Comprehensive Chilled-Water System Design

System Catalog

Disconnected Loads Can't Use Energy

Chilled-water systems provide customers with flexibility for meeting first cost and efficiency objectives, while centralizing maintenance and complying with or exceeding energy code minimum requirements. A comprehensive approach to system design can minimize the power draw of the entire system are inherently easier to control for highest efficiency, lower first costs and lower energy costs. Right-sizing equipment means smaller electrical connections—a great way to do more with less. Less money *and* less energy.

State-of-the-art design

Chilled-water systems employing the best practices in this catalog align with current industry guidance for high-performance, all while reducing first cost. By judiciously applying advanced technology and controls, state-of-the-art doesn't lead to high complexity or algorithms that are difficult to understand. In fact, it's quite the opposite.

Efficient, reliable, cost-effective

Chilled-water systems provide the ultimate in flexibility and efficiency for achieving cooling, heating, and ventilation. Larger motors are more efficient, and centralized systems have fewer moving parts and higher reliability. Chilled-water systems have long lives and centralized maintenance.

These design practices are also cost effective—better design choices lead to fewer pounds of piping and water, smaller cooling towers, pumps, transformers, power wiring, which in turn lead to additional savings in pipe hangers, building structure, and more.

Repeatable, simple yet flexible

Tracer® chiller plant controls provide sequencing and advanced optimization strategies to reduce energy use, with intuitive dashboards that explain what the system is doing and why.

Pump, valve and cooling tower controls, as well as terminal units, air-handlers and zone sensors can communicate wirelessly. Air-Fi® wireless controls make construction management easy—there's no need to delay wall or ceiling installation for control wiring. Air-Fi also leads to better reliability, with self-healing mesh networking, and easy sensor relocation to accommodate future space use changes.

By using industry-leading applications such as Tracer® chiller plant control, all projects benefit from the experiences of others.

Sustained high performance

Best practices in chilled-water system design take advantage of the capabilities of the components, unlocking system design attributes that lead to high performance that lasts from year one to year sixty. While many chillers are themselves still operating sixty years later, pipes and other elements regularly do. Systems designed this way are resistant to developing and suffering from low-delta T syndrome, in which chilled-water systems lose valuable cooling capacity and operate inefficiently.

Trane chillers, chilled-water coils and terminals are available in a range of efficiency tiers to match your budget and energy goals.

System Components

images courtesy of Flow Control Industries and Armstrong Fluid Technology

Best practice and code compliant system components

- Coils with high (15°F+ ∆T) water temperature rise
- Turbulators to improve coil full- and part-load performance
- Pressure-independent control valves to eliminate the need for balancing valves and to guarantee full and part load delta T
- Pre-programmed, factory-commissioned Tracer® DDC controls with wired or Air-Fi® wireless communications

Completion Modules

A chilled-water system has many parts, and a good portion of these can be pre-assembled, tested and shipped together for streamlined installation. Completion modules save a project time, money and space.

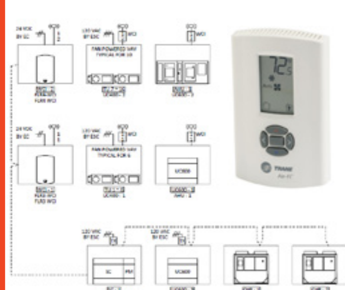
- Factory quality
- Single-source responsibility
- Warranty system support
- Tested and commissioned
- ETL® listed
- Built and backed by Trane
- Easier project staging both on- and off-site

Chillers

- Industry leading full and part load efficiency
- Three compressor types (scroll, helical-rotary, centrifugal)
- Current and next generation refrigerants available now
- Variable water-flow compatible
- Pre-engineered, factory-assembled, and factory-tested
- Customized configurations and options, efficiency tiers
- Variable- and fixed-speed compressors

Cooling towers

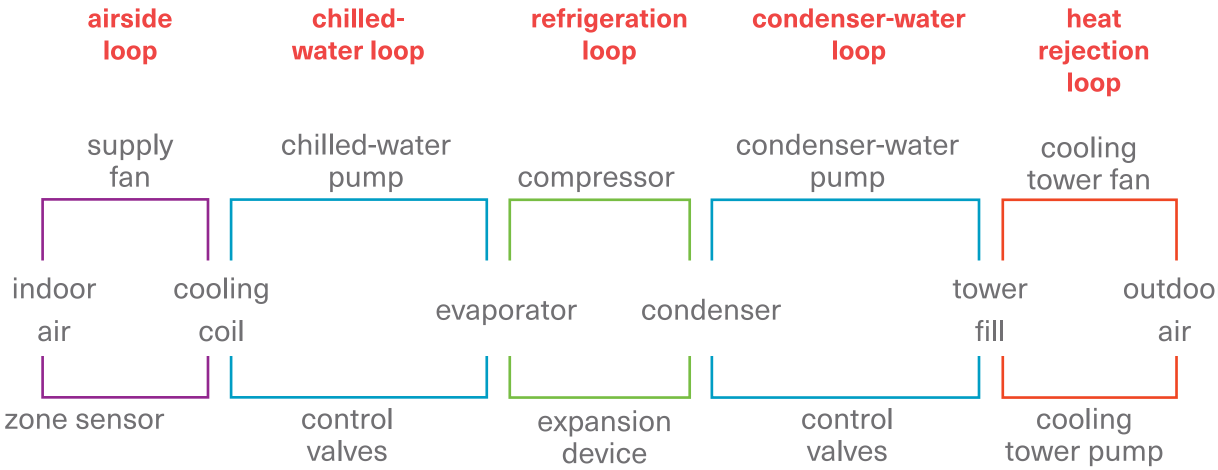
- 14°F+ cooling-tower range to save energy and cost
- 50 percent or better cooling tower water turndown for efficient staging, waterside free cooling support and code compliance
- Variable speed condenser pumps to reduce or eliminate balancing valves
- Makeup water from condensate reclaim



Tracer controls

- Optimized system control sequences and intuitive, easy-to-use operator interface
- Open protocol integrates easily with other systems (power meters, VFDs, other controls platforms)
- Mobile apps provide access from whereever
- Air-Fi® wireless communication eliminates wires between equipment controllers and zone sensors, and between equipment and system controllers, allowing for faster installation, increased location flexibility, and easier relocation
- Self-healing wireless mesh, extended signal range, and conformance to ASHRAE® Standard 135 (BACnet®)

System Overview



Components

The above graphic depicts five "loops" commonly used in a chilled-water system to remove heat from zone or process loads. This system comprises one or more chillers, cooling tower(s), condenser-water pumps, chilled-water pumps, and load terminals served by control valves. Fixed- or variable-speed compressors provide cooling, while flow rates are optimized for a combination of efficiency and cost.

Coordinated, integrated

The Tracer® Chiller Plant Control system controller uses pre-engineered yet flexible control sequences to achieve high performing system operation. Routines include staging, mode control, chiller-tower setpoint optimization, and trim-and-respond pump-pressure reset or chilled-water temperature reset.

As the loads in the system change, variable-speed fans in the cooling tower are modulated to maintain the tower sump at setpoint, while cooling is staged or modulated to maintain the chilled-water temperature at setpoint. Load terminals such as cooling coils in central station air-handlers, area-level blower coils, zone-level fan coils, or sensible-cooling terminals respond to changes in the zone cooling loads by modulating chilled-water valves and by staging or modulating fans.

Flexible applications

Chilled-water systems can be designed to grow and adapt to building and load changes over time. Systems are often sized to easily incorporate future cooling load expectations and to recover heat. Cooling is distributed by water, which is a relatively benign substance compared to distributed refrigerant. Comfort and process cooling loads can share the same system.

Scalable

Chilled-water systems are an excellent choice for large buildings, such as office towers, healthcare, higher education, data centers and indoor agriculture. Expansion is relatively easy when loads increase, or as interior spaces are built out.

Centralized maintenance

Maintenance tasks are easier when they are centralized and out of occupied spaces. Long-lived components mean fewer replacements over the course of a building's life.

High performing

Water-cooled heat rejection is more effective than air-cooled. Centralized equipment uses more efficient, larger motors.

Simplified

Chilled-water systems can be efficient by design, with easy to understand controls.

State-of-the-Art Design

A well-engineered system exploits the dramatic improvements in modern chiller efficiency to further improve overall system efficiency. By working the chiller a little bit harder on the most challenging cooling days, designing differently unlocks cost savings now, plus saves energy. This is accomplished by reducing the water flow-rates—on the chilled-water side and on the condenser-water side of the system. Savings are significant in many cases, and not only affect the cooling system but also the electrical system, building construction, site permitting and power infrastructure.

There is a truism that systems are typically oversized. Engineers are conservative. Most people interpret this to mean that the HVAC equipment has too much cooling and/or heating capacity. But what about the capacity of the rest of the system? "Rightsizing" doesn't just mean the equipment— it's also the pipes, valves, water volume, and building structure.

The techniques in this design guide allow you to have either the lowest first cost, or the lowest energy cost, or a combination of both first cost and energy savings. In some instances it's possible to have both the lowest first and the lowest energy cost.

Design differently to save the project

When projects are over budget, redesigning flow rates provides no-compromise opportunities to reduce cost.

- When the budget demands it
- When there is limited space or structural support
- When electrical infrastructure can be downsized
- When limited by existing elements in system expansions

Design differently to save energy

System efficiency can be maximized when designs use optimized flow rates.

- Keep larger pipes to further reduce connected kW and save more energy
- Reinvest reduced water weight structural savings in other energy and reducing building components
- Arrange chillers in series counterflow to decrease chiller and system energy consumption

ANSI/ASHRAE/IES Standard 90.1-2016, Energy Standard for Buildings Except Low-Rise Residential Buildings

- 15°F + ΔT cooling coil selection, 57°F+ return[1]
- 50% cooling tower water-flow turndown[2]
- Variable speed pumping for chilled water[3]
- Pipe sizing[4] and insulation[5]

ASHRAE Learning Institute, Fundamentals of Design and Control of Central Chilled-Water Plants, 2016

- 25°F ΔT chilled water starting point[6]
- 15°F ΔT condenser water[7]

ASHRAE Advanced Energy Design Guides

- At least 15ºF ΔT chilled water (hospitals)[8]
- 12-20ºF ΔT chilled water (K-12 schools)[9]
- At least 14ºF ΔT condenser water

ASHRAE GreenGuide[10]

- 12-20°F ΔT chilled water
- 12-18°F ΔT condenser water

CoolTools™ Chilled Water Plant Design and Specification Guide, 2000[11]

- 15-18°F ΔT chilled water

Kelly and Chan, Optimizing Chilled Water Plants, HPAC Engineering, 1999[12]

