enhance the cooling process either by humidification of the air only or by combination of air humidification and latent heat transfer.

This standard provides recommendations and defines face values. National or regional requirements, which differ from these recommendations, must be adhered to first.

## 3. Normative References

- EUROVENT 9/5 Empfehlungen zum wirksamen und sicheren Betrieb Ihrer Verdunstungskühlanlage.
- Dr. A. Olkis, Mikrobiologische Kontrolle in Rückkühlsystemen, 6. VDMA-Kühlturmtagung, 2003.
- Aqua Nederland: Legionella-bestrijding in koel- en proceswater.
- Legionella et tours aéroréfrigérantes, guide des bonnes pratiques.
- MSC : Legionnaires' Disease – the control of Legionella bacteria in water systems.
- Ministerie van de Vlaamse Gemeenschap : Voorkom Legionella
- Ondeo-Nalco : European Good Practice Guide
- KIWA : Omvang en preventie van vermeerdering van legionella in koeltorens en luchtbehandelingsapparaturen.
- The Water Management Society: Keeping your cooling tower safe.
- Expert Verlag: Legionellen – ein aktuelles Problem der Sanitärhygiene.
- ASHRAE Guideline 12-2000 : Minimizing the risk of Legionellosis associated with building water systems.
- CTI : Legionellosis Guideline – Best Practices for Control of Legionella.
- European Commission – IPPC Bureau: Reference document on the application of best available techniques for industrial cooling systems.
- ARBO informatie A1-32
- DIN-Taschenbuch 255, Instandhaltung Gebäudetechnik – Normen, Technische Regeln.

- Omvang en preventie van vermeerdering van Legionella in Koeltorens en luchtbehandelings-apparaturen KWA/ KIWA NL.
- Control of microbial growth in air handling and water systems of buildings SAA/SNZ.
- VDI 6022: Hygienic standards for ventilation and air conditioning systems.
- Legionnaires' Disease, The control of Legionella bacteria in water systems, Health and Safety Commission U.K.

## 4. Fundamentals

*Evaporative Cooling*

Evaporative cooling can be applied in a large number of different products, such as open cooling towers, closed circuit cooling towers, hybrid cooling towers (open or closed) or adiabatic coolers. In all of these applications water is subjected to an air stream, hence creating an aerosol either directly through the exposure of spray water to the air stream or indirectly through the impact of the air stream on water, which has accumulated on the construction inside or outside the heat transfer equipment. In some evaporative cooling products, such as open cooling towers or closed circuit cooling towers water is typically circulated. Although these products can also be used in once through systems, in this document they are referred to as evaporative products with circulating water loops. For such products care must be taken to avoid excessive accumulation of dissolved solids. In some hybrid cooling towers and adiabatic coolers, water is only used to humidify the air and in certain designs it is aimed to achieve this without recirculation of the spray water. In this chapter these products are referred to as evaporative products without circulating water loops. Also in these applications care must be taken to operate with the right water quality. Regardless the fact whether or not the spray water is recirculated or not, the recommendations with regard to the control of microbiological growth made in this standard must be adhered to.

*Evaporation and Blow Down*

In evaporative cooling equipment with circulating water loop the cooling is accomplished by evaporating a small portion of this water as it flows through the unit. When the water evaporates, the impurities originally present in the water remain. Unless a small amount of water is drained from the system, known as blow-down, the concentration of dissolved solids will increase rapidly and lead to scale formation or corrosion or both. Also, since water is being lost from the system through evaporation and blow-down, this water needs to be replenished.

The total amount of replenishment, known as make-up, is defined as:

**Make-up = evaporation loss + blow-down**

The evaporation loss depends on a variety of factors, such as mass flow ratio air to water, climatic conditions and the heat rejection achieved. For this reason an easy way of how to calculate the evaporation loss on an annual base is not available. The general formula of 0,44 litres of water evaporation per 1000 kJoule of heat rejection is based on summer conditions with dry air and should only be used to estimate the evaporation loss at design conditions. This simplified formula is not suitable to calculate evaporation losses year round.

The amount of blow-down is determined by the design cycles of concentration for the system. These cycles of concentration depend on the quality of the make-up water and the design guidelines for the quality of the recirculating water. Depending on the materials of construction of the system the water quality guidelines may differ and the system designer or manufacturer's instructions must be adhered to in this regard.

Cycles of concentration are the ratio of the dissolved solids concentration in the recirculating water compared to the dissolved solids concentration in the make-up water. Once the design cycles of concentration have been defined, the blow-down rate can be calculated:

**Blow down = evaporation loss / cycles of concentration -1**

The cycle of concentration is related to the water quality and the water treatment programme. It must be limited to a certain value to avoid undesirable scaling and/ or corrosion. As a general rule it is recommended that the design cycles of concentration should not exceed 5. Above 5 the water savings through smaller amounts of blow-down become less and less significant. Increased cycles of concentration reduce the water contamination but go hand in hand with a high operating risk, as any loss of control quickly leads to undesirable scaling or corrosion within the system.

*Circulating Water Quality*

In addition to impurities present in the make-up water, any airborne impurities or biological matter are carried into the tower and drawn into the recirculating water. Over and above the necessity to continuously bleed off a small quantity of water, a water treatment programme specifically designed to address scale, corrosion and biological control should be initiated when the system is first installed and maintained on a continuous basis thereafter. Moreover there must be an ongoing programme of monitoring in place to ensure that the water treatment system is maintaining the water quality within the control guidelines. The incoming make-up water will normally have a tendency to be either corrosive or scale forming and this will also be influenced by the water temperature and the cycles of concentration. Steps must be taken to prevent both corrosion and scale formation.

*Scale Formation*

Excessive scaling on the heat transfer surfaces within an evaporative cooling product greatly reduces heat transfer efficiency and could even destroy its structure. This can result in higher cooling temperatures than designed and eventually system down-time. Scale formation always causes higher energy conbasintion, and this applies all year round regardless of the load on the system. Whilst scale itself is not considered as a nutrient for bacteriological growth, heavy scale formation provides a breeding haven for micro-organisms and can therefore add to the risk of bacteriological contamination.

Depending on the main supply water and system operation, scale formation can be prevented by the correct combination of softening of the make-up water, control of pH and bleed-off and dosing of scale inhibitor chemicals. Physical methods for controlling scale such as electro-magnetic or ultrasonic techniques and others are also available. The control of scale needs to be carefully evaluated on a case-by-case basis.

Scale formation is independent of the materials of construction of the system components therefore it needs to be a clear objective to avoid scale formation in the first place.

*Corrosion*

Premature or rapid corrosion is detrimental to the cooling system components and may shorten equipment life considerably. Corrosion by-products, such as iron oxides, can furthermore encourage bacteriological growth. For these reasons corrosion within a cooling system should be minimised at all times. To achieve this the water quality must be kept within the limits specified by the supplier of system components and, in many cases, the dosing of a chemical corrosion inhibitor as well as the control of the pH value is recommended.

*Note: Due to advances in chemical blending most water treatment chemical suppliers offer a corrosion and scale inhibitor as a single chemical.*

*Biocidal Control*

Proper operation, blow-down and chemical water treatment for scale and corrosion are not a guarantee of controlling bacteriological growth in a cooling system. Therefore specific attention must be given to the matter of bacteriological control. Not only can bacteriological growth reduce heat transfer efficiency by formation of slimes or biofilms but, more importantly, proliferation of bacteria can sufficiently contaminate the recirculating water that it becomes a potential health hazard. Amongst the harmful bacteria the most important in this context is Legionella Pneumophila which, in uncontrolled conditions, could result in cases of Legionnaire's Disease.

There is a wide range of systems, which allow controlling the microbiological growth (including Legionella). A water treatment specialist should advise on the best biocidal treatment for a particular cooling system.

*Fouling*

Fouling of heat exchange surfaces due to dirt, sludge and slimes in the system will not only affect thermal performance, but may also encourage the growth of bacteria. In open cooling towers, for example, it even may destroy the fill pack. Therefore steps must be taken to avoid a build up of dirt and debris within the cooling tower and the rest of the system.

For systems with dirty water or where significant amounts of airborne dirt and debris are carried into the system, filtration of the recirculating water may be needed. Usually this is side stream type where a portion of the water is drawn from a water collection basin, filtered and then returned to the system.
Sometimes silt and sludge can be controlled with chemical biodispersants, which are either dosed separately or blended with a chemical biocide.