- 18°F ΔT chilled water
- 14°F ΔT condenser water

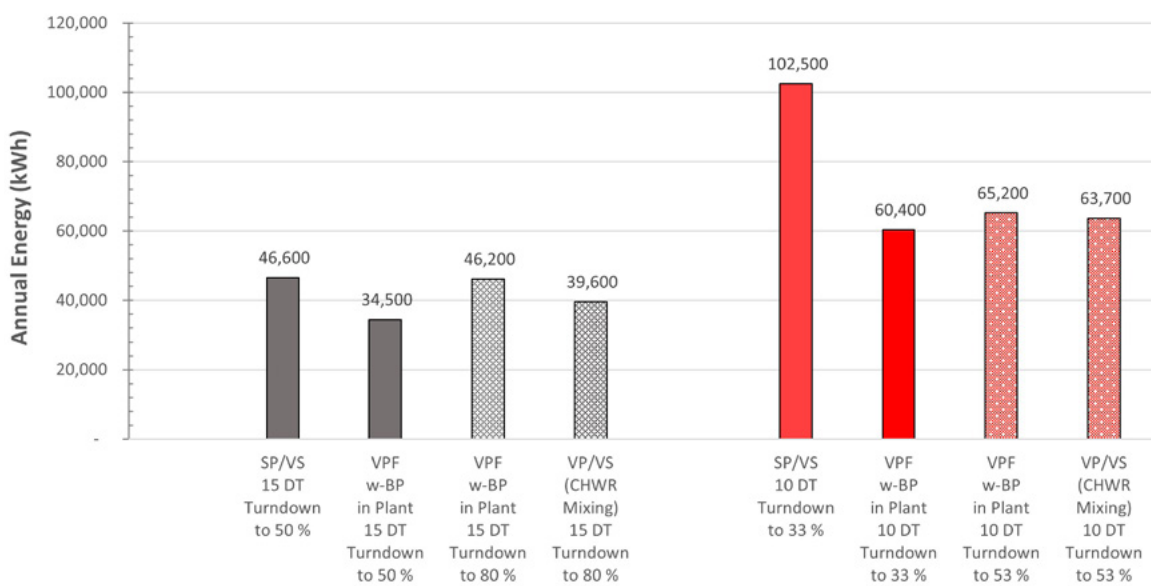
1 ANSI/ASHRAE/IES, 2016. ASHRAE 90.1 Energy Standard for Buildings Except Low-rise Residential Buildings. section 6.5.4.7, 100.
2 Ibid., section 6.5.5.4, 101.
3 Ibid., section 6.5.4.2, 98.
4 Ibid., section 6.5.4.6, 100.
5 Ibid., section 6.4.1.1.3, 85.
6 Taylor, Steven T., P.E. 2017. "*Fundamentals of Design and Control of Central Chilled-Water Plants*", ASHRAE. 159-164.
7 Ibid., 164-167.
8 ASHRAE/IESNA/AIA/USGBC/USDOE. 2012. *"50% Advanced Energy Design Guide for Large Hospitals."* HV35, 201.
9 ASHRAE/IESNA/AIA/USGBC/USDOE. 2014. *"50% Advanced Energy Design Guide for K-12 School Buildings."* HV6, 172.
10 Swift, John M., Jr. and Tom Lawrence, ed. 2012. "*ASHRAE GREENGUIDE: The Design, Construction, and Operation of Sustainable Buildings.*" ASHRAE.
11 Pacific Gas and Electric. 2000. "CoolTools™ Chilled Water Plant Design and Specification Guide." 4-26.
12 Kelly, D. and T. Chan. 1999. "*Optimizing Chilled Water Plants*." Heating/Piping/Air Conditioning (HPAC) Engineering. 71.

Selecting a Design Configuration

There are many choices about how to configure a chilled-water system. Some may be limited by what is already installed. However in many cases upgrades to existing plants are necessary and present attractive opportunities to reduce cost and energy consumption.

Besides picking a flow rate, typical choices on the chilled-water side of the system include decoupled versus variable-primary flow, parallel versus series chillers, as well as how to size and site bypass lines. On the condenser-water side, choices include manifolding or dedicating the towers and pumps, winter operation and whether or not to dynamically vary the condenser pump flow This section explains the various pros and cons to each of these choices, and the cost and efficiency implications.

One consideration when choosing is the pump energy consumed by different configurations of chilled-water systems.



Energy impact of plant configuration, turndown and flow rate on pumping energy

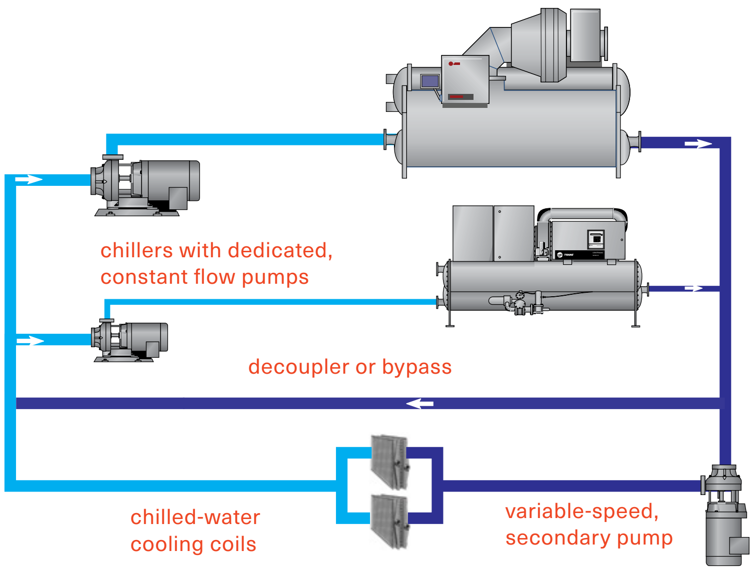
Pump energy impact of configuration

The color-paired performance groups above show annual performance of constant flow, primary/secondary, variable-primary flow and variable-primary/variable-secondary flow systems. The left bar in the pair shows a traditional 10°F ΔT design. The right bar shows pump energy consumed by these same configurations with a modern 15°F ΔT design. The energy impact of chillers with less flow turndown is also shown.

This comparison solely considers the pump energy. The energy consumed by the entire system will also vary between the various options and control strategies. A key benefit of varying flow through the chillers is that it allows the controls to delay starting a chiller when the operating chillers can handle increased flow. This delays the start of a cooling tower and condenser water pump and may save system energy. A full-year comparison of the entire system is advised when energy conservation is a key consideration for your project.

The following pages provide descriptions and summaries of other aspects of common chilled- and condenser-water configurations. These are neither exhaustive explanations nor comprehensive comparisons. Many other variations can be applied to address specific job needs.

Chilled-Water Configuration: Decoupled (Classic Primary-Secondary)



Typical Applications

- Asymmetrical plants with chillers of unequal size, vintage, pressure drop
- Chillers without sufficient flow turndown capabilities
- Existing plants with sunk cost in pumps and pipes, equipment rooms that are difficult to modify
- Systems without airside-induced "low delta-T" syndrome

This system configuration consists of one or more chillers, often arranged in parallel with each other, with dedicated or manifolded chiller pump(s). A bypass pipe decouples the operating pressures and flow of the chiller (primary) side from the building distribution (secondary) side of the system. This allows for independent management of each chiller's and the distributed system flow. Chillers are added when optimal for system operation or when the flow through the bypass goes "deficit". That is, when the secondary flow exceeds primary flow and some return water mixes with supply water, thereby raising the temperature going to the distribution system. The secondary pump speed is controlled based on a remote differential pressure or the valve positions of the terminal devices, typically coils. Varying the secondary pump(s) speed maintains the distribution system differential pressure.

Advantages

- Relatively easy to expand—often a dedicated pump is installed per chiller and sized for its chiller's flow and pressure drop. This neutralizes operating complexity within plants with chillers of different age, size or pressure drop.
- Accommodates asymmetry in chiller capacity, size, age, and capabilities—allowing for system expansion and right sizing.
- System controls stage chillers on load, temperature or flow. Chillers are added when there is not enough chiller capacity or flow to sustain secondary supply temperature, a condition that can be simply sensed by temperature. Typically, there is no need for direct flow measurement.
- Simplest system operation and control—highest reliability system.

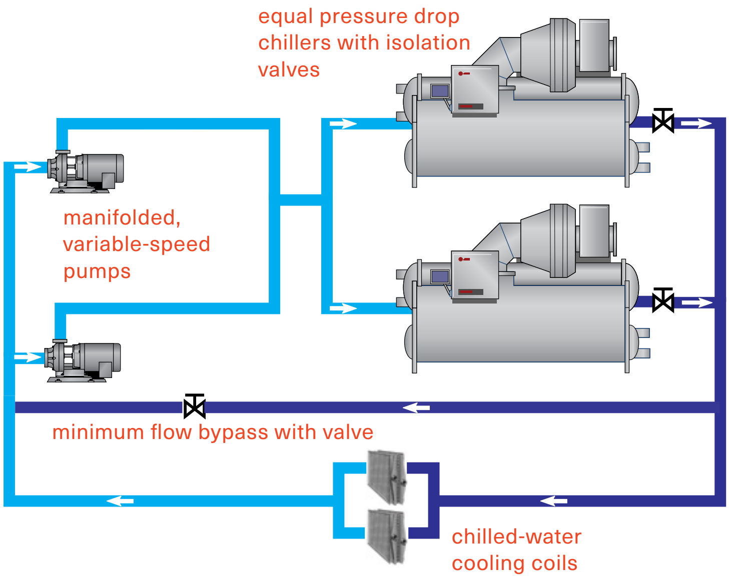
Disadvantages

- More pumps mean more expense on new construction.
- Cannot compensate for chronic airside low chilled-water ΔT.
- Constant chilled-water flow limits the use of extra chiller capacity that may be available, for example when relatively cool water enters the chiller condenser.

Best practices

- Size the bypass pipe based on largest design flow of one chiller—not the distribution pipe diameter. It should be free of restrictions and about an equivalent length of ten pipe diameters. The goal is to provide decoupling of pressure and flow while preventing the unintended mixing of supply and return chilled-water streams. A check valve in the bypass is not desirable as it puts pumps in series which can make pump and chiller control difficult.
- Match load and flow efficiently between primary and secondary loops with asymmetrical or "swing" chillers.
- Monitor critical valve positions at the cooling coils serving air-handlers or fan-coils. Use trim-and-respond logic on either pump pressure setpoint or chilled water setpoint.
- Select chiller for 2 to 4°F lower supply chilled-water temperature than the cooling coils, to allow supply temperature reduction compensation for airside low ΔT or increased system load.
- Install pressure-independent cooling coil control valves to preserve system capacity and minimize energy consumption.
- Expect higher distribution system ΔT at part load. Investigate if not.

Chilled-Water Configuration: Variable-Primary Flow (VPF)



Typical Applications

- Symmetrical plants with chillers of equal size, capabilities and pressure drop
- Systems exhibiting an undesirable airside induced “low delta-T” syndrome
- Chillers with sufficient flow turndown and control capabilities
- Retrofits for existing plants with constant flow pumping and VPF-suitable chillers

This system configuration consists of one or more chillers, often arranged in parallel with each other, with manifolded pumps. A valve opens in a smaller bypass pipe whenever system flow does not meet the chiller minimum. Chillers are added when the operating chiller(s) are no longer achieving the system setpoint temperature. The system pumps' speed is determined based on a remote differential pressure or the valve positions of the terminal devices, typically coils.

Advantages

- Costs less to install, typically costs less to operate
- Enables chillers to fully load
- Able to over-pump chillers to accommodate systems with low ΔT
- Symmetry of chillers simplifies which chiller to operate, common parts and performance expectations
- System controls stage chillers on temperature and compressor power, both reliable and repeatable measurements, or based on measured tons
- No need for swing chillers to minimize surplus flow

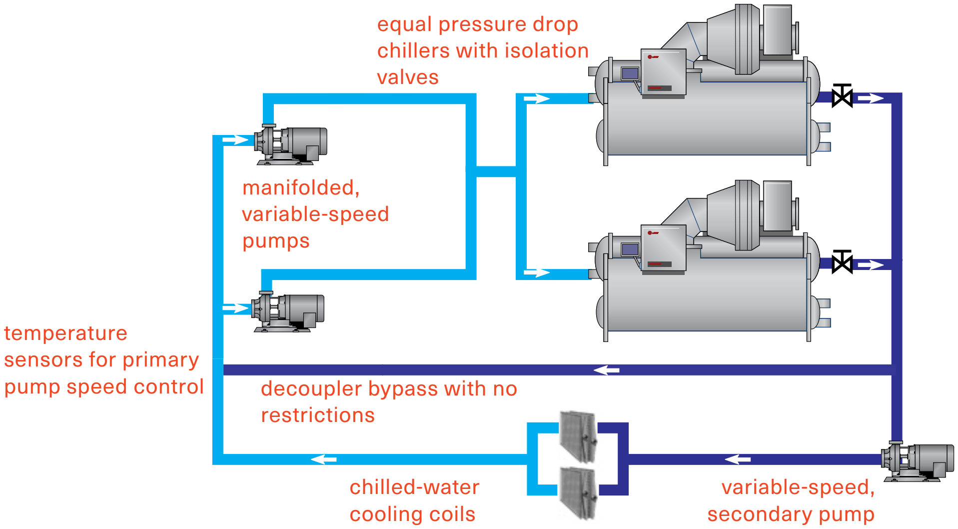
Disadvantages

- Chiller staging and controls are more complex
- Bypass valve operation is critical for system reliability
- Selected chillers must have adequate flow turndown
- Different size, flow or pressure drop chillers may make reliable control and sequencing difficult or impossible
- Airside low ΔT increases system pumping energy significantly
- Significant pump and pipe changes are required to retrofit from primary-secondary flow
- Chiller not universally suitable for this configuration

Best practices

- Select for equal or nearly equal pressure drop if chillers are in parallel. Flow and therefore load will divide equally across all operating chillers.
- Minimize surplus flow and limit the need for bypass by selecting chillers with good flow turndown. Aim for at least a 2:1 chilled-water-flow turndown.
- Identify chiller flow and rate-of-flow change limitations.
- Size the bypass and bypass valve for the highest chiller minimum flow. Oversizing makes accurate and stable control difficult.
- Consider series chillers for reduced flow disruption during sequencing. Although series chillers typically have higher pressure drop at design flow, pressure drop and energy reduce as the flow and load go down.
- Select chillers and chiller options that automatically tune the control response for higher and lower flow rates.
- Monitor critical valve positions at the cooling coils serving air-handlers or fan-coils. Use trim-and-respond logic on either pump pressure setpoint or chilled water setpoint.
- Work with a system controls vendor who has demonstrated expertise with this system configuration.
- Commit to operator training and refresher courses about system operating intent, sequences and limitations.
- Install pressure-independent control valves to preserve system capacity and minimize energy consumption.
- Expect higher system ΔT at part load. Investigate if not.

Chilled-Water Configuration: Variable-Primary, Variable-Secondary Flow (VPVS)



Typical Applications

- Asymmetrical plants with chillers of unequal size, vintage, pressure drop
- Systems exhibiting an undesirable "low delta-T" syndrome
- Chillers without significant flow turndown and controls capabilities
- Retrofits for existing plants with primary-secondary flow and variable-flow suitable chillers

This configuration combines the features of classic primary/secondary and variable-primary-flow systems. It consists of one or more chillers, often arranged in parallel with each other. For existing primary-secondary system conversions, the existing bypass pipe can be used. For new systems, the bypass pipe may be sized similar for the minimum flow of the largest chiller in the system. In either case, the bypass has no restrictions in it.

Add a chiller when the operating chillers no longer achieve the system setpoint temperature, or earlier if it reduces system energy use. The primary pumps' speed and flow creates a slight surplus flow. This can be achieved using flow matching or using a return water temperature difference before and after the bypass. Secondary pumps are controlled by remote differential pressure.

Advantages

- Often results in the lowest overall system pumping energy, particularly with chillers that have limited flow turndown
- Reduces system load versus chiller interaction, improving system control dynamics and providing more stable operation
- More easily sequenced chillers, despite differences in capacity, flow or pressure drop, than in other arrangements
- May over-pump chillers to accommodate systems with low air-side ∆T
- Easier, faster and lower cost retrofit from a classic primary-secondary configuration—it doesn't require piping changes—by adding VFDs to the primary pumps and modifying the control logic

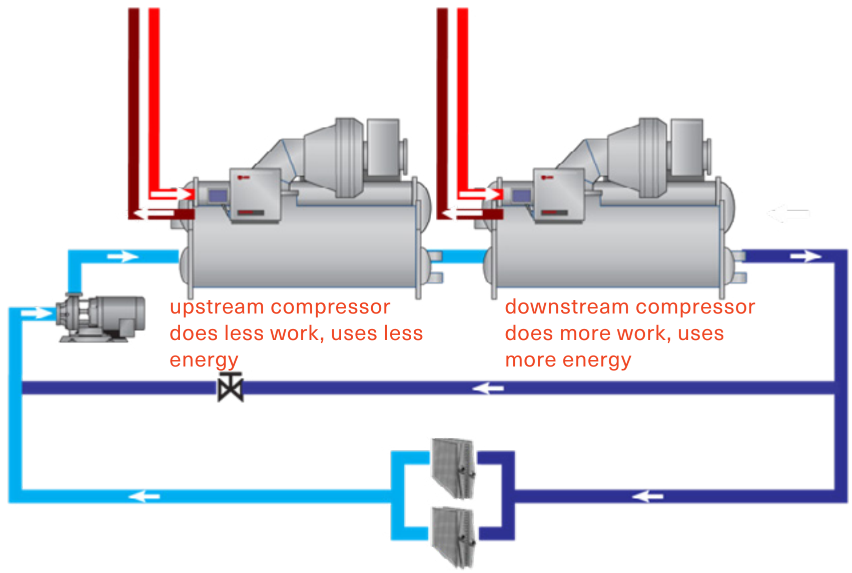
Disadvantages

- Higher first cost for new installations compared to variable-primary-flow systems—more pumps and associated electrical connections

Best practices

- For new systems size the bypass pipe diameter based on the largest chiller's minimum flow (not distribution pipe diameter), free of restrictions, with pressure drop equal ten pipe diameters's worth of length. This decouples pressure and flow while preventing unintended mixing of the supply and return chilled water streams.
- With chillers in parallel, select for equal or nearly equal pressure drop. Flow and load will divide equally across all operating chillers.
- Select chillers for a sufficient amount of chilled water flow turndown. Aim for turndown to at least 80% of design. Less that that results in minimal pumping energy savings.
- Select chillers and chiller options that automatically tune the control response for higher and lower flow rates.
- Use cooling coil valve positions and trim-and-respond logic to reset distribution pump pressure setpoint and minimize pump energy. Raise setpoint when one or more valves are nearly wide open. Lower setpoint when no valves are nearly wide open.
- Work with a system controls vendor who has demonstrated expertise with this system configuration.
- Commit to operator training and refresher courses about system operating intent, sequences and limitations.
- Install pressure-independent cooling coil control valves to preserve system capacity and minimize energy consumption.
- Expect higher distribution system ∆T at part load. Investigate if not.

Chilled-Water Configuration: Series Chiller Evaporators with Parallel Condensers



Typical Applications

- Free cooling
- Heat recovery
- Variable-primary-flow systems
- Low flow systems (>15°F ΔT)
- Chillers with continuous unloading compressors (such as screw and centrifugal)
- Chillers with single-pass evaporators

This system configuration consists of one or more chillers, arranged in series with each other on the chilled-water side of the system. Condensers are piped in parallel. When additional chillers are needed, series pairs are added in parallel with the first pair. Each set of chillers gets either a dedicated pump or an isolation valve.

Advantages

- No flow disruptions during transitions (adding or subtracting a chiller) because flow is already going through both chillers before the transition
- Upstream chiller can be equipped for onboard refrigerant migration free cooling while downstream chiller is set up for integrated mechanical mode or heat recovery.
- Variable primary flow reduces pump energy penalty at lower load/lower flow conditions.

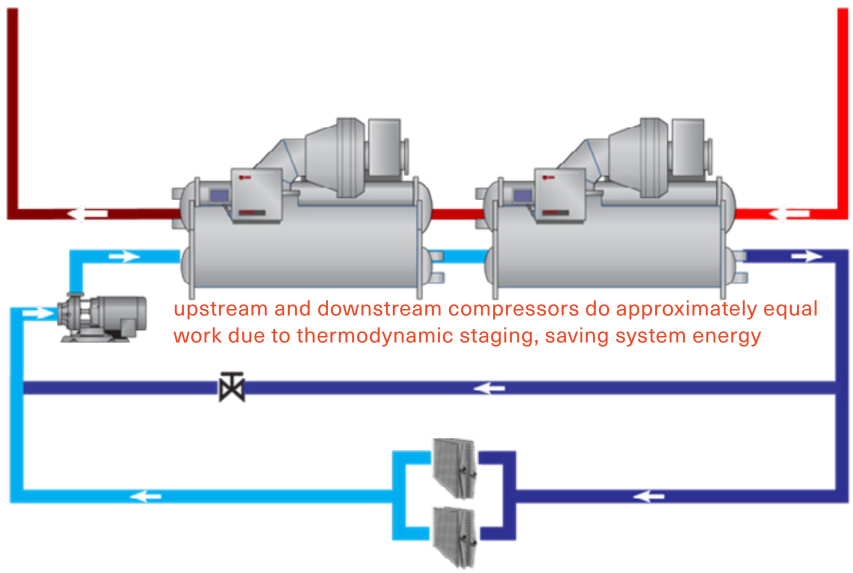
Disadvantages

- System energy not optimized (see series-counterflow)
- Higher pump energy at design flow conditions, variable flow can overcome at reduced load/flow
- System ΔT must be maintained in order to load the chillers

Best practices

- Free cooling on upstream chiller allows the free-cooling equipped chiller to see the warmest chilled water temperatures and the coldest condenser water temperatures. This increases the number of hours when free cooling is advantageous. A chiller in this position is easier to preferentially load and it also means that the cycle can continue uninterrupted by allowing the downstream chiller to automatically pick up any load not satisfied by the upstream chiller.
- Heat recovery on downstream chiller with a parallel condenser circuit allows the chiller to adjust its condensing pressure independently of the upstream chiller. Condenser water is routed to the heating loop either directly or indirectly through another heat exchanger. Shed only the excess heat by adjusting the upstream chiller capacity to leave the desired heat rejection load for the downstream chiller. Upstream chiller could be in free- or mechanical-cooling mode, if equipped.
- Size upstream chiller for achieving design system setpoint at reduced flow. This allows the downstream chiller to be taken offline for service while the upstream chiller makes the desired temperatures.
- Consider service bypasses (not shown) around each of the chillers.

Chilled-Water Configuration: Series Chiller Evaporators and Series Condensers



Typical Applications

- District cooling with either large tonnage and/or long distances
- Heat recovery
- Variable-primary-flow systems
- Low flow systems (>15°F ΔT)
- Chillers with continuous unloading compressors (such as screw and centrifugal)
- Chillers with single-pass evaporators and single-pass condensers

This system configuration consists of one or more chillers, arranged in series with each other on the chilled-water side of the system. The condenser flow is also series, with the flow running counter to the chilled-water flow. The chiller receiving the warmest chilled water also receives warmer condenser water. In this way, the work of the chiller compressors is spread evenly across the plant—saving energy. Larger system ΔTs are typical so that chillers (especially those using plate heat exchangers) can stay below velocity limits.

When additional chillers are needed, pairs are added in parallel. Each set of chillers gets either a dedicated pump or an isolation valve.

Advantages

- Best system energy consumption by reduced compressor lift, lowest flow rates and excellent flow turndown
- No flow disruptions during transitions (adding or subtracting a chiller) because the flow is already going through both chillers before the transition
- Reduced pump penalty with variable-primary flow at lower load/lower flow conditions

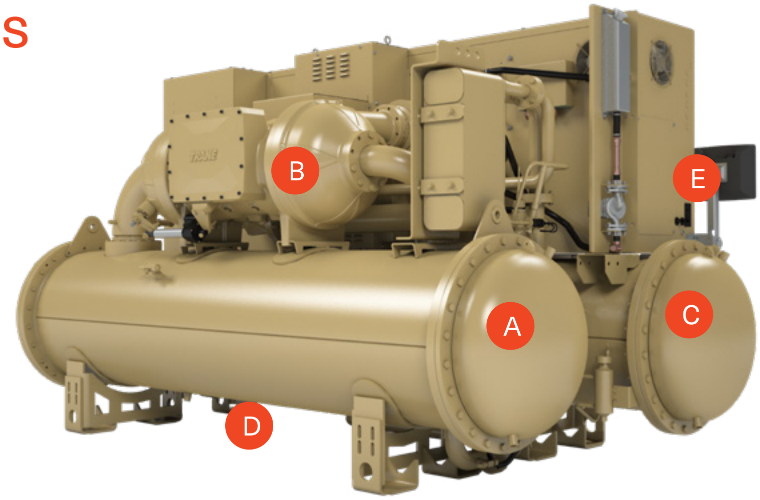
Disadvantages

- Higher pressure drop leads to higher pump energy at design flow conditions, variable flow can overcome this at lower load/flow conditions
- System energy not optimized (see series-counterflow)
- System ΔT must be maintained in order to load the chillers.

Best practices

- A minimum ΔT across both series chillers (especially for those using plate heat exchangers) might be 14°F ΔT, while typical would be 18 to 20°F ΔT. Higher ΔTs (25°F+) are achievable with this configuration.
- Best efficiency is achieved when chillers are selected for the duty (i.e. upstream chiller is optimized for the intermediate water temperatures.) More redundancy is achieved when the upstream chiller is capable of creating the final chilled water temperature with hotter condenser water. Variable speed compressor(s), if available, eliminate the efficiency penalty of the less-than-optimal compressor operating at the warmer setpoint.
- Consider service bypasses (not shown) around each of the chillers.