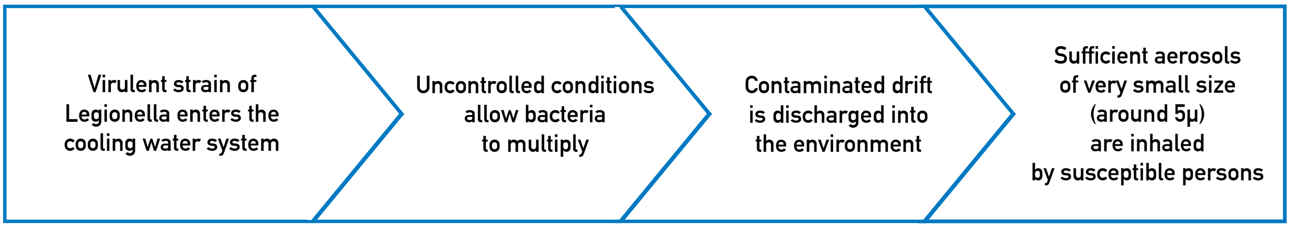
*Legionnaires' Disease*

Legionnaires' Disease is an uncommon but serious form of pneumonia. It affects only a small percentage of people who are susceptible to an infection of this kind. It can only be contracted by inhaling contaminated aerosols. It cannot be contracted by drinking contaminated water.

Legionella, the bacteria, which causes the disease, is commonly found in surface water such as ponds and rivers. Only some species of the bacteria, such as Legionella Pneumophila, can become harmful to humans. It is likely to exist in low concentration in most water systems. In such concentrations the bacteria is harmless. It requires an improbable and avoidable chain of events to cause people to be infected with Legionella bacteria.

*Chain of Events*

An outbreak of Legionnaires' Disease associated with evaporative cooling equipment requires a 'Chain of Events' with ALL EVENTS in the chain LINKED together and occurring in sequence.




To effectively prevent the risk of Legionnaires' Disease, it is necessary to influence this chain of events at any link. There are three chain links, which can be influenced by good design and correct operation of the cooling system:

- prevent conditions that encourage multiplication of bacteria
- minimise drift or aerosol effect in the discharge air stream
- reduce changes of inhalation by people through equipment location and/or personal protection

The measures mentioned above are not equally effective in terms of prevention. By far the most important measure is to prevent uncontrolled conditions that allow the bacteria to multiply.

*Conditions that enhance multiplication and distribution of Legionella*

If a virulent strain of Legionella enters the cooling system, a number of factors dictate whether multiplication can occur. To become harmful Legionella bacteria, particularly the species which affect humans, must proliferate in an uncontrolled manner in the recirculating water. Typically concentrations of total aerobic bacteria up to 10.000 cfu/ml mean the system is under control but concentrations of more than 100.000 cfu/ml require immediate corrective actions to reduce the bacterial level. If the concentration of the Legionella species is measured separately, it must not be higher than 1000 cfu/l. If this concentration is exceeded, corrective action must be taken.

Testing of Legionella should be done according to recognised standards. The following conditions can lead to high concentrations of Legionella:

- **Temperature:** Below 20°C the bacteria do not multiply (but will still survive). The maximum growth rate is at a temperature of 37°C. This is the temperature range typically found in evaporative cooling applications.
- **Nutrients:** For growth to occur nutrients for Legionella multiplication must exist in the cooling system. Typical nutrients are sediments, sludge, corrosion debris and materials, such as untreated wood and natural rubber, which support microbiological growth. Algae, slimes and fungi also provide nutrients for Legionella multiplication.
- **Havens:** Biofilms, slimes and scale can provide a haven for the growth of Legionella. Regular inspection and, if required, cleaning and disinfection are needed to minimise these within the cooling system.
- **Aerosols:** Evaporative cooling by its design involves close contact between water and air and droplets of water become entrained in the airstream. However not all of the water entrained in the air is potentially harmful. Plume from, for example, cooling towers and evaporative condensers is often mistakenly considered as environmental pollution. Plume occurs when warm air discharging from the cooling tower condenses upon contact with colder ambient air. However this is pure water vapour and does not contain bacteria.

On the other hand water droplets that are entrained in the air stream and carried outside the equipment as drift loss or splash out could be harmful if they are contaminated with Legionella bacteria. Measures must be taken to minimise the amount of droplets that can escape from evaporative cooling equipment.

Whilst the efficient reduction of drift loss and splash out may help to reduce risk, it cannot be viewed as a "stand alone" preventive measure.

Evaporative cooling equipment is only a part of a cooling system and to control the risk of Legionnaires' Disease requires therefore a look at the total cooling system in as far as it is directly connected to the water fed to the evaporative heat exchanger. System safety is not only a matter of correct selection and installation of components for the heat rejection, but also involves water and biocide treatment, a proper assessment of risks, as well as a plan, which describes the operation of the cooling system in function of the process to be cooled. Finally the evaporative cooling equipment itself should meet certain design requirements, in which case the operation risk is further reduced.

## 5. System Safety

*Design Requirements*
Product Design Recommendations, Access for Inspection, Maintenance and Cleaning

*Inspection and Maintenance:*
It is important that access is provided to the areas listed below, requiring regular inspections and maintenance:

- drift eliminators (if applicable)
- water distribution systems
- bearings and drives
- air inlet louvers
- electrical equipment
- cold water basins (if applicable)
- strainers, valves (if applicable)
- controls requiring settings and/or regular adjustments
- heat transfer section

For this purpose the equipment shall have an appropriate amount of adequately sized access doors or hatches. If the interior of the equipment is large enough to be entered by people sufficient access doors or hatches are required. Where the use of access doors or hatches is not possible access can be provided by the removal of certain parts of the enclosure of for example eliminators.

If the equipment is supplied with accessories, such as air intake or discharge ducts or sound attenuators these components must be equipped with adequate access in order to avoid any obstruction to the access to the maintenance and inspection points listed above. For larger equipment and depending on the location of the interior maintenance and inspection points, interior walkways and/or ladders should be provided. Depending upon site conditions it also may be necessary to install ladders, safety cages, stairways, access platforms, handrails and toebords for the safety and convenience of the authorised service and maintenance personnel. The need for such external access provisions is usually determined by the installer of the equipment.

*Access for cleaning*
The design of most evaporative cooling products usually does not permit mechanical cleaning of the entire interior, but mechanical cleaning of the cold water basin (if applicable), where the largest amount of sludge and dirt accumulates should be possible. Unless the access provisions for inspections and maintenance already provide sufficient access to the cold water basin, additional access provisions must be made to allow access to the cold water basin. This can be achieved by removable access doors or hatches or removable air inlet louvers depending on the product design. The cold water basin design should be so that it permits easy flushing to one or more central points and for this purpose it is recommended to apply a sloping basin bottom design where possible. Components installed in the basin, such as strainers or strainer hoods should be accessible or removable so that proper mechanical cleaning is possible. Large basins should be equipped with interior ladders to facilitate access by maintenance and service personnel. In addition to the cold water basin, mechanical cleaning of the water distribution system should be possible. For this reason nozzles should preferably be of the removable type. Areas of the equipment, which are not accessible for mechanical cleaning should at least be designed such that flushing, chemical cleaning and disinfection are possible.

## Design of cooling towers without water stagnation

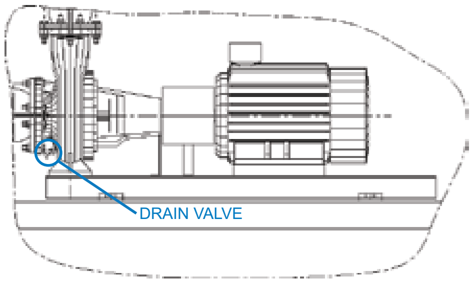
*Tower Casing*

The tower casing should avoid water stagnation. For this reason basins and walls should not have a slope on the opposite direction of the water flow direction. Basins shall have a drain connection or hole to allow proper drainage.

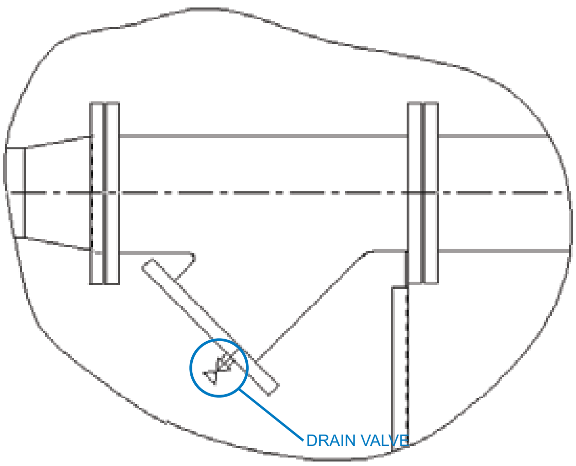
*The pipes connected to the cooling tower*

The piping should preferably have no point below the basin, but must be self-drainable or drainable.