Chillers



Key Components

- A Evaporator heat exchanger
- B Compressor
- C Condenser heat exchanger
- D Expansion device
- E Unit controller

In a water-cooled HVAC system, the chiller extracts heat with a refrigerant that is selected and manipulated to "boil" at the temperature of the chilled-water or chilled-fluid loop. This removes the latent heat of vaporization from the chilled-water loop. The compressor then "pumps" this now vaporized refrigerant from a low pressure to a higher pressure. The condenser heat exchanger then cools the refrigerant to the point where it condenses back to a liquid, at a higher pressure, giving up the latent heat of fusion to the condenser-water loop. The high pressure refrigerant liquid is then sent through an expansion device that lowers the pressure of the liquid. The heat removed in the condenser is sent to a heat sink, typically cooling towers (most common), ground loops or heating systems.

Performance metrics

Each chiller selection provides a lot of numbers. Some of them are important for understading the performance of that particular chiller in a given system.

Efficiency measures the amount of cooling effect that is delivered versus the amount of energy required to do it. For water-cooled chillers, common units are kW/ton and coefficient of performance, COP. For proper electrical sizing and energy code compliance, full-load efficiency is a key efficiency metric. For code compliance, there is also a part-load efficiency metric (IPLV or NPLV), depending on the design conditions. We use IPLV for standard design conditions (and always for positive displacement chillers) and NPLV for non-standard design conditions for centrifugal chillers. For evaluation of one chiller versus another, Trane created myPLV®—a metric that adjusts for the applied climate zone, building type, plant size, number of chillers, tower control strategy and other factors. It can even create one based on a user-entered system load profile. The output provides suitable test conditions that represent common operating points for that chiller once installed.

Approach is a measure of the effectiveness of a heat exchanger. Approach is the temperature difference between the refrigerant and the fluid. Changes in approach over time at the same system conditions can indicate the need for service.

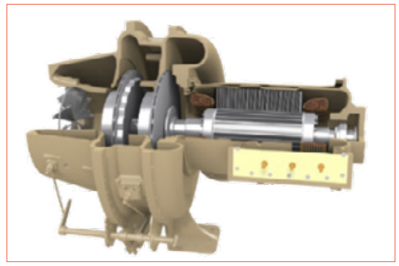
Pressure drop is a measure of the waterside resistance to flow. It is used directly during pump selection, but it is indirectly a measure of where the design flow rate falls in the range of flows of a given heat exchanger. Besides the flow rate, it is affected by the number, type and diameter of tubes in a shell-and-tube heat exchanger. In a brazed-plate heat exchanger, it is affected by the number of plates, channels and sizes of the channels. A slightly higher pressure drop, particularly in a shell-and-tube heat exchanger, is usually an indication that the heat exchanger has a good flow-rate turndown.

Turndown characterizes the chiller's ability to operate with less than the design flow rates, in both the evaporator and condenser. Turndown is essential when selecting chillers for variable-flow-rate applications.

Amps, both for running and starting are helpful, as are other electrical metrics such as minimum circuit ampacity (MCA) and maximum overcurrent protection (MOCP), for electrical system and component sizing.

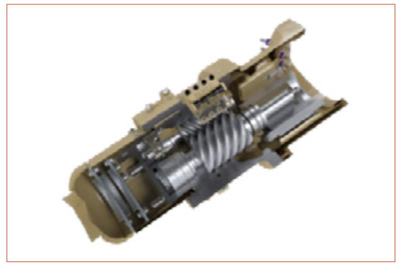
Chiller Variations

Sound, footprint, efficiency and capacity are key factors that differentiate one chiller style from another. Each chiller platform has advantages in one or more of these criteria.



Centrifugal compressor

Centrifugal chillers use a compressor that develops pressure by converting velocity to static pressure. Refrigerant is collected by an impeller rotating on a shaft, then channeled through a channel called a volute to convert the energy of rotation into potential energy. The pressure that results must be higher than the condensing pressure in order for this device to work. The exit refrigerant pressure is a function of the refrigerant, the impeller diameter and the speed, as well as the geometry of the volute.



Screw compressor

Positive displacement chillers use a compressor that captures a volume of refrigerant and squeezes it into smaller chambers to increase its pressure. Typical modern chillers of this type use either helical-rotary "screw" or scroll compressors. These types of chillers are often smaller and are well suited to higher condensing pressure applications such as thermal storage, heating and air-cooled condensing.

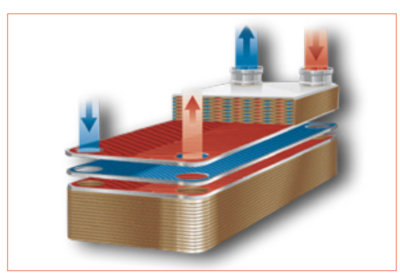
Scroll compressor

Variable speed devices may be applied to all three types of compressors: centrifugal, screw and scroll. These take the place of a traditional starter. Their purpose is to change the speed of the compressor motor in response to changes in the pressures in the evaporator and condenser, and to a lesser degree, the amount of cooling desired. When properly applied, variable-speed devices save energy.

Heat exchanger types

Shell-and-tube heat exchanger

Shell-and-tube heat exchangers have a vessel - the shell - with tubes inserted inside. The refrigerant can be outside of the tubes (flooded) or inside the tubes (direct-expansion.) Distributing the refrigerant and enhancing the tube surfaces, so that the refrigerant molecules interact efficiently with the fluid on the other side of the tubes, while changing phase, is the focus of a lot of engineering. This type of heat exchanger has a wide flow-rate application range.



Brazed-plate heat exchanger

Image courtesy of SWEP

Brazed-Plate Heat Exchangers (BPHE) create areas where refrigerant and liquids exchange energy by welding (brazing) plates together to form channels. Their primary advantage over shell-and-tube is compact size. The range of flow rates is more limited and this type is used most often on smaller, packaged and less customizable chillers.

Chiller Application Considerations

In many ways, the chiller should be the last thing in the chilled water system to be selected. Virtually all other elements impact the chillers, and some chillers will be more suited than others for the intended application. This is a significant paradigm shift from business as usual. Because it's so unusual to think this way, this catalog should be reordered to start with the coil selections.

System Design Order of Operation

ASHRAE's Fundamentals of Design and Control of Central Chilled-Water Plants suggests starting with coil and tower selections to derive, rather than select system temperatures and flow rates, then proceed to chiller selection. Sometimes existing systems present immovable design limitations, though it's important to evaluate whether this is true before accepting any impediments to advancing the system design.

Performance Testing

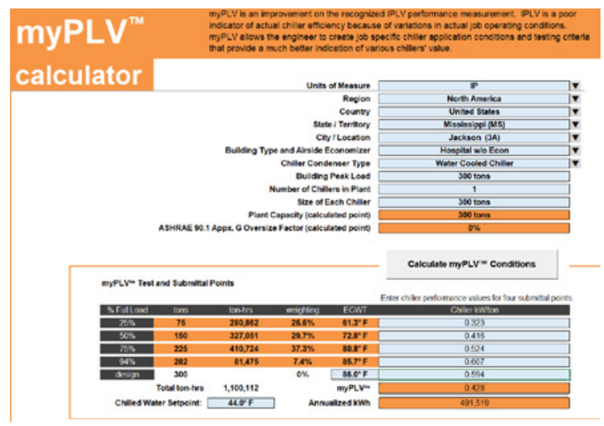
Factory performance tests confirm that your chiller's actual performance matches what was predicted during the selection process before the chiller is installed on site.

Standard AHRI tests are a well-recognized industry practice, performed by all chiller manufacturers. However, a chiller's operating conditions vary significantly based on the needs of the building and its occupants. Data centers, hospitals and retail locations all have specific requirements unique to their application and location. With today's evolving HVAC system designs and customers' diverse performance expectations, standard AHRI tests are often no longer sufficient to accurately confirm that a chiller will operate as required.

That's why Trane designed and built industry-leading testing facilities, capable of evaluating performance based on customer-defined parameters including building type and geographical location. Before the chiller leaves the factory, the new Trane myTest™ program validates chiller performance under the conditions at which it should operate once installed.

AHRI or myPLV® Verification

Verifying chiller performance in real-world conditions is at the core of Trane testing capabilities. Accurate performance starts at the design stage by calculating the appropriate myPLV rating points. The manufacturer-agnostic myPLV tool leverages industry-standard



myPLV tool assists with design choices and performance conditions

building model data, calculating four performance points (94, 75, 50 and 25 percent) based on the specific building type, location and plant design, providing accurate weighting points and condenser temperatures. The myPLV tool also calculates the ton-hours at each of those points necessary to accurately estimate annualized energy use.

Utilizing the myPLV tool from the beginning assures that the selected chiller is appropriate for the particular application. Then, myTest certification confirms the chiller performs as expected. More about myPLV online here.

AHRI 575 sound tests can also be performed in the factory.

"Performance testing of systems is essential to ensure that all the commissioned systems are functioning properly in all modes of operation. That is a prerequisite for the owner to realize the energy savings that can be expected from the strategies and recommendations contained in this Guide."

--Advanced Energy Design Guide, ASHRAE 2009

Air- versus Water-Cooled

The choice between air- and water-cooled chillers generally comes down to several factors, such as operator sophistication, cooling tons, site constraints (such as space, water scarcity, acoustics or climate), first cost and life-cycle cost.

Operator sophistication and availability. Air-cooled systems can be easier to operate, due to the simple fact that there are fewer components. Is a trained operator available? Comprehensive system controls can equalize most of the perceived difference in complexity. However, operators need to be onsite to inspect elements like cooling towers operating in winter.

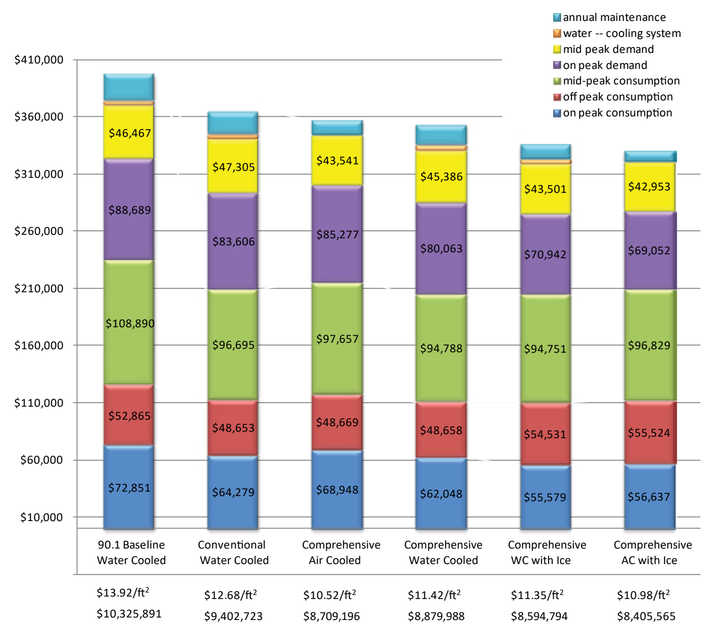
System size. Any chiller that ships assembled is limited by the size of the equipment that transports it. While the largest water-cooled chiller that ships fully assembled might provide 3500 tons of cooling, the largest air-cooled chiller provides less than 600 tons.

Site constaints. Air-cooled chillers are installed outdoors, while water-cooled chillers are almost always indoors with cooling towers outdoors. What kind of space is available for the system? Is the water quality and availability good for water-cooled equipment? Is the air-cooled equipment sound or the cooling tower plume objectionable to the neighbors? Is it a cold climate application where the operating hours are low? Is the air quality suitable for outdoor equipment? Tree seeds, pollens, poor air quality or proximity to the ocean can impact outdoor equipment performance and life expectancy.

First, installed cost. A comprehensive review of the overall first costs must be done for each project, including equipment, site preparation, installation and commissioning.

Life-cycle cost. Air-cooled systems are exposed to the elements and typically don't last as long as water cooled systems do. Air cooled systems don't carry water treatment costs and chemicals. There is no cooling tower to winterize. System efficiency is lower in air-cooled systems than water cooled, though thermal storage can perhaps make up the difference.

Only a comprehensive full-year analysis that includes installed costs, energy and water, maintenance and replacement costs can determine the true total cost of ownership for a given system.



Refrigerant Selection

The industry continues to work through global and national associations to engage with non-governmental organizations (NGOs) and governments to ensure that we transition away from high-GWP refrigerants in a way that is technically feasible, safe, and allows for servicing of existing equipment to ensure a useful life from equipment investments.

Trane offers chillers today in various sizes and types that feature low Global Warming Potential refrigerants. Chillers with this option carry the EcoWise® designation.

The entire CenTraVac® chiller portfolio has earned third-party verification with a product-specific Type III Environmental Product Declaration (EPD), confirming that its environmental impacts are the lowest in the water-cooled chiller industry.

UL CERTIFIED ENVIRONMENTAL PRODUCT DECLARATION UL.COM/EPD

EcoWise™

Air-Cooled Chillers

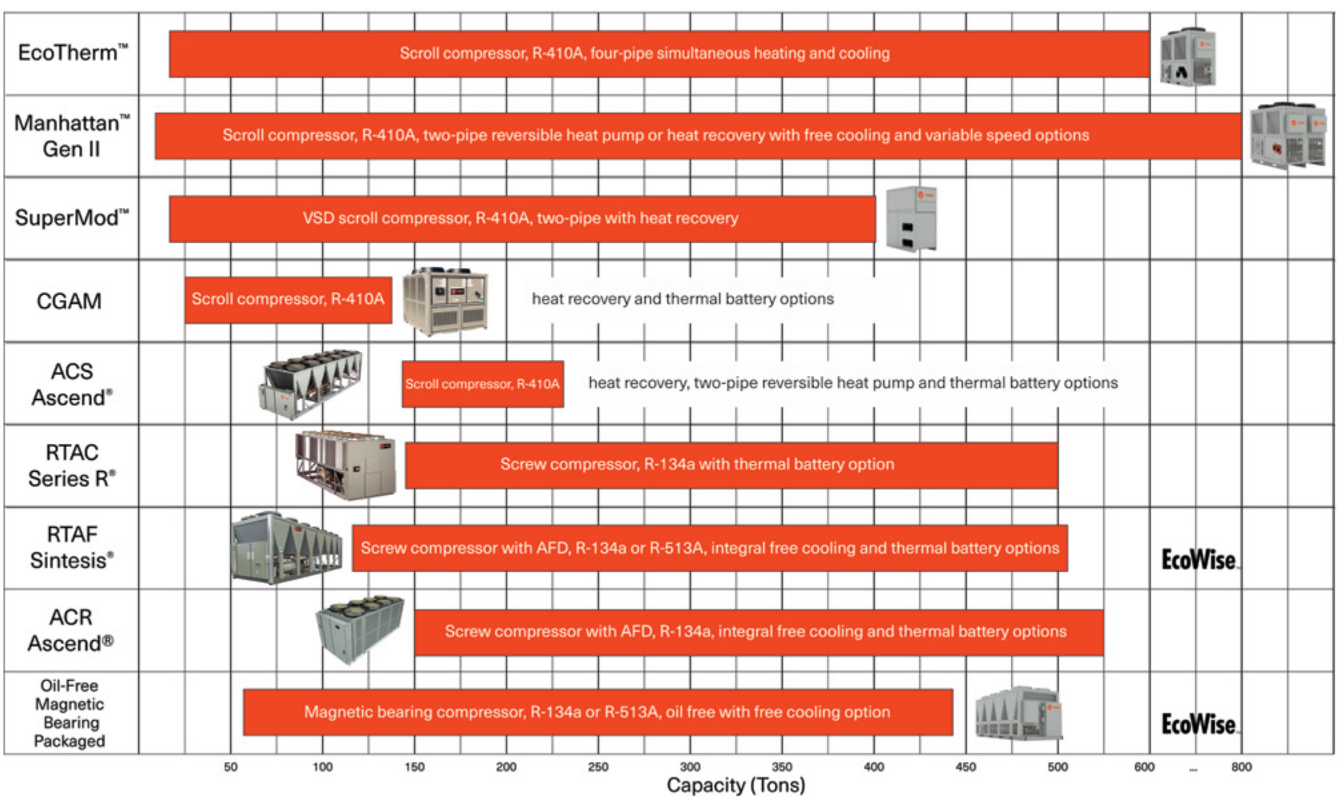
Air-cooled chillers have the advantage of including the entire condensing system in the same package that also chills the water. Optimizations on refrigerant temperatures, fan speed, compressor speed and staging are all accomplished in the on-board unit controller. This control over the larger portion of the system recovers some of the efficiency lost by the higher condensing pressures experienced in air-cooled systems. In addition, air-cooled chillers consume no water. Cooling capacities in packaged air-cooled chillers are limited by transportation. Modular arrangements are assembled onsite to increase air-cooled capacities and resolve installation constraints or costs.

Because of their higher temperature capabilities and better efficiency improvement at night, air-cooled chillers are ideal candidates for Thermal Battery™ energy storage systems.

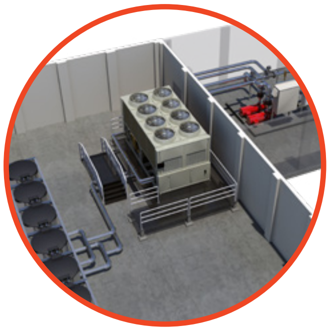
Sound, footprint, efficiency, capacity, installation, service considerations and price are key factors that differentiate one chiller from another. Each chiller platform has advantages in one or more of these criteria. Trane provides interactive selection programs through Trane Select Assist software available online.

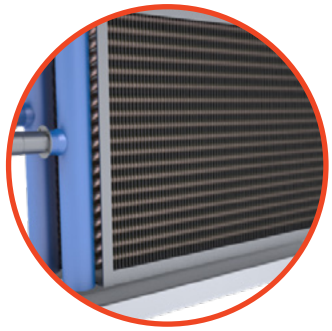
For more information

Air-cooled chiller portfolio at trane.com



Air-Cooled Chiller Selection Considerations

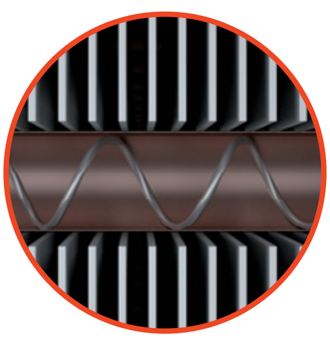




System Configuration and Size
How big and how it's configured drive a lot of choices. For example, variable flow through the evaporator determines, through flow turndown, whether air-cooled chillers make sense (or if variable flow makes sense), or if asymmetry is a help or a hindrance. See previous section for more information on how system configuration impacts chiller selection and vice versa.

Chilled Water Temps and Flows
Temperatures on the chilled water side are an output of the coil and airside selections. By starting with a specific temperature or ΔT in mind, system optimizations may be left behind. This catalog gives guidance on how to select coils for best operation at design and off-design conditions.

Condensing Temps
Temperatures on the condenser side are determined by the location (design drybulb temperature) and whether or not the unit will be used for heating. Partial or full heat recovery, and reversible heat pumps are available variations of standard air-cooled chillers.



Water Quality, Fouling, Fluid Type
The water or fluid to be used in the system impacts the tubes used in a shell-and-tube heat exchangers, flow switch settings, the amount of freeze and burst protection in cold climates, limits and safeties, as well as capacity and efficiency.

Energy Storage
If the chiller will be used now or in the future as part of an energy storage system—whether water or ice storage—minor machine changes may be necessary at the time of selection, and may impact the suitability of a particular chiller for the energy storage application.

Efficiency and Price
Besides the many other considerations, sometimes it all comes down to a decision on the right balance of efficiency and price. Trane has tools to help discover the value that each selection offers—from spreadsheet-based tool myPLV® to TRACE® 3D Plus full-year, whole-building energy and economic simulation.

Water-Cooled Chillers

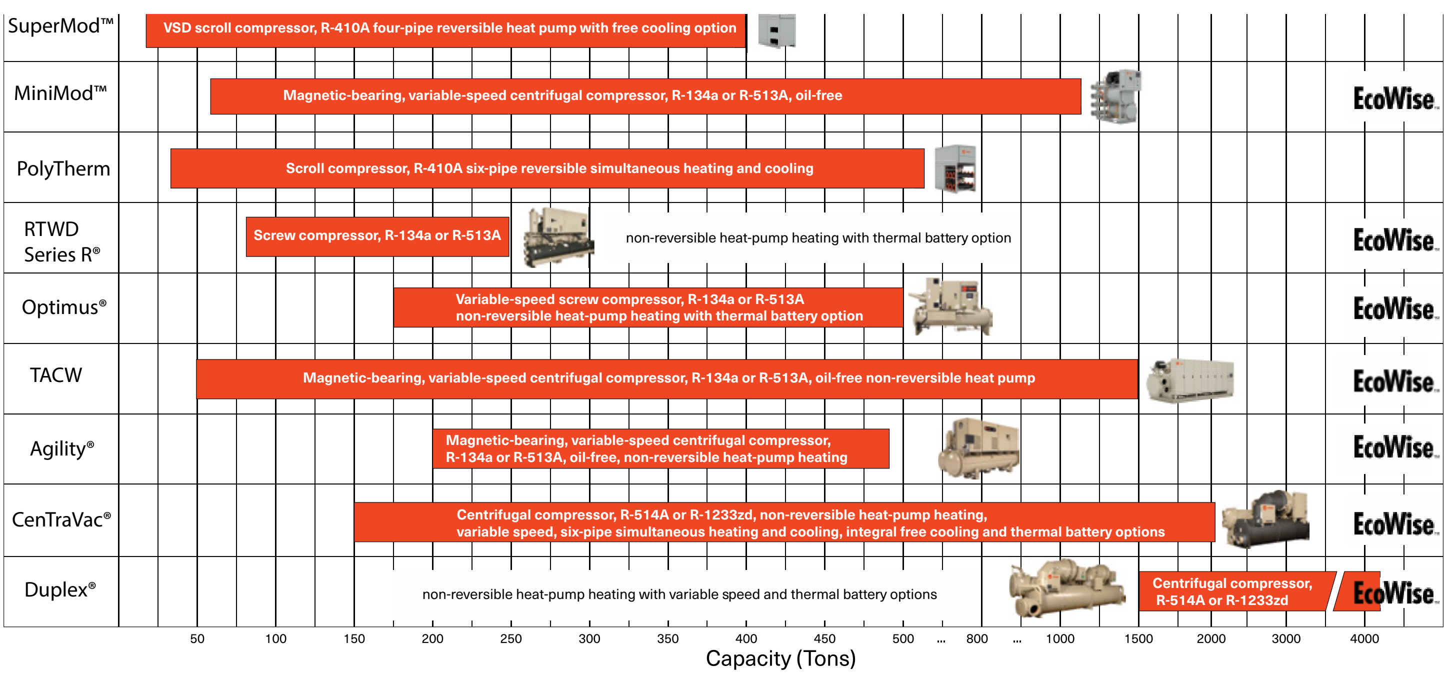
Water-cooled chillers have several advantages, including the flexibility to site chillers and heat rejection in different locations. Optimizations occur within a system controller programmed to accommodate the specifics of the application -- the types and quantities of chillers, pumps, and cooling towers for example. Because rejected heat is entrained in water, it can be easier to divert to heating systems. Comprehensive designs create robust systems that do not rely too heavily on system controls to avoid limiting conditions while still delivering state-of-the-art performance.

The Trane® water-cooled chiller portfolio includes centrifugal, helical rotary and scroll compressor models, ranging in capacities from 20 to over 4,000 tons. Regardless of the chiller you choose, you'll benefit from the exceptional efficiency coupled with reliable performance that has made Trane chillers the industry standard for decades.

Sound, footprint, efficiency, capacity and price are key factors that differentiate one chiller style from another. Each chiller platform has advantages in one or more of these criteria. Trane provides interactive selection programs through Trane Select Assist software available from www.traneselectassist.com.

For more information

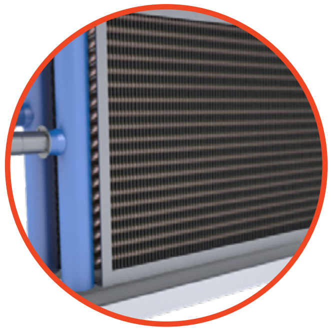
Water-cooled chiller portfolio at trane.com



Water-Cooled Chiller Selection Considerations

System Configuration and Size

How big and how it's configured drive a lot of choices. For example, variable flow through the evaporator determines, through flow turndown, whether packaged or configured chillers make sense (or if variable flow makes sense), or if asymmetry is a help or a hindrance. See previous section for more information on how system configuration impacts chiller selection.