Example pump:



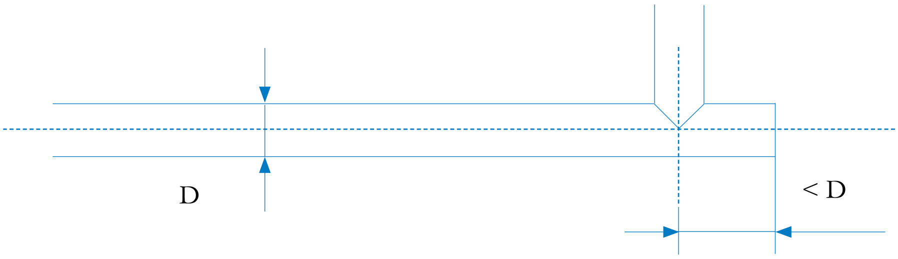

Example Y filter:




Example of a connection at right angle of the tube end.
The length of the main piping should be as short as possible after the connection to avoid a dead end pipe.

## Water Distribution Systems

Water distribution systems should be designed in a way, that they can drain, when the water supply is stopped.




*Equalising Lines*
For multiple cell installations, which do not have a common cold water basin, equalising lines may be required between the cold water basins of the individual cells. Equalising lines must be equipped with sufficient shut off valves so that the individual basins can be isolated. Furthermore the equalising lines should have a drain and whenever possible the blow down of the installation should be installed in the equalising line to ensure a regular water flow through the piping. Equalising lines for multiple cell closed circuit wet cooling tower installations are not recommended and normally not needed either for this type of products.

*Materials of Construction*
Materials used for the construction of evaporative cooling equipment should not be supporting microbiological growth (such as untreated wood or natural rubber). Internal surfaces should facilitate cleaning.
Materials of construction should have a good resistance against corrosion, such as galvanised steel, coated galvanized steel, stainless steel or organic materials such as FRP.

*Shielding from Sunlight and other External Influences*
Exposure to sunlight enhances the development of many bacteria, in particular algae. The development of algae, which can be a nutrient for Legionella, should be avoided in evaporative cooling equipment. The casing must be as impervious as possible to sun rays. The water basin should be shielded as much as possible from the exposure of direct sunlight, for example by the use of louvers. Such methods will also reduce the effect of wind gushes and reduce splash out from the basin, especially when the fan(s) does not operate. Entry of birds, vermin, leaves, debris, contaminants or other nutrients must be avoided, as much as possible.

## Drift losses

In all evaporative cooling systems spray water is in contact with an air stream. Water distribution systems, using high-pressure nozzles to create droplets, are suspect for droplet spectra which contain very small droplets that may be entrained directly to the air and may also pass even sophisticated droplet separators.

Hence droplet spectra which place emphasis to bigger diameters are preferred. This should be achieved by use of low-pressure nozzles or gravity driven water distributions.

There are also trickle film systems available which produce directly a water film out of the distribution header. The entrainment of water droplets occurs not only in the region where the water is distributed; it is also a possible effect from the surface of the falling water film on the heat exchanger surface. The exhaust air may contain also droplets which are created by recondensation on small nuclei in the air and water droplets which are condensed on structure parts of the cooling tower, which are downstream of the droplet separator., e.g. fan support beams. Drift loss should be determined downstream of the droplet separator.

Since the chemical content of drifted droplets is the same as that of the circulating water, long term exposure of nearby structures or surroundings to the droplets can have a degenerative or aggravating effect. In particular in areas of limited rainfall. To minimize drift, eliminators, based on several techniques and application methods are operated in such “open” systems.

*Drift eliminators*
The function of the drift eliminator is to catch the droplets which are being carried away in the leaving air stream. Working method and aerodynamic design will have important effects on this function. By creating multiple changes in the direction of the exhaust airflow, centrifugal forces are exerted to the droplets which are carried by the air. Through inertial impaction and direct interception, entrained droplets are stripped from the leaving air stream with a minimum pressure drop.

*Corrugated blade*
Blades cut out of corrugated sheet material are connected by spacers to panels which are arranged above the water distribution means; or in crossflow cooling towers in the entrance of the plenum chamber in front of the fan. The corrugated profile admitted a higher air velocity at an acceptable pressure drop. Different dimensions for the spacer make it possible to vary the space between the blades for various air velocities. The composed "panels" can have handy dimensions and the shape of the profile makes a non-interrupted join between the panels possible. Materials used for these devices are generally fibre cement plates or plastic or FRP.

*Special shaped profiles*
The modern drift eliminator modules are specially designed utilizing a series of sinusoidal-shaped blades. In this generation of drift eliminator modules too, the space between the shaped blades is varied for various air velocity designs. Furtheron additional restrictions on each blade are possible to maximize capture entrained water droplets. The efficiency is relatively high in comparison with the pressure drop. Materials used to these panels are mostly plastics like PVC and PP.
The self-supporting profiles are produced by extruding and combined by spacers or thermo formed film-modules with integrated spacers, glued or welded to handy panels.

*Modular Drift eliminator*
This category of drift eliminators is comparable with the shaped profile drift eliminator however figurate in length and width direction. In this way the surface of the drift eliminator is divided into many air passage canals. The walls of these canals can have the sinusoidal shape or a kind of serpentine arrangement, sometimes combined with other obstructions to increase the separating efficiency.
The efficiency is very high related to an acceptable pressure drop. Materials used to the modular drift eliminators are thermo plastics like PVC and PP, thermo formed or injection moulded, glued or welded to handy panels.

*Conclusions*
For evaporative cooling equipment requiring drift eliminators, it is important to install drift eliminators with high efficiency. Eliminators should cover the full area of the air movement. The velocity of the air moved through the eliminator must not exceed the maximum velocity suitable for a particular design. Exceeding the maximum velocity will result in the air sheering the droplets out of the eliminator. Typical air velocities range from 3,5 to 6,0 m/s. The eliminators should be accessible for regular inspections and readily removable for cleaning or replacement. Drift eliminators must be installed so that the collected water droplets can drain back into the cooling tower. With modern drift eliminators and a good cooling tower design the opportunity to minimize the phenomenon described as drift.

The selection of the appropriate drift eliminator in combination with the proper installation makes it possible to achieve drift losses less than 0,01 % of the circulating waterflow.

## Splash Out

Under certain weather and operating conditions it is possible that water splashes out of a cooling tower. Splash droplets usually are thick and hence fall out in the vicinity of the equipment. These droplets cannot easily be inhaled due to their size and the locations where they generally fall out and hence are of lower concern, when evaluating the risk of Legionella proliferation. Nevertheless splash out should be avoided, when and where possible. Depending on the design of the product, louvers, inlet air eliminators or windwalls can be used for that purpose.
Where and when possible also the operation with "water pump on and fan motor(s) off", should be avoided as in this operation mode, typically splash out is more eminent.

*Accessory Design Recommendations*
Accessories installed in the discharge air of evaporative cooling equipment may be exposed to drift and because of this reason they must be designed in a way that they can be inspected and, if necessary be cleaned and disinfected. Typical discharge accessories are:

- sound attenuators
- plume abatement coils
- dampers or a combination thereof
- fan screens or other

These discharge accessories must be designed in a way that they do not obstruct the access to the interior of the equipment itself. Furthermore access provisions must be made to allow inspections and (where necessary) maintenance and (when necessary) cleaning and disinfection. Baffles should preferably be equipped with external protection, such as perforated steel plates which also increase mechanical stability during handling and reduce the exposure to sunlight radiation. The preferred design approach is however to allow cleaning and disinfecting "in situ", without the need to remove certain components. Supporting L or U flanges should be arranged so that water cannot accumulate on them. If U channels must be installed with the U flanges showing upwards, the channels must have drain holes.

## System Design Recommendations

*General Requirements*

It is recommended to draw up a risk analysis for the cooling system in order to assess the consequences that may arise from contamination with Legionella and how to avoid the risk. The risk analysis must address the location of the cooling tower in relation to the susceptibility of the surrounding, i.e. industrial estate with restricted access, unrestricted area with low population, residential area, sensitive area (for example hospital) etc. Also the prevailing wind direction and the distance to the "critical neighbours" must be accounted for. In general, cooling towers should be located as far as possible from open windows or air intakes to buildings.

For the cooling system also an operating plan should be developed. This plan should include a description of all system components, their technical specifications and operating limits, as well as a description of their functionality within the cooling system and the anticipated control philosophy. Both risk assessment and operating plan should be available before system start up, preferably in the system design stage.

It is imperative that a cooling system has a suitable biocide treatment with automatic or continuous operation. The biocide treatment must be set up before system start up, initiated with start up and maintained continuously thereafter.

A water treatment programme specifically designed to address scale and corrosion of the recirculating water must be implemented when the cooling system is first operated and continuously maintained thereafter.

A user logbook, in which all relevant maintenance and repair actions, test results and events are noted should be available at the time of system start up. The logbook should also contain a list of system components and their source, the maintenance procedures recommended by the supplier as well as the operating limits of these components. It is also recommended that the logbook contains a list of people, who are authorised to access the site and conduct maintenance and/or repair work and, when applicable, a list of subcontractors with authorised access.