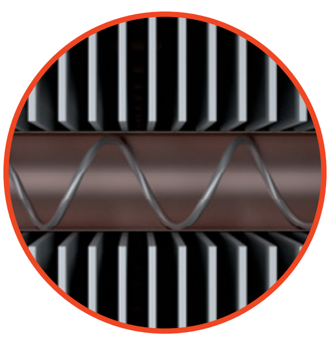


Chilled Water Temps and Flows

Temperatures on the chilled water side are an output of the coil and airside selections. By starting with a specific temperature or ΔT in mind, system optimizations may be left behind. This catalog gives guidance on how to select coils for best operation at design and off-design conditions.

Condensing Temps and Flows

Temperatures on the condenser side are determined by the location (design wetbulb temperature), tower selection and limitations, and by condenser water flow optimization. See the condenser flow optimization section for more on this topic. If the system will recover condenser heat, what is the desired temperature?



Water Quality, Fouling, Fluid Type

The water or fluid to be used in the system impacts the tubes used in a shell-and-tube heat exchangers, needed compressor capabilities, motor selections as well as heat exchanger options such as tube cleaning systems, coatings, sacrificial anodes and other options.

Energy Storage

If the chiller will be used now or in the future as part of an energy storage system—whether water or ice storage—minor or major machine changes may be necessary at the time of selection, especially for centrifugal chillers. Most Trane chillers support both types of energy storage.

Efficiency and Price

Besides the many other considerations, sometimes it all comes down to a decision on the right balance of efficiency and price. Trane has tools to help discover the value that each selection offers—from spreadsheet-based tool myPLV® to TRACE® 3D Plus full-year, whole-building energy and economic simulation.

Condenser-Water Flow Rate Optimization

Design flow-rate considerations

The decision on an optimum flow rate to use for the condenser water loop can be evaluated using the flow optimization portion of myPLV. It can solve for best efficiency, best cost, or a combination of efficiency and cost advantages.

Best efficiency may be achieved by leaving the cooling tower and condenser water pipes sized for 3 gpm/ton, but operated at something lower. This entails selecting a chiller that is capable of creating slightly different condensing pressures. The optimium flow rate will vary based on the application, climate zone, load profile, etc.

Lowest installed costs are achieved when the cooling tower, condenser water pump and condenser pipes are downsized. The impact on peak and annual energy use may be minimal and can be quantified in the flow optimization calculation.

Typical Applications

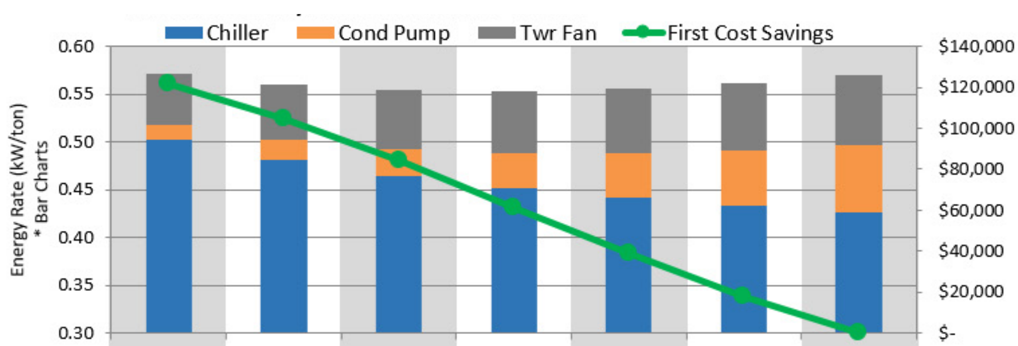
- New projects
- Chillers being replaced
- Towers being replaced
- Expanded capacity needed
- Energy conservation

First cost and operating cost benefits are maximized when the cooling tower and condenser water pump are right-sized but the condenser pipes are kept large. In many cases, there is little to no energy impact of these changes. In fact, a right-sized cooling tower often leads to lower overall system energy consumption.

The first cost benefits are not trivial. Consider all aspects of the system cost, such as roof space and reinforcement, electrical savings, pipe costs and structural support differences, and more.

For more information

Video on condenser-water flow optimization



		1.5	1.75	2	2.25	2.5	2.75	3
	Condenser Flow (gpm/ton)	**1.5**	**1.75**	**2**	**2.25**	**2.5**	**2.75**	**3**
	Selected Flow				X			
	Annualized Results							
	Energy Savings (%)	-0.3%	1.8%	2.8%	3.0%	2.4%	1.4%	0.0%
	Energy Cost Savings ($)	$ (3,408)	$ 8,304	$ 14,207	$ 15,648	$ 12,747	$ 7,761	$ -
First Cost Delta vs 3 gpm/ton	Condenser Pump Cost (Δ$)	$ 26,478	$ 22,466	$ 18,288	$ 13,948	$ 9,450	$ 4,799	$ -
	Cooling Tower Cost (Δ$)	$ 95,098	$ 82,296	$ 65,837	$ 47,549	$ 29,261	$ 12,802	$ -
	Condenser Piping Cost (Δ$)	-	-	-	-	-	-	-
	Total Installed Cost (Δ$)	$ 121,576	$ 104,762	$ 84,125	$ 61,496	$ 38,711	$ 17,601	$ -

myPLV condenser-water flow-rate optimization — balanced first and energy cost option

Variable Condenser-Water Flow

Using system controls to optimize energy

In existing plants, chiller capabilities may make it difficult to operate the plant with ASHRAE GreenGuide-recommended condenser-water flow rates. In cases like these and without chiller replacement(s) planned, it can be beneficial to turn the system into one that uses a lower flow rate some of the time, and a higher flow rate at other times. This strategy is commonly referred to as variable condenser-water flow.

Trane controls can be configured to adjust cooling tower fan speed, condenser-water pump speed and chiller speed simultaneously. Many limit conditions must be determined and programmed into the system. These include: chiller surge and water flow-rate limits, condenser pump limits, tower flow rate limits. In most cases, a very small throttling range for the condenser pump results in the most efficient operating point.

The chart below shows the efficiency benefit of implementing variable flow when ASHRAE GreenGuide flow rates are not an option. In all cases, an optimized cooling tower temperature setpoint made a big difference in energy. The variable flow (second from bottom row) had nearly identical energy use as the GreenGuide-informed, constant flow rate design (middle row.) Variable flow on the GreenGuide design showed virtually no benefit on systems with two or more chillers.

Typical Applications

- Existing plants
- Single chiller plants
- Little to no equipment changes
- Control upgrades needed
- Systems with high condenser water flow (3 gpm/ton+)
- Energy conservation

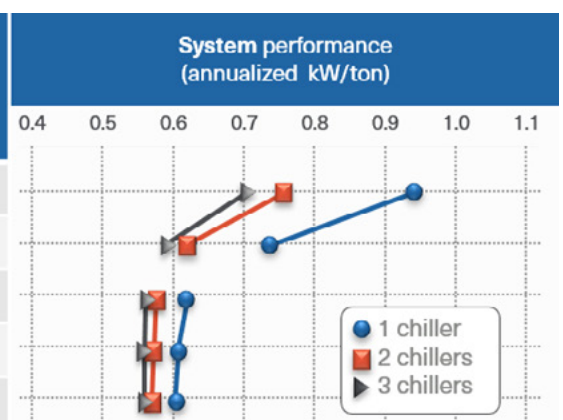
Best practices

- Use the ASHRAE GreenGuide's suggestion of 12 to 18°F ΔT for condenser-water systems (2.3 to 1.6 gpm/ton) to reduce plant installed and life-cycle costs.
- Consider varying cooling tower fan speeds in all installations.
- Consider varying condenser-water pump and cooling tower fan speeds on systems not designed using the ASHRAE GreenGuide guidance, and where the plant operators are on board, training and retrained when the operators change. When used, keep the control method understandable, transparent and as simple as possible (but not simpler.)

For more information

Engineers Newsletter Live available online

Chiller type	Cooling tower fan	Condenser water flow rate (gpm/ton)	Cond water flow type	Tower control method
Var. speed	Var. speed	3	Constant flow	85°F
Var. speed	Var. speed	3	Constant flow	Optimized
Var. speed	Var. speed	2	Constant flow	Optimized
Var. speed	Var. speed	3	Variable flow	Optimized
Var. speed	Var. speed	2	Variable flow	Optimized



Annualized energy consumption of GreenGuide-informed condenser-water flow-rates versus dynamically variable flow rates

Cooling Towers

In a water-cooled HVAC system, condenser water absorbs heat from refrigerant vapor and turns the refrigerant back into a liquid. The warmed condenser water then rejects heat via a cooling tower. The cooling tower must also reject the heat of compression from the refrigeration cycle.

Benefits of using a water-cooled system (versus an air-cooled system) include lower energy costs and a smaller footprint, especially in larger systems. Condensing temperatures may be up to 35°F lower than in air-cooled equipment, due to the evaporative cooling process, which improves overall system efficiency and reduces energy consumption.

How a cooling tower works

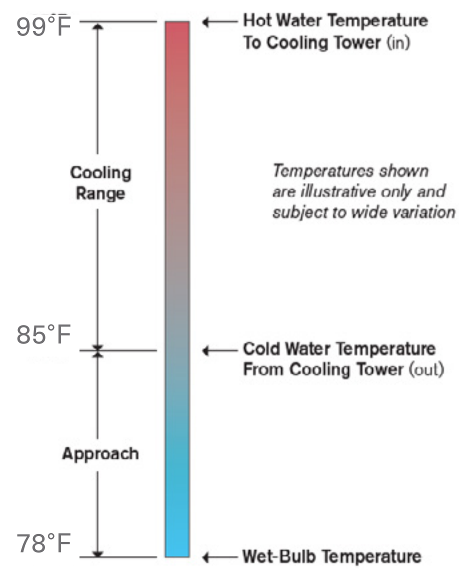
Heated water pumped from the condenser to the cooling tower is sprayed onto banks of heat transfer material called "fill." The fill is designed to slow the flow of water and create as much heat-transfer surface area as possible (where air and water come into contact). Water flowing through the cooling tower is exposed to air brought through the tower by a fan.

Whenever the water and air meet, a small amount of water is evaporated, creating a cooling action. The cooled water is then returned to the condenser where it absorbs heat, and the cycle repeats.

Performance metrics

Approach is the difference between the cold (leaving) water temperature and the entering wet-bulb temperature. Cooling tower manufacturers often use approach as a benchmark for cooling tower performance. All other things being equal, a cooling tower with a smaller approach is thermally superior to a tower with a larger approach. Due to the influence approach has on cooling tower performance, towers are often selected to reach the lowest approach that is economically feasible.[1]

Range is the difference between the hot (entering) water temperature and the cold (exiting) water temperature. A common misconception is that range is influenced by the cooling tower's performance. In reality, range is determined by the process and approach is what



defines the cooling capability of the cooling tower. The figure above provides a visual representation of the relationship between range and approach.[2]

Turndown characterizes the cooling tower's ability to distribute reduced water flow over the fill while maintaining a uniform air-side pressure drop to minimize the risk of ice and scale formation. ASHRAE 90.1-2016 requires open-circuit cooling towers configured with multiple- or variable-speed condenser water pumps be designed so that all open-circuit cooling tower cells can be run in parallel with the larger of either the flow that is produced by the smallest pump at its minimum expected flow rate or 50 percent of the design flow for the cell.

At reduced heat load, significant energy saving opportunities are available when a cooling tower can operate at reduced flow with more cooling tower cells operating together at lower fan speeds. This requires towers with sufficient water flow turndown capabilities.

1 Cooling Tower Approach, Marley/SPX Cooling Technologies White Paper

2 Cooling Tower Range, Marley/SPX Cooling Technologies White Paper

Cooling Tower Variations

Open-circuit cooling towers evaporate a portion of the circulating water to cool it directly by the atmosphere. This is the most energy-efficient way of cooling the process but may introduce particulates and contaminants.