**Table 1: System Requirements**

| Type of Requirement | Time of Activity |
|---|---|
| Cooling system risk analysis to assess the risk of Legionnaires' Disease. | Before system start-up |
| Operating plan including water treatment and maintenance to avoid the risk. | Before system start-up |
| Installation of suitable biocide treatment with automatic or continuous operation. | Before system start-up and maintained continuously thereafter |
| Installation of a water treatment system to control scale and corrosion as necessary depending on the supply water quality. | Before system start-up and maintaned continuously thereafter |
| A logbook to record service and maintenance activities. | Before system start-up and updated regularly (weekly or monthly) |
| System cleaning and disinfection. | Before start up, annually or after a shut down period longer than one month or at the earliest possible shut down, when it is not possible to stop the installation easily |

*Specific System Requirements*

The evaporative cooling product should be installed in a way that access is maintained to the access doors provided with the equipment and other critical maintenance and inspection points, such as water distribution system and drift eliminators.

Connected pipework should be designed without dead legs and areas where stagnant layers of water may occur. The pipework should be foreseen with sufficient drain connections to allow proper drainage. In general the extend of external pipework should be limited as much as possible. The lesser the extend of the pipework, the easier it is to keep it clean.

Heat exchangers integrated in the cooling system should be accessible for inspections and cleaning. If heat exchangers cannot be dismantled provisions must be made to allow chemical cleaning and disinfection. It must also be possible to properly drain the heat exchangers, where needed special drain connections must be foreseen.

All materials of construction must be compatible with each other to avoid galvanic corrosion. The corrosion resistance of the materials used must be in line with the anticipated quality of the water.

## Operational Recommendations

The responsible operator must assure at all times, that the equipment is operated within the range of conditions provided by the equipment manufacturer.

*Mechanical Maintenance*
A specific maintenance programme needs to be established and then monitored to ensure that the required actions are taken. This means that maintenance tasks are properly scheduled, carried out and records kept. The procedures outlined below will help to establish this programme for the cooling equipment.

**Table 2: Typical Mechanical Maintenance Schedule**

| Description of service | Start-Up | Monthly | Every six months | Shut-down | Annually |
|---|---|---|---|---|---|
| Inspect general conditon of the system | X | | | X | X |
| Inspect heat transfer section(s) for fouling and scaling | X | | X | | |
| Inspect water distribution | X | | X | | |
| Inspect drift eliminators for cleanliness and proper installation (if applicable) | X | | X | | |
| Inspect basin (if applicable) | X | | X | | |
| Check and adjust basin water level and make-up (if applicable) | X | | X | | |
| Check water treatment | X | X | | | |
| Check proper functioning of blow-down (if applicable) | X | X | | | |
| Check operation of basin heaters (if applicable) | X | | X | | |
| Clean basin and basin strainer (if applicable) | X | | X | | |
| Drain basin (if applicable) and piping | X | | | X | |

Refer to manufacturer's instructions for detailed description of maintenance procedures.
*Note : Initial start-up and after seasonal shut-down period.*

## Maintenance Procedures

*Inspect general condition of the system*
The inspection should focus on the following areas:

- Damage to protective finishes (if applicable)
- Signs of corrosion
- Evidence of scaling
- Accumulation of dirt and debris
- Presence of biofilms

Listed below are the actions to be taken if any of the above are found during inspection:

**Table 3: Actions to be taken after inspection**

| | |
|---|---|
| **Damage to protective finishes:**<br>**- small damage**<br>**(scratches, pin holes, small blisters)**<br>**- large areas of damage** | Repair, following instructions of the manufacturer.<br>Consult manufacturer for repair recommendations. Check the water treatment programme and records. Make analysis of recirculating water quality and compare against recommended control guidelines. |
| **Signs of corrosion** | The same procedure as above. |
| **Evidence of scale** | Hardness of recirculating water is too high.<br>This could be the result of:<br>- inadequate blow-down<br>- malfunction of softener or water treatment<br>In case of local or soft scale formation, try mechanical removal.<br>If there is significant scale formation throughout the equipment, chemical cleaning is needed.<br>Contact the manufacturer or competent water treatment company for recommendations. |

| | |
|---|---|
| **Accumulation of dirt and debris** | Clean out dirt and debris. If necessary system should be drained and filled with fresh water. At start up apply biocide shock treatment. |
| **Presence of biofilms** | If there is evidence of biofilms, the system, including piping should be drained, flushed and cleaned of slimes, algae and other organic contamination.<br>Refill with clean water and apply intitial biocide shock treatment. Check pH value and ongoing biocide treatment. |

*Inspect heat transfer section(s) for fouling and scaling*
Minor fouling can usually be removed chemically or by temporary changes to the water treatment programme. Contact a water treatment supplier for advice. Major fouling and scaling requires cleaning and flushing or even the replacement, thereafter replenishment with fresh water and a review of the effectiveness of the water treatment. In severe cases, it may be necessary to remove the heat exchanger.

*Inspect water distribution*
The water distribution system should be free of dirt and debris. All nozzles, troughs etc. need to be in place and clean. In case of contamination, clean the water distribution system as per the manufacturer's instructions. Replace damaged or missing nozzles, as well as any nozzles which cannot be cleaned.

*Inspect drift eliminators (if applicable)*
Drift eliminators must be inspected from both sides unless they are integrated in the fill pack, in which case only one side can be inspected. Drift eliminators must be clear of debris and any foreign matter. Remove any dirt or obstructions. Damaged or inefficient eliminators must be replaced with qualified ones. Eliminators should fit tightly with no gaps.

*Inspect basin (if applicable)*
The cleanliness of the basin is a good guide to the overall condition of the cooling system. In the case of larger basins (usually concrete) regular cleaning and flushing may not be practical. If not already done take water samples and check the aerobic bacteria count. If this is above the recommended level, apply biocide shock treatment or temporarily adjust biocide treatment until required values are maintained.

*Check and adjust basin water level and make-up (if applicable)*
Set basin water level in accordance with the manufacturer's recommendation. Check functional operation of the make-up system and adjust settings as per the manufacturer's requirements. Replace any worn or damaged components in the water level control and make-up assemblies.

*Check chemical feed equipment*
Check that the chemical feed equipment has power and that it is functioning normally. It is recommended that a more detailed check be carried out on a regular basis by the water treatment service provider.

*Check proper functioning of blow-down*
In the case of continuous blow-down with a metering valve in the bleed line, ensure that the valve is unobstructed and that blow-down water can drain freely. Measure the blow-down flow rate by recording the time needed to fill a given volume. For automatic blow-down using conductivity control, ensure that the conductivity probe is clean and that the blow-down solenoid valve is operational. Unless there is a specific set point adjustment procedure, the water treatment company should check and adjust set points.

*Check operation of basin heaters (if applicable)*
Basin heaters must only operate in the winter to prevent the basin water from freezing. Under no circumstances should basin heaters operate at other times as they could potentially heat the water to temperature levels, which are favourable for bacteriological growth. Ensure the heater thermostat is properly set and clean. Also ensure that heater control and safety devices, such as low-level cut-out switches, are operational and properly incorporated into the control circuit.

*Clean basin strainer (if applicable)*
Remove the strainer from the basin. Clean mechanically or with a high pressure hose. Replace if damaged or corroded. Re-install as per the manufacturer's instructions.

*Drain basin (if applicable) and piping*
During a prolonged shutdown it is recommended to drain the basin and the associated piping. Ensure the drain remains open, so rain water or melting snow can drain from the basin. Also ensure that all piping exposed to freezing conditions is drained; if not this piping has to be insulated and heat-traced. Piping that will not be drained should be valved off to avoid contact with the atmosphere. Shut off the make-up water supply.

## Qualification of Personnel

The operation, maintenance and repair of equipment incorporated into the evaporative cooling loop and including water treatment components and controls should be undertaken only by personnel authorised and qualified to do so. All such personnel should be thoroughly familiar with the equipment, the associated systems and controls and the operating and maintenance instructions submitted by the component suppliers as well as the operating plan for the system. Proper care, procedures and tools must be used in handling, operating and repairing the above mentioned equipment to prevent personal injury and/or property damage. It is recommended to keep a list of authorised personnel in the system logbook.

*Skill required*
The minimum qualification of people to use and maintain cooling towers is as follows:

- Capable to read drawings and tower manufacturer's instructions for use and maintenance
- To be instructed about:
  - the health and safety regulation into force on site and in the country
  - the risk analysis into force on the site
  - Legionella Disease (protection, prevention, symptoms)
  - Cooling tower function and driving (make-up, blow-down, energy contamination, etc., what is possible to be done and what is strictly forbidden by manufacturer)
  - notion of water treatments and of water treatment diagnosis
  - what it is to survey: drift eliminators, fouling, scaling,...
  - cleaning and disinfection operation and programs
  - maintenance of electrical and mechanical equipment

## Water Quality

The table below indicates typical recommended control parameters and their required values to control biological growth and scale formation. Maximum values for rates of corrosion should be stipulated by the system designer and verified by the water treatment specialist.

Water Quality Parameters
- pH, Hardness
- TAB
- Legionella

**Table 4: Water Quality**

| Type of Parameter | Recommended Face Value |
|---|---|
| Total aerobic bacteria (TAB) | Not exceeding 10.000 cfu/ml |
| Legionella | Not exceeding 1000 cfu/litre |
| pH Value | Between 7 and 9 |
| Hardness of recirculating water | < 36 °F<br>< 20 °D<br>< 360 mg/l as $CaCO_3$ |
| Other parameters, such as chlorides, sulphates and conductivity | As per system specification or water treatment specialist recommendations |

*Recommended Monitoring Schedule*
The quality of the water may vary during operation. Diagnose of a problem based on a single water analysis is usually not possible. For this reason it is important that water samples are regularly taken and that the analysis of these water samples is kept on record.

A well functioning water treatment system reduces the need for cleaning and disinfection significantly. Monitoring the microbiological concentration below the face values vastly helps to prevent biological contamination. The following table summarises the recommended monitoring scheme.

**Table 5: Typical Water Quality Monitoring Schedule**

| Control Activity | Time of Execution |
|---|---|
| Check operation of water treatment system | Initial start-up and after seasonal shutdown period. Thereafter monthly. |
| Check stock of chemicals | Initial start-up and after seasonal shutdown period. Thereafter weekly. |
| Monitor TAB concentration | Weekly |
| Monitor re-circulating water quality against Control Parameters | Monthly |
| Visual inspection for algae, biofilm formation | Every 6 months |
| Check LS concentration | If TAB remains high (see Table 6) after corrective action or if LS contamination is suspected. |

*Water Quality Control Procedures:*

- *Check operation of water treatment system*
  It is imperative that proper water treatment is in operation at start-up and continuously operated and maintained thereafter.

- *Check stocks of chemicals*
  It is important not to run out of chemicals and arrangements should be made to replenish stocks of chemicals well before they are exhausted.

- *Monitor Total Aerobic Bacteria (TAB) concentration*
  There are various methods to determine the total aerobic bacteria concentration. The use of dip slides is a recommended practice. For evaporative cooling equipment the following control levels should be observed.

**Table 6: TAB Concentration Corrective Action Levels**

| TAB concentration in cfu/ml | Recommended Action |
|---|---|
| Below 10.000 | No action required. |
| Between 10.000 and 100.000 | Repeat test and if high TAB concentration is confirmed increase biocide treatment. If high TAB persists carry out LS test. If LS concentration at 100 cfu/l or above is confirmed, clean and disinfect the system. Repeat test every two weeks until LS concentration remains below 100 cfu/l |
| Above 100.000 | Immediate cleaning and disinfection is required. |

## Monitor Recirculating Water Quality against Control Parameters

*Check make-up water quality*
Take a sample of the make-up water to the cooling tower. Mark sample and record the date. Usually 1 litre of sample water is sufficient. The analysis must be made within a few days after the sample has been taken.

As a minimum the following parameters need to be checked:

- pH
- total hardness
- alkalinity
- chlorides
- sulphates
- conductivity

Compare the analysis with previous records or, in the case of a first sample at start-up, with the water data used to choose the water treatment system. If results deviate from design data or previous data, it is recommended to analyse three more samples taken in successive weeks. Based on the results, find the cause of varying make-up water quality with the assistance of a water treatment specialist and adjust the water treatment programme accordingly.

*Note : Where the make-up water quality is variable, it is recommended to install a conductivity controlled blow-down system. In addition more care needs to be taken in monitoring the chemical water treatment. Consult a competent water treatment company for advice.*

*Check circulating water quality against guidelines*
Follow the same procedure as the make-up water except for the location of sample taking. Usually the basin is the best place to take circulating water samples. Make sure the sample is not taken in an area influenced by any make-up water or chemical dosage. Do not take samples shortly after cleaning and/or refilling operations – allow minimum 3 days of operation under significant load before a sample is taken. Other locations such as the blow-down line can also be considered for sample taking.

In the case of installations with filtration do not use backflush water from the filter for sample taking. Compare the results with the water quality control parameters for the system. If any of the given limits are exceeded significantly, immediate action is required. In many cases an increase of the blow-down will provide a satisfactory solution. It is however recommended to consult a reputable water treatment specialist. Where the limits are slightly exceeded, compare results with previous records and look for trends. If these show increased or persistent deviations, adjustments to the water treatment programme may be needed. It is recommended to temporarily increase the sample taking to one sample per week for three weeks. If these samples are within limits, no action is required. If not adjustment to the water treatment programme is needed.

*Visual inspection for algae, biofilm formation*
If the recommended maximum levels for TAB concentration are not exceeded and corrective action (if required) is taken in good time, it is unlikely that biofilms will develop within the system. Nevertheless it is recommended to visually inspect the system for biofilm every six months. Since a visual inspection of ALL system internals is generally not possible, it is sufficient to inspect the "critical" areas, i.e. these areas where biofilms are likely to develop first. The top and bottom of the fill pack, drift eliminators and basins, as well as areas where the water may be stagnant during shutdown, are the most "critical" areas. If biofilm formation is noted, it is necessary to clean and disinfect the system (see below). It is also recommended to conduct a functional check of the biocide treatment, as the formation of biofilm may be a result of system malfunction.

*Check LS concentration*
Unless specified by local regulations, it is not normally necessary to test for Legionella concentration in the recirculating water. If however contamination with Legionella is suspected, a test should be carried out by an accredited laboratory. Depending on the results of the Legionella test, the actions listed in Table 7 will apply.

**Table 7: Legionella Concentration and Corrective Measures**

| Legionella Concentration in cfu/l | Corrective action |
|---|---|
| Less than 100 | No action required. |
| Between 100 and 1000 | Adjust biocide treatment. |
| Between 1000 and 10.000 | Corrective action. |
| Larger than 10.000 | Immediate disinfection, cleaning if necessary. |

## System Cleaning and Disinfection

*Cleaning*
It is important that the cooling system is cleaned prior to initial start-up or before being put back into service after a prolonged shutdown.

It is also recommended that the cooling system is drained and cleaned annually. In heavily industrialised areas or if the recirculating water is contaminated this may be needed more often. Where high aerobic bacteria count is suspected or is a re-occurring problem the system should be disinfected as described below PRIOR to the cleaning operation.

Once the system is drained an inspection of all the internal surfaces will indicate the extent of physical cleaning needed. All silt, sludge and debris should be removed from the basin. Where the fill pack is heavily fouled or contaminated it should also be cleaned or replaced. The water distribution system and drift eliminators should be thoroughly cleaned and inspected for damage or missing parts. Sound attenuators or other accessories that show signs of contamination will also require cleaning. After cleaning, the system should be flushed thoroughly and re-filled with fresh water. Before putting the equipment back into service the appropriate start-up level of treatment chemicals, especially biocidal treatment, must be added.

*Disinfection*
Disinfection must be carried out in accordance with a proper procedure and also take into account the safety of the cleaning and disinfection staff.

Typically disinfection is achieved using sodium hypochlorite solution to maintain a residual value of 5 – 15 mg/l of the free chlorine.

It is necessary to consult specialised personnel and possibly the suppliers of the system components. Chlorinated water should be de-chlorinated before draining and after disinfection the system must be thoroughly flushed through with clean water.

*Monitoring and Record Keeping*
In order to be able to monitor the efficient and safe operation of the cooling system all maintenance and water quality monitoring actions should be recorded in a cooling system logbook.
If a specialist maintenance contractor or water treatment company is servicing the cooling system, copies of their visit reports and service actions should also be reviewed carefully and filed in the logbook.

As a minimum the following records should be kept:

- Commissioning and initial start-up reports
- Monthly, six monthly and annual mechanical maintenance actions
- Seasonal shutdown and start-up actions
- Monthly and annual water quality monitoring actions
- Monthly water treatment service reports
- Weekly TAB test results
- Cleaning and disinfection actions
- Cooling system problems and corrective actions taken

## 6. Personal Safety

The health and safety of both employees and other people not connected with the work activity but who are in the vicinity of the installation, must be protected. Please ensure that personnel working on the cooling water system have taken the following precautions:

- Fans, pumps, heaters etc. are electrically isolated before commencing any inspection or maintenance work.
- Normal protective clothing is adequate for all internal inspection and cleaning operations. However, note requirement for half face respirator masks when working on equipment that may be contaminated.

*Personal Protection*

Maintenance or cleaning personnel working on equipment that may be contaminated should wear half face respirator masks of P3 or equivalent type or better.