Closed-circuit cooling towers, also called fluid coolers, keep the process fluid (which may not be water) in a closed, clean loop while circulating tower water over a coil. It operates similarly to an open-circuit cooling tower, using evaporative cooling, but eliminates direct contact between the atmosphere and the process fluid. Closed-circuit towers reduce contaminants but decrease energy or heat transfer efficiency.

Crossflow cooling towers have air flowing horizontally while the water falls vertically, across the flow of the air. This design uses basins and gravity to distribute water over the fill. Hot water basins are universally applied on crossflow cooling towers. Water distribution devices within the basin have a direct effect on variable flow, water flow turndown and cold weather operation. Options for crossflow towers can allow turndown greater than 3:1 without additional pump head.

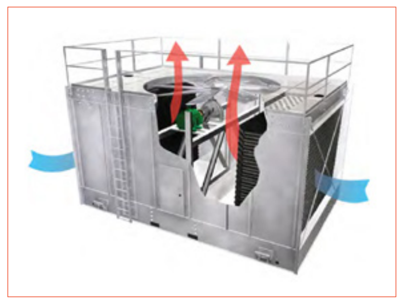
Counterflow cooling towers have air flowing upward, counter to the direction of falling water. Counterflow cooling towers use pressurized spray systems to distribute water. Pipes and nozzles are spaced to not restrict airflow. Counterflow cooling towers typically are lighter and more compact, which may make inspections, maintenance and repair more difficult, depending on the design. Counterflow cooling towers use fewer nozzles to distribute water across the fill, which may increase minimum flow. Some counterflow tower designs and modifications offer greater than 3:1 turndown on water flow.[3]

Induced-draft cooling towers have axial fans on top to draw air through the fill media.

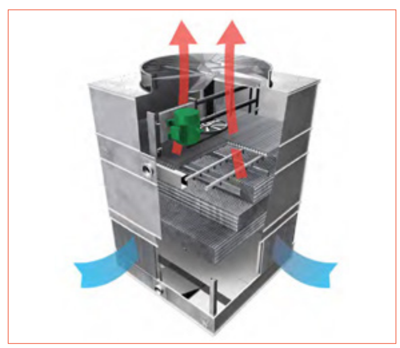
Forced-draft cooling towers push air through the fill with centrifugal or axial blowers located at the base of the air inlet face, or underneath the cooling tower.[4]

Open-circuit cooling tower

Closed-circuit cooling tower "fluid cooler"



Crossflow cooling tower



Counterflow cooling tower

Induced-draft fan

Forced-draft fan

images courtesy of SPX Cooling Technologies and TowerTech

3 Crossflow vs Counterflow Cooling Towers White Paper and Video
4 Induced-Draft vs. Forced-Draft Cooling Towers White Paper

Cooling Tower Variations (Continued)

Axial fans predominate the cooling tower industry because of their ability to move large volumes of air at relatively low static pressures. They are more compact, lower weight, and cost less than centrifugal fans. Axial fans use about half the horsepower of centrifugal fans but emit more sound, especially near the top of the cooling tower, due to the fan tip speed at full speed. However, axial fans usually do not operate at full speed. Variable frequency drives are used to reduce fan speed and have a cubic effect on power reduction, introducing operational cost savings while also reducing sound levels.

Axial fan

Centrifugal fans are typically used for indoor or ducted installations because they can operate against relatively high static pressures. However, their inability to handle large volumes of air and characteristically high input horsepower requirements limit use to smaller applications. They emit lower sound at discharge due to the position of the exhausting air, especially in combination with ducting arrangements.

Centrifugal fan

Factory-assembled cooling towers are built and shipped as complete units or in sections, depending on their overall size and shipping constraints. Some towers are completely factory-assembled, and shipped ready for installation at the site, potentially in less than one hour per module or tower. Most larger cooling towers are manufactured in modules or sections of modules at the factory, and shipped ready for final assembly. When shipped in sections, labor should be anticipated at the jobsite to complete final assembly, such as fastening the top and bottom sections, and mounting some mechanical equipment and fan shrouds.


Factory-assembled cooling tower

Field-erected cooling towers are primarily constructed at the site. Tower components are fabricated, marked, and shipped to the site for final assembly. They often include longer lead times, longer on-site installation time, and more workers on-site for assembly. The manufacturer usually provides labor and supervision for final assembly.


Field-erected cooling tower

images courtesy of SPX Cooling Technologies and TowerTech

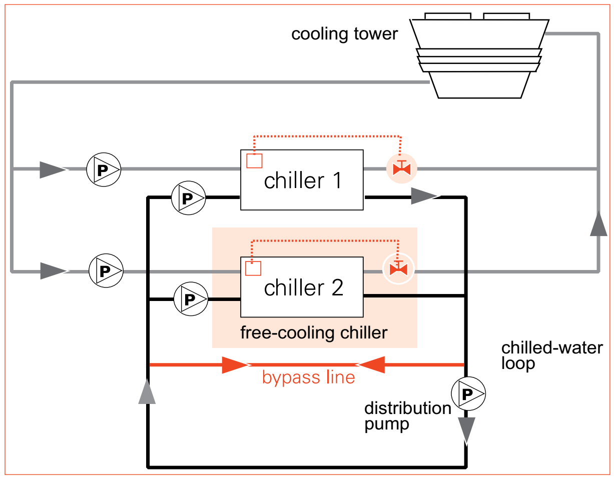
Cooling Tower Energy Saving Strategies

Waterside economizer (free cooling)

"Free cooling" is an energy-saving method when cool outdoor air temperatures are available. Waterside economizers use the evaporative cooling of a cooling tower to produce chilled water without compression cooling. Waterside economizers are suited for climates where the wet-bulb temperature is lower than 55˚F for 3,000 hours or more (most of the U.S.)

Integrated economizers are ideal for data centers and other critical applications with relatively high loads all year. The integrated economizer allows gradual transitions to and from full economizer to full chiller operation.

See other Trane publications and programs for more information on waterside economizers[1,2,3].



Waterside economizer cycle

Cooling tower staging

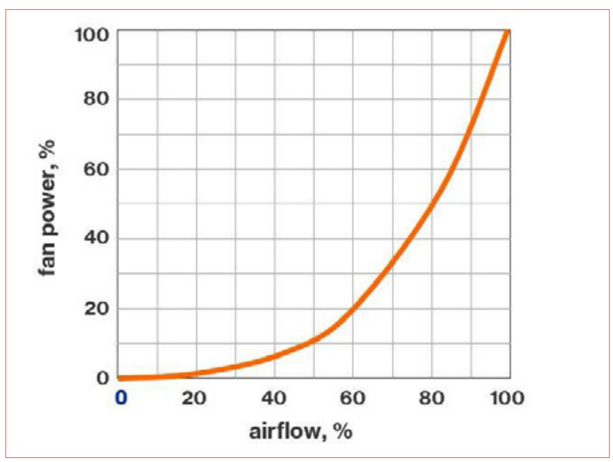
System efficiency can be improved by using more tower cells than chillers. Spreading the heat rejection from the chillers over more tower cells gives the system more surface area for heat transfer. The cooling tower fans slow down to achieve setpoint. This is a way to maximize the effectiveness of the installed cooling tower capacity and may be required by ASHRAE 90.1. Sufficient tower water flow turndown and performance at lower flows are essential for this strategy and should be considered when selecting tower technology and optional features.[4]

	One cell	Two Cells
Total flow (gpm)	1000	1000
Flow per cell (gpm/cell)	1000	500*
Tower setpoint (°F)	65	65
Wet bulb temperature (°F)	60	60
Approach (°F)	5	5
Range (°F)	5.6	5.6
Fan speed (%)	100%	39 %
Total fan power (bhp)	40.0	23.4
Tower fan power savings (bhp)	0	16.6

Effect of operating more tower cells at reduced water- and air-flow

Fan speed control (fixed vs. variable)

Variable Frequency Drives (VFD) are designed to combine absolute temperature control with ideal energy management. Using a VFD can lower operating costs as much as 30% compared to a two-speed motor system, or 70% compared to a single-speed motor system. The cooling tower operator selects a cold water temperature and the system varies the fan speed to maintain the setpoint temperature. Precise temperature control is accomplished with far less stress to the mechanical equipment components. Cooling tower capacity varies directly with the fan speed.



Tower fan energy as a function of flow

1 Airside and Waterside Economizers, Trane Engineers Newsletter Live program
2 Free Cooling with Waterside Economizers, Trane Engineers Newsletter, 2008.
3 Keeping the Free in Free Cooling, Trane Engineers Newsletter, 2011
4 All Variable-Speed Chilled Water Plants, Trane Engineers Newsletter Live program

Cooling Tower Cold Weather Operation

Plume Abatement

Cooling towers produce cold-weather condensation plumes which can impact visibility, transportation and public perception. Plume abatement technologies can effectively address these challenges and also contribute to significant water savings.

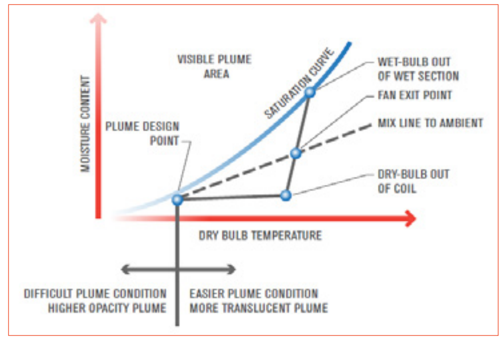
Hybrid wet-dry cooling towers employ technologies to keep the plume from supersaturating as it leaves the tower and mixes with the cooler ambient air. As a result, visible plume is greatly reduced.

Freeze protection

In colder climates, many designers and operators are concerned with operating cooling towers in subfreezing temperatures. By following some simple operating guidelines, cooling towers can and have been successfully operated in very cold climates (-15°C / 5°F) as shown in the photograph at right.

Sustained freezing conditions, such as more than 24 hours without dry bulb temperatures going above 32°F, can be considered “sustained freezing conditions” as no daily freeze-thaw cycle will exist. Wind speeds and other factors should also be considered. In general, when the weather report has a wind chill factor forecasted below 32°F for more than a day, operators should implement their freezing operation strategy. Preferably the strategy is built into the design, automated and in use at all times.

In comparison to comfort cooling, data centers may operate year-round with a high load factor, resulting in the cooling tower size being driven by the economizer duty in cold weather. This can result in the cooling tower being oversized for summer duty. Cooling towers operating in economizer mode must produce water temperatures that are at least equal to, or lower than the chilled water temperatures that would otherwise be produced during conventional chiller operation. Note also, that when such data centers are lightly loaded, which is typical in the early years of operation, a potential impact exists due to the larger cooling tower size under freezing conditions.



Cooling tower cold-weather condensation plume

Before and after plume abatement

Cooling tower operating during freezing conditions

images courtesy of SPX Cooling Technologies

Cold weather operation and methods to avoid and reverse icing are specific to the manufacturer and design. Contact the cooling tower manufacturer for further information.[5]

5 Cold Weather Operation of Cooling Towers by Marley/SPX Cooling Technologies

Cooling Tower Water Use and Maintenance

Water use

Cooling towers were developed to improve systems that formerly used once-through water from lakes and rivers. Water is conserved by recirculating. The consumption of water by evaporative cooling is a function of the heat load and ambient air temperature. The lower the heat load and/or ambient temperature, the less evaporation occurs. When access to water is restricted, hybrid evaporative cooling equipment may be an option. This technology uses a combination of wet and dry components to maximize cooling efficiency at high heat load conditions and minimize water use at reduced load.

As small amounts of water leave the tower and evaporate to remove heat, the water inside the tower becomes more concentrated with dissolved solids such as minerals that produce scale. To minimize this buildup, cooling towers continuously “blowdown” or “bleed off” a portion of concentrated water and replace it with fresh make-up water to maintain acceptable water chemistry.

Cycles of concentration is the ratio between the dissolved solids in the tower water and dissolved solids in the make-up water. High cycles of concentration reduce the amount of blowdown water and make-up water required.

Drift refers to entrained liquid water droplets from the recirculating flow in the discharge air. Unlike the purified condensate water that collects on surfaces before becoming entrained in the air stream, drift droplets contain the impurities and chemicals contained within the recirculating water.