This precaution is needed:

- if stagnant or contaminated water has not been drained off
- if adjacent cells are still operating
- when cleaning with a high pressure jet
- if a high LS concentration has been measured

## ANNEXE 1: TYPICAL CONTENTS OF COOLING SYSTEM LOGBOOK

Section 1 : Owner Information

- Name and address of plant owner.
- Responsible plant manager/engineer
- System operator(s)
- Person(s) in charge of maintenance

Section 2 : System Components

- Supplier/type of cooling tower or evaporative condenser, serial number, cooling system reference number
- Supplier/type of biocide treatment, description and reference numbers of components/chemicals
- Supplier/type of water treatment, description and reference numbers of components/chemicals
- Supplier/type of auxiliary equipment [pump(s), heat exchanger(s), filter(s), other] and serial numbers of components
- Suppliers' technical data sheets and/or catalogues.
- Operating limits (temperatures / pressure / water quality etc.)

Section 3 : Subcontractors / Service Providers

- Full address and contact details of subcontractors/service providers and names of people admitted to site.

Section 4 : Risk Analysis

- Cooling system risk analysis, if available.

Section 5 : Operating and Maintenance Plan

- Operating plan (description of cooling system and water treatment, control sequence, shut-down periods etc.)
- Mechanical maintenance schedule (see Attachment A)
- Suppliers' operating and maintenance literature.

Section 6 : Data Logging and Record Keeping

- TAB testing and results (see Attachment B)
- Water quality monitoring and results (see Attachment C)
- Event record keeping (see Attachment D)

Section 7 : Safety

- Location of cooling tower(s) (if not already in risk analysis)
- Personal safety instructions for mechanical maintenance.
- Personal safety instructions for water treatment system.
- Safety data sheets for all chemicals.
- Personal safety instructions for auxiliary components.

Section 8 : Reports

- Insert all relevant reports (commissioning reports, certificates, training records etc.).

# ATTACHMENT A: TYPICAL RECOMMENDED MAINTENANCE SCHEDULE FOR COOLING TOWERS AND EVAPORATIVE CONDENSERS

| Description of service | Start-up or after Shut-down | Weekly | Monthly | Every six months | Annually |
|---|---|---|---|---|---|
| **Inspect general condition of unit** | | | | | |
| *Check debris from unit* | | | | | |
| *Inspect basin - clean and flush if required* | | | | | |
| *Clean basin strainer* | | | | | |
| *Check and adjust basin water level and make-up* | | | | | |
| *Inspect heat transfer section(s) for fouling* | | | | | |
| *Inspect water distribution* | | | | | |
| *Check drift eliminators* | | | | | |
| *Check water quality against guidelines* | | | | | |
| *Check chemical feed equipment* | | | | | |
| *Check and adjust bleed rate* | | | | | |
| *Check pan heaters and accessories* | | | | | |
| *Drain basin and piping* | | | | | |
| Inspect protective finishes | | | | | |
| Check fans for rotation without obstruction | | | | | |
| Check fan and pump motors for proper rotation | | | | | |
| Check unit for unusual noise/vibration | | | | | |
| Check motor(s) voltage and current | | | | | |
| Lubricate fan shaft bearings | | | | | |
| Check and service fan drive system | | | | | |

## ATTACHMENT B : TAB TESTING AND RESULTS

| Week | Date sample taken | TAB Concentration cfu/ml | Remarks | Signature of tester |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
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# ATTACHMENT C : TYPICAL WATER QUALITY MONITORING CHECKS

## A. Make-up Water

| Parameter | Control value | Jan. | Feb. | March | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | | | | | | | | | | | | | |
| Total hardness | | | | | | | | | | | | | |
| Alkalinity | | | | | | | | | | | | | |
| Chlorides | | | | | | | | | | | | | |
| Sulphates | | | | | | | | | | | | | |
| Conductivity | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Remarks | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Signature | | | | | | | | | | | | | |

## B. Recirculating Water

| Parameter | Control value | Jan. | Feb. | March | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | | | | | | | | | | | | | |
| Total hardness | | | | | | | | | | | | | |
| Alkalinity | | | | | | | | | | | | | |
| Chlorides | | | | | | | | | | | | | |
| Sulphates | | | | | | | | | | | | | |
| Conductivity | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Remarks | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| Signature | | | | | | | | | | | | | |

## ATTACHMENT D : EVENT RECORD KEEPING

| Type of event:<br>- Inspection<br>- Maintenance<br>- Cleaning<br>- Disinfection | Date of event | Remarks | Signature |
|---|---|---|---|
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# Formulas and Symbols

21

## 1. Fan Laws

The fan laws can be used to approximately predict the performance of equipment with a different fan speed:

Flow 2 = Flow 1 (kW2/kW1)1/3

## 2. Formulas

**Range** = Entering Temperature – Leaving Temperature

**Approach** = Leaving Temperature – Wet Bulb Temperature

**Heat Rejected:**

Heat Rejection (kW) = Flow (l/s) x range (°C) x 4,186

**Temperature conversions:**

Fahrenheit to Celsius : Temp (°C) = 0,55565 temp (°F) – 32

Celsius to Fahrenheit : Temp (°F) = 1,8 Temp (°C) + 32

**Basic Electrical:**

**E = I x R**

E = Voltage (Volts)
I = current (amps)
R = resistance (Ohm)

## 3. Symbols

**cfu/l:** Unit of Legionella count: colonies formed unit per litre of water.

**cfu/ml:** Unit of bacterial count: colonies formed unit per millilitre of water.

**l/s:** Measure of liquid flow rate (litres per second).

**LS:** Legionella species.

**$m^3$/s (Cubic meter per Second)**: A standard measurement of airflow that indicates how many cubic meter of air pass by a stationary point in one second.

**TAB = Total Aerobic Bacteria:** Concentration of aerobic bacteria in water, usually expressed as cfu/ml

# Glossary 22

**Adiabatic Coolers:** Equipment used to transfer heat from a process to the atmosphere by lowering the temperature of the entering air by humidification, with constant enthalpy.
**Aerosol:** Fine water droplets entrained in an air stream.
**Air-Conditioning:** The control of the temperature, humidity, cleanliness (quality) and movement of air in a confined space.
**Airflow:** The distribution or movement of air through a space; generally measured in cubic feet per minute (cfm).
**Air Handling Unit:** The central component of an HVAC system that distributes conditioned air to a variety of destinations.
**Air Inlet Louvers:** Devices installed at the air inlet to minimize splash-out and exposure of the basin water and heat transfer media to sunlight.
**Algae:** Small, usually aquatic plants which require light to grow.
**Ambient:** The surrounding atmosphere.
**Ambient Air Temperature:** The surrounding air temperature, such as the outdoor air temperature around a building.
**Approach:** The difference between the leaving water temperature and the ambient wet-bulb temperature.
**ARI**: Air-Conditioning and Refrigeration Institute.
**ASHRAE:** American Society of Heating, Refrigeration and Air Conditioning Engineers.
**Automatic Blow-Down:** Determined as a function of heat load keeping the concentration factor between acceptable limits.
**Backflush Water:** Water used to flush a filter and thereafter removed from the system.
**Biocide:** A chemical capable of killing living micro-organisms.
**Biofilm:** Organic deposits inside the cooling system.
**Biological Contaminants:** Living organisms or agents derived from those organisms (e.g., viruses, bacteria, fungi, and mammal and bird antigens) that can be inhaled and can cause many types of health effects including allergicreactions, respiratory disorders, hypersensitivity diseases, and infectious diseases. Also referred to as "microbiologicals" or "microbials."
**Bleed:** Water deliberately removed from evaporative cooling equipment to control the concentration of dissolved solids in the system.
**Blow-Down:** Water discharged from the system to control the concentration of salts or other impurities in the circulating water.
**Bypass Connection:** An inlet connection provided in the cold water basin of a unit that allows recirculating water to bypass the heat transfer media when system pumps are running but evaporative cooling is not required.
**Capacity:** The output or producing ability of a piece of equipment. Evaporative cooling capacity is normally referred to in kW.
**Carryover:** Excessive drift.
**Casing:** The exterior panels of an evaporative cooling unit.
**Cell:** The smallest subdivision of a unit that can operate independently; often multiple cells are used together to form one "unit" of a greater capacity.

**Celsius (C):** A temperature scale based on the freezing (0 degrees) and boiling (100 degrees) points of water. Also known as Centigrade. Conversion to Fahrenheit: °F = 1.8(°C) + 32.
**Charge:** The amount of refrigerant placed in a refrigeration unit.
**Chiller:** A device that produces chilled water to provide cooling for HVAC and industrial applications.
**Circulating Water:** See "Recirculating Water."
**Closed Circuit Cooling Tower:** Equipment in which the process fluid circulates inside a heat exchanger which is cooled by water circulating in direct contact with air. The heat exchanger may be inside or close-coupled outside the cooling tower.
**Cogeneration:** Simultaneous production of two or more forms of useable energy from a single fuel source, e.g. heat energy and electrical or mechanical power, in the same facility.
**Coil:** A tube, often including fins, through which gas or liquid is passed, exchanging thermal energy with air or water surrounding it for heating or cooling purposes.
**Cold Water Basin:** The collection pan that houses the cold water processed by the evaporative cooling unit.
**Combined Flow:** The use of both a coil and wet deck surface for heat transfer in a closed circuit cooling tower or evaporative condenser. Combined flow designs reduce evaporation in the coil section.
**Combined Inlet Shields:** Air inlet filters, preventing biological growth from sunlight and eliminating splash-out.
**Comfort Cooling:** The process of treating air to control its temperature to meet the comfort requirements of the occupants of a conditioned space.
**Commercial:** The commercial sector is generally defined as non-manufacturing business establishments; this classification includes hotels, restaurants, office buildings, retail stores, educational institutions, etc.
**Commissioning:** The start-up of a building that includes testing and adjusting HVAC, electrical, plumbing, and other systems to assure proper functioning and adherence to design criteria. Commissioning also includes the instruction of operating personnel in the use of the building systems.
**Compressor:** The pump of a refrigerating mechanism that draws a low-pressure gas on the cooling side of the refrigerant cycle and compresses the gas into the high-pressure side of the cycle. The compressor maintains adequate pressure to cause refrigerant to flow in sufficient quantities to meet the cooling requirements of the system.
**Conduction:** The transfer of heat through a solid material. The transfer of heat energy through a material (solid, liquid or gas) by the motion of adjacent atoms and molecules without gross displacement of the particles.
**Constant Blow-Down:** Blow-down achieved by a fixed setting of a metering valve in the blow-down piping. The amount of blow-down is independent from the heat load (evaporation loss).
**Contactor:** A switch used to make or break an electrical circuit.
**Convection:** The movement of heat by airflow.
**Cooling Tower:** Any device in which atmospheric air and water are distributed together over a heat transfer medium in order to lower the temperature of the water through evaporative cooling.
**Corrosion Inhibitors:** Chemicals designed to prevent or slow down the waterside corrosion of metals.
**Counterflow:** The flow of air is in the opposite direction of the flow of water.
**Crossflow:** The flow of air is at a right angle to the direction of the flow of water.
**CTI:** The Cooling Technology Institute (CTI) is an organization comprised of evaporative cooling equipment owners and operators, equipment manufacturers and component suppliers, and water treatment specialists, which advocates and promotes the use of environmentally responsible Evaporative Heat Transfer Systems for the benefit of the public through education, research, standards development, government relations, and technical information exchange.
**Current:** A flow of electrons in an electrical conductor. The strength or rate of flow is generally measured in amperes.
**Cycles of Concentration:** Ratio of the concentration of elements in the circulating water compared to the concentration in the make-up water.
**Damper:** A series of movable plates that can be opened or closed to control the flow of air through a space.
**Dampers (Discharge):** Modulating airfoil blades installed at the air discharge of the evaporative cooling device with the aim to reduce air flow or heat loss at standstill conditions.
**Dead Legs:** Areas in the water piping through which the water is not circulated.
**Decibel (dB):** A decibel describes the relative loudness of a sound. The dimensionless unit of measurement used in noise control. Logarithmically expresses the ratio of sound level to a reference level (0.0002 microbar).
**Defrost Cycle:** The process of removing ice or frost buildup from a piece of equipment during the winter months.
**Delta (or Delta T or ƒT):** A difference in temperature. Often used in the context of the difference between the entering water temperature and the leaving water temperature of a cooling tower or closed circuit cooling tower.
**Demand (Utility):** The rate at which electricity or natural gas is delivered to or by a system, part of a system, or piece of equipment at a given instant or averaged over any designated period of time. Electricity demand is typically expressed in kilowatts.
**Demand Billing:** The electric capacity requirement for which a large user pays. It may be based on the customer's peak demand during the contract year, on a previous maximum or on an agreed minimum. Measured in kilowatts.
**Demand Charge:** The sum to be paid by a large electricity consumer for its peak usage level.

**Design Conditions:** A set of conditions specific to the local climate and expected building usage, used to calculate the cooling load for a building.
**Dewpoint:** The temperature at which air becomes saturated with water and begins to condense, forming a dew.
**Dissolved Solids:** Inorganic and organic matter in true solution. Usually expressed as mg/l or ppm.
**Drift:** The water aerosol carried out of an evaporative cooling unit by the discharge air.
**Drift Eliminator:** A component of most evaporative cooling units that is designed to remove water droplets from the air passing through it.
**Drift Losses:** The portion of the water flow rate lost from the device in form of droplets mechanically entrained in the discharge air stream, commonly expressed as a percentage of the circulating water flow rate. It is independent of water lost by evaporation.
**Dry-Bulb Temperature (DB):** The temperature measured by a standard thermometer. A measure of the sensible temperature of air.
**Efficiency:** The ratio of the output to the input of any system.
**Electric Resistance Heater:** A device that produces heat through electric resistance.
**Energy:** Broadly defined, energy is the capability of doing work. In the electric power industry, energy is more narrowly defined as electricity supplied over time, generally expressed in kilowatts.
**Energy Management System:** A control system designed to regulate the energy consumption of a building by controlling the operation of energy consuming systems, such as the heating, ventilation and air conditioning (HVAC), lighting and water heating systems.
**Entering Water Temperature (EWT):** The temperature of the fluid as it returns to the evaporative cooling equipment from the system heat source.
**Enthalpy:** A thermodynamic function of a system, equivalent to the sum of the internal energy of the system plus the product of its volume multiplied by the pressure exerted on it by its surroundings.
**Equalizer Connection:** A connection in the cold water basin of a unit that allows piping (the piping is called an "equalizer line") to be run from that unit to the basin of another unit; equalizer lines serve to correct any difference in water levels that may develop during operation.
**Equalizing Lines:** Connecting pipes between multiple cooling tower cells operating in parallel with the aim to establish a common operating water level in all cells. Usually required only with open cooling towers.
**Evaporation Loss:** The amount of water evaporated into the atmosphere during the heat transfer process.
**Evaporative Cooling:** Cooling accomplished through the exchange of latent heat in the form of evaporation.
**Evaporative Cooling Equipment:** Heat transfer equipment using the evaporation of water to enhance or accomplish the transfer of heat from a process to the atmosphere.
**Evaporative Cooling Installations:** Installations in which water is exposed to an air stream with the aim to enhance the cooling process either by humidification of the air only or by combination of air humidification and latent heat transfer.
**External Pulldown Volume:** The volume of water in any external piping and heat exchangers that will drain back to the unit when the pump is shut down, which is equal to the total pulldown volume minus the water suspended in the unit and its distribution system.
**External Static Pressure:** The pressure imposed on cooling equipment by external sources such as ductwork and sound attenuation.
**Fahrenheit (F):** A temperature scale in which the boiling point of water is 212 degrees and its freezing point is 32 degrees at normal atmospheric pressure. Conversion to Celsius: ºC = (ºF – 32)/1,8.
**Fan, Axial:** An air moving device consisting of impeller blades oriented around a central shaft, usually with an aerodynamic inlet housing; axial fans typically move large volumes of air at low pressures as compared to centrifugal fans for the same fan horsepower.
**Fan, Centrifugal:** An air moving device consisting of impeller blades radially oriented parallel to a central shaft, bound with a rim and hub; centrifugal fans typically move smaller volumes of air than axial fans but at a higher pressure for the same fan horsepower.
**Fan Coil Unit:** A terminal unit that delivers conditioned air directly to the occupied space.
**Fan Deck:** The finished surface adjacent to a horizontally mounted axial fan, sometimes used as a working surface to perform maintenance when the proper safety precautions are taken (handrails, ladder, etc.).
**Fiberglass Reinforced Polyester (FRP):** A non-corrosive composite material comprised of a plastic resin matrix, glass fiber reinforcement and other additives.
**Fill:** See "Wet Deck."
**Filtration:** The process of separating solids from a liquid by means of a filter media through which only the liquid passes.
**Flume Box:** A short channel that runs between two cooling towers, allowing water to flow from one cold water basin to another; a flume box serves to correct any difference in water levels that may develop during operation and generally has a greater capacity of water flow than an equalizer line.
**Forced Draft:** Refers to the location of the fan(s) on evaporative cooling equipment. On forced draft equipment, the fans

are located at the air inlets to "force" or push air through the unit.
**Fouling:** Organic growth or other deposits on heat transfer surfaces causing loss of efficiency.
**Frequency:** The number of cycles that an alternating current moves through in each second. Standard electric utility frequency in Europe is 50 cycles per second (50 Hertz).
**Full Load Amps (FLA):** The current draw of a motor under full load.
**Galvanic Corrosion:** Corrosion caused by the difference in electrochemical tension of different materials in direct or close contact in a humid environment.
**Heat Exchanger:** A device for the transfer of heat energy from the source to the conveying medium.
**Heat Pump:** A device that is capable of both heating and cooling space, depending on user comfort requirements. Heat pumps are generally individually controlled and therefore a heat pump in one room may be heating, while a heat pump in an adjacent room may be cooling.
**Heat Transfer:** Moving heat from one location to another.
**Hertz (Hz):** A unit of electromagnetic wave frequency that is equal to one cycle per second.
**Hot Water Basin:** The collection pan that houses the hot water in an evaporative cooling unit with a gravity distribution system.
**Humidity:** The amount of moisture in the air.
**HVAC:** Heating, Ventilation and Air Conditioning.
**Hybrid Cooling Tower:** Apparatus incorporating two modes of heat transfer operating simultaneously wet and dry, with the aim to reduce water consumption and/or to reduce or eliminate the visibility of the plume. Hybrid cooling towers can be of the open- or closed-circuit type.
**Induced Draft:** Refers to the location of the fan(s) on evaporative cooling equipment. On induced draft equipment, the fans are located on the air discharge side of the equipment to "induce" air through the unit.
**Industrial:** The industrial sector is generally defined as manufacturing, construction, mining, agriculture, fishing, and forestry establishments.
**Inspection Points:** Locations within or at the evaporative cooling device, which must be accessible for visual inspection.
**Interference:** The reintroduction of warm discharge air from one evaporative cooling unit into the air inlet of an adjacent unit. To avoid interference, layout guidelines provided by equipment manufacturers should be closely followed.
**Inverter:** See "Variable Frequency Drive."
**ISO 9001: 2008:** A comprehensive, internationally recognized standard which is concerned with all aspects of quality management in the design, engineering and manufacturing of a product.
**Latent Heat:** Heat that causes a change in state when added or removed, but does not cause a change in temperature. For example, heat that evaporates a substance from a liquid to a vapor but does not increase its temperature.
**Leaving Water Temperature (LWT):** The temperature of the fluid as it leaves the evaporative cooling equipment to return to the system heat source.
**Legionella:** A genus of bacteria; most species of this genus are capable of causing disease in humans. LD, Legionnaires' Disease, is a pneumonia like disease caused by one genus of Legionella.
**LS Concentration:** Concentration of Legionella species, usually expressed in cfu/l.
**Legionella Species:** All types of Legionella bacteria together, generally expressed in cfu/l.
**Legionnaires' Disease:** A rare but serious form of pneumonia: disease caused by Legionella Pneumophila.
**Life-Cycle Cost:** The amount of money required to own, operate and maintain a piece of equipment over its useful life.
**Load:** The demand for services or performance made on a machine or system, i.e. amount of heat rejection required by the evaporative cooling equipment.
**Louver:** A series of sloping vanes that allow the entrance of air but prevent the escape of water droplets.
**Make-Up Water:** Water added to the recirculating water to compensate for losses from evaporation and bleed.
**Maintenance Points:** Locations within or at the evaporative cooling device requiring maintenance. Sufficient access to these points to carry out the requested maintenance procedure must be assured.
**NEMA:** National Electrical Manufacturing Association.
**Nozzle:** A device used for regulating and directing the flow of a fluid.
**Once-Through System:** Heat exchange system in which the cooling water is not recirculated.
**Open Cooling Tower:** Apparatus wherein the process fluid is warm water which is cooled by the transfer of mass and heat through direct contact with atmospheric air.
**Parts Per Million (PPM):** A unit which represents a comparison of mass to mass, volume to volume, mass to volume, etc.; commonly used to represent the concentration of dissolved solids in the recirculating water of evaporative cooling equipment.
**Plenum:** The open area of a crossflow evaporative cooling unit through which air is pulled before being discharged to the atmosphere.
**Plume:** Saturated discharge air that forms a visible cloud over evaporative cooling equipment under certain temperature and humidity conditions.

**Plume Abatement Coils:** Finned coils integrated into the evaporative cooling device with the aim to reduce or eliminate visible plume by warming part or all of the discharge air moved through the device. Plume abatement coils can be integrated into the process fluid cycle or fed by external heat sources.
**Polyvinyl Chloride (PVC):** A polymer of vinyl chloride often used for a heat transfer media surface (film) and piping on factory-assembled evaporative cooling equipment.
**Power:** The rate at which energy is transferred. Electricity for use as energy is also referred to as power.
**Preventive Maintenance:** Regular maintenance implemented to reduce the possibility of sudden or unexpected equipment failures.
**Pulldown:** Water that collects in the cold water basin of a unit when the system pumps shut off.
**Pump, Spray:** A water moving device on a closed circuit cooling tower or evaporative condenser for transporting the spray water from the basin to the water distribution system in order to wet the heat transfer surface.
**Pump, System:** A flow moving device for transporting the fluid to be cooled (water in a cooling tower; water, glycol, or other fluid in the case of a closed circuit cooling tower) to the tower and back to the system in a continuous loop.
**Range:** The difference between the entering water temperature and leaving water temperature of an evaporative cooling unit. See also "Delta."
**Recirculating Water:** The water being circulated over the coil or fill in an evaporative cooling unit.
**Recirculation:** Situation that occurs when the warm discharge air flows back into the air inlets of the evaporative cooling equipment. To avoid recirculation, layout guidelines provided by equipment manufacturers should be closely followed.
**Reclaiming:** Processing or returning used refrigerant to the manufacturer or processor for disposal or reuse.
**Refrigerant**: A chemical that condenses from a vapor to liquid and, in the process, decreases in temperature.
**Refrigerant Charge:** The amount of refrigerant in a system.
**Retrofit:** Broad term that applies to any change after the original purchase, such as adding equipment or accessories to an existing installation.
**Risk Analysis:** Analysis combining the frequency of a potentially occurring incident and its severity and the prevention thereoff.
**Saturation Temperature:** Also referred to as the boiling point or the condensing temperature. This is the temperature at which a refrigerant will change state from a liquid to a vapor or vice versa.
**Scale:** The accumulation of solids from the minerals contained in water, most often referred to as hardness deposits, i.e. calcium and magnesium.
**Scale Inhibitor:** Chemical added to water to inhibit formation of scale.
**Scaling:** Deposit of oversaturated dissolved solids. Calcium Carbonate scaling is the most common one.
**Sensible Heat:** Heat that causes a change in temperature when added or removed, but does not cause a change in state.
**Separator:** A device which uses centrifugal force to separate particles from a suspension; used to remove sediment from evaporative cooling systems.
**Setpoint:** The temperature to which a thermostat is set to result in a desired heated space temperature.
**Sound Attenuator:** Component used on the air inlet or air discharge of an evaporative cooling unit to reduce airborne noise.
**Splash-Out:** Droplets ejected outside the cooling tower through the air inlets, due to wind turbulences or when the fans are stopped.
**Specific Heat:** The quantity of heat, in kJ, needed to raise the temperature of one kilogram of material one degree Celsius.
**Start-Up:** Start of the system with water after a period of shutdown.
**Strainer:** A filter used to remove large, suspended solids from a liquid.
**Subcooled Liquid:** Liquid refrigerant that is cooled below its saturation temperature.
**Suction Connection:** The outlet connection through which leaving water is pumped back to the chiller.
**Sump:** The cold water basin of the evaporative cooling equipment.
**Sump Sweeper Piping:** Eductor nozzles fitted into pipework located in the cooling tower basin, increasing water circulation and agitation of the sump.
**Superheated Vapor:** Refrigerant vapor that is heated above its saturation temperature.
**Thermal (Energy) Storage:** A technology that lowers the amount of electricity needed for comfort conditioning during utility peak load periods. A building's thermal energy storage system might, for example, use off-peak power to make ice at night, then use the ice for cooling during the day.
**Thermostat:** A temperature control device that consists of a series of sensors and relays that monitor and control the functions of a heating and cooling system.
**Total Pulldown Volume:** The sum of the water suspended within the unit and its distribution system during operation, plus the water in any external piping and heat exchangers draining back to the unit when the pump is shut down.
**Valve:** Any device used to control the flow of a fluid through piping.
**Variable Frequency Drive (VFD):** An electronic device that controls the speed of a motor by controlling the frequency of the voltage supplied to that motor. Also known as an inverter.

**Visible Plume:** The discharge air stream of the device when it becomes visible (wholly or in part) by the condensation of water vapour as the moist air stream is cooled to the ambient temperature.

**Water Distribution (System):** System for receiving the water entering the device and distributing it over the area where it contacts the air.

**Water Treatment Program or System:** Everything done to the circulating water to control scaling, corrosion and fouling. It must be adapted to the actual water quality which varies with location and time. It may include filtration, chemical and/or biocide additives, physical treatment, …

**Wet-Bulb Temperature (WB):** The temperature at which water, by evaporating into air, can bring the air to saturation at the same temperature.

**Wet Deck:** A heat transfer surface where air and water interface; also known as fill.

*Notes*

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