Drift eliminators may be used for environmental permitting purposes or to limit the deposition of drift droplets on structures, vehicles, and populated areas. Drift rates vary with product type, eliminator design, application point and operation. Modern eliminator designs are more efficient than their predecessors—both at capturing drift and achieving lower pressure drop. The latest technology often can achieve 0.001% drift rate, down to 0.0004% drift rate, depending on the tower type and configuration.

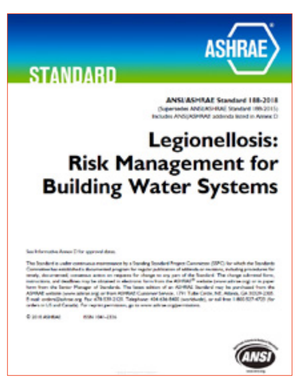
Water treatment

Microorganisms, including the bacteria Legionella pneumophila, can exist in plumbing including cooling towers. At startup, the development of an effective water management plan and implementation of maintenance procedures are essential for preventing the presence, dissemination and amplification of Legionella bacteria and other waterborne contaminants. It is critical to minimize or eliminate areas of basin sedimentation and fill fouling within the cooling tower where embedded microorganisms are protected and proliferate. Before operating the cooling tower, the water management plan and maintenance procedures must be in place and regularly practiced.

Water treatment professionals should evaluate, clean and treat your water prior to startup. Cooling towers must be cleaned and disinfected regularly in accordance with ASHRAE Standard 188 and Guideline 12.

Water chemistry during the initial cooling tower operation is crucial for preventing premature corrosion of galvanized steel (white rust). For at least the first eight weeks of operation, the pH in galvanized steel cooling towers should be controlled between 6.5 and 8.0 with hardness and alkalinity levels between 100 and 300 ppm (expressed as $CaCO_3$).

Consult the cooling tower user’s manual for startup and maintenance guidance specific to the manufacturer.



ASHRAE Standard 188

ASHRAE Guideline 12

Cooling Towers Built by SPX Cooling Technologies

Key components

- A Air-water heat exchanger "fill"
- B Induced-draft axial fan
- C Fan motor, typically variable speed

NC Tower Advantages

Excellence in cooling tower design, efficiency, quality and value define towers from SPX Cooling Technologies, Inc. An unmatched array of cooling tower configurations provides selection options for a wide range of applications and operational requirements.

The NC® crossflow cooling tower provides more fully-assembled, CTI-certified, deliverable tons of cooling than any other packaged cooling tower in the market. The NC cooling tower offers significant customer advantages, including:

- Designed to operate all year
- Adapts to various energy management techniques
- Up to 2189 tons available in one cell
- Fewer cells reduce costs, piping and electrical connections.
- Published sound criteria and specifications independently validated per CTI ATC-128 test code
- Geareducer® gear drive requires no oil changes for first 5 years
- 5-year mechanical warranty
- Factory-installed, single inlet piping reduces components
- Factory Mutual "FM APPROVED" options to meet rigorous loss-prevention standards

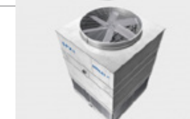
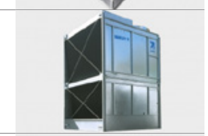
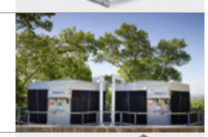
For more information

UPDATE™ Tower Selection Software is designed to correctly size and configure the cooling tower for your specific application.

Register at www.spxcooling.com/update.

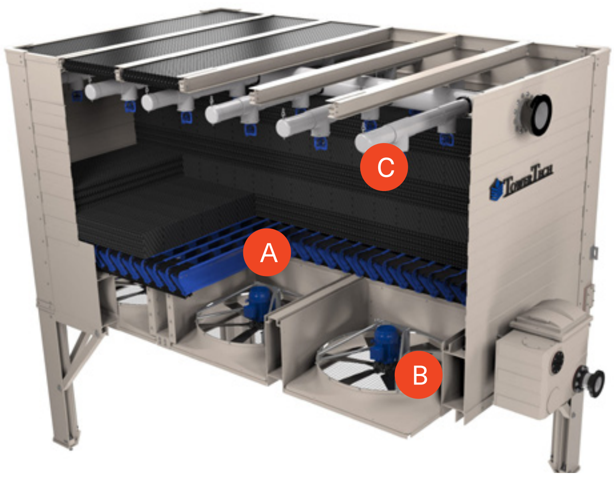
A comprehensive digital library of how-to and instructional videos, engineering data, white papers and product information is available from www.spxcooling.com.

Cooling Tower model selection guide

Type	Model	Factory or Field assembly	Crossflow or Counterflow	Induced or Forced Draft	Flow Range (gpm)	Thermal Capacity (tons)	Construction G-235, SST, FG	FM Option	Special Features or Applications	Picture
Open Circuit	NC	Factory	Crossflow	Induced	132-7746	101-2189	Galvanized or Stainless Steel	Yes	low sound, low flow, MOA, single inlet piping	
Open Circuit, Hybrid	NCWD	Factory	Crossflow	Induced	1180-3100	393-1033	Galvanized or Stainless Steel	Yes	plume abatement, MOA	
Open Circuit	MD	Factory	Counterflow	Induced	352-12,602	89-756	Galvanized, Stainless Steel or Fiberglass	Yes	poor water quality, site placement flexibility	
Open Circuit	AV	Factory	Crossflow	Induced	125-772	375-2316	Galvanized or Stainless Steel	Yes	site placement flexibility, space limitations	
Open Circuit	Aquatower	Factory	Crossflow	Induced	15-1000	8-126	Galvanized, Stainless Steel or Fiberglass	No	small tonnage	
Open Circuit	Quadra-flow	Field	Crossflow	Induced	300-4250	129-1047	Stainless Steel or Fiberglass	No	low height, knockdown, field assembly	
Open Circuit	MCW	Factory	Counterflow	Forced	40-2905	18-600	Galvanized or Stainless Steel	No	ducted installation	
Closed circuit fluid cooler	MH	Factory	Crossflow	Induced	31-7330	78-628	Galvanized or Stainless Steel	Yes	energy conservation	
Closed circuit fluid cooler	ΔT	Factory	Counterflow	Induced	75-1800	45-308	Galvanized or Stainless Steel	No	dry operation	
Closed circuit fluid cooler	LW	Factory	Counterflow	Induced	40-1200	18-107	Galvanized or Stainless Steel	No	low height, one piece	
Closed circuit fluid cooler	MC	Factory	Counterflow	Forced	30-860	11-205	Galvanized or Stainless Steel	No	ducted installation, not CTI listed, 90.1-exempted applications	

Cooling Towers Built by Tower Tech

TTXR Series Modular Cooling Tower, a forced-draft, counter-flow cooling tower



Key components

- A Air-water heat exchanger “fill”
- B Forced-draft axial fans
- C Spin-Free™ spray nozzles

Tower Tech Advantages

The Tower Tech TTXR Series Modular Cooling Tower interconnects individual modules to accommodate virtually any cooling capacity and future expansion.

- Increased performance and water flow turndown
- Lowest life-cycle cost
- Smaller footprint
- Industry leading 15-year limited warranty

Increased performance and water flow turndown is achieved by optimizing the water distribution system through controlled turndown, by using Spin-Free™ spray nozzles designed for better fill coverage at all flows and through uniquely managed basin water. In systems with lower design condenser water-flow rates, this added turndown enables advanced chiller-tower staging and control optimization. Tower cells can be active longer and under more load and flow combinations, for improving the effective heat-transfer surface area and decreasing energy use.

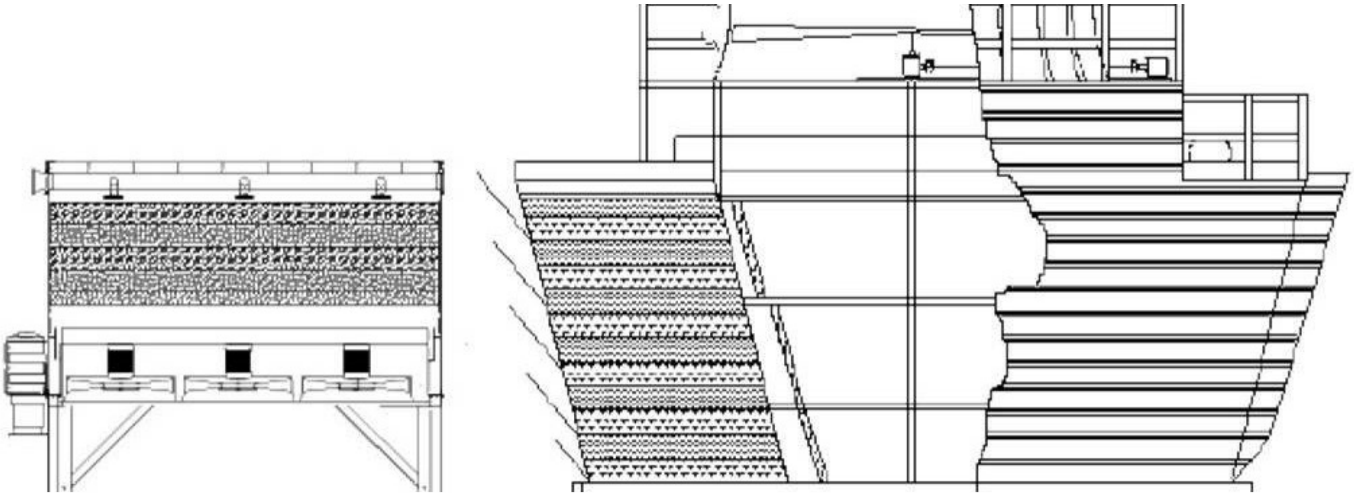
Lowest life-cycle costs are achieved through lower installation, maintenance and water costs. All scheduled inspections and routine maintenance can be safely performed at ground level. Tower Tech uses spray nozzle designs that are unlikely to clog. The spray patterns cover fill better at lower flows and pressures, leading to less scaling. Fan and fan-motor life are extended by locating the fans in the cool, dry, ambient air stream on the entrance face of the tower. Neither the fans nor the motors on a forced-draft cooling tower are subjected to the hot, moist air stream at the exit of the tower encountered in an induced-draft cooling tower.

Quick installation in less than 30 minutes that reduces labor cost is made possible by its factory-assembled, modular design, with a pre-engineered certified substructure that reduces infrastructure cost.

Lowest drift rates (0.0004%, certified) are achieved due to the lower discharge velocities implicit in forced-draft designs. TowerTech's design further reduces drift by using a flow-through basin to eliminate splash out. Enclosing the fill (thereby not using louvers) eliminates windage and paths for water to escape. Water use and chemical treatment costs are significantly reduced.

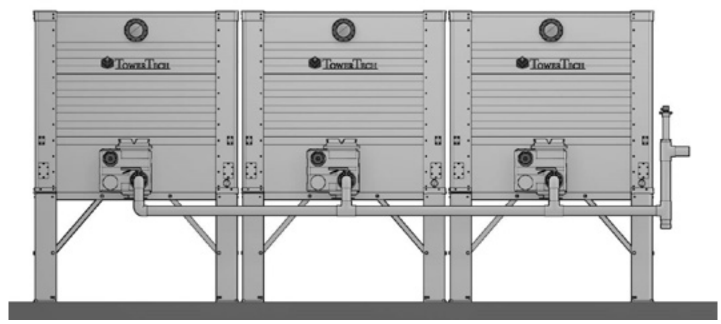
With the longest lifespan of any factory-assembled cooling tower, TowerTech offers an industry-best, 15-year limited warranty.

Smaller footprints are achieved through a combination of design elements. The TTXR Series towers contain Spin-Free™ spray nozzles that disperse hot water from the water distribution piping to the fill media. Its lateral spray pattern allows the nozzle to be positioned as close as one inch above the surface of the fill material, saving several feet of pump head and reducing height. A turbine in the nozzle atomizes the flow efficiently.



Tower Tech (left) versus induced-draft cooling tower of same capacity

Variable water flow through the cooling tower is a function of the tower's water-flow turndown capabilities and ability to maintain good fill coverage/wetting at reduced flow. Even when chiller-condenser flow is constant, opening as many cells as possible is required by the energy codes, and leads to variable flow from the cooling tower's perspective. Conventional water distribution in cooling towers sacrifices energy savings because it raises the minimum tower-water flow-rate, below which towers are turned off and isolated, thereby reducing system heat transfer performance.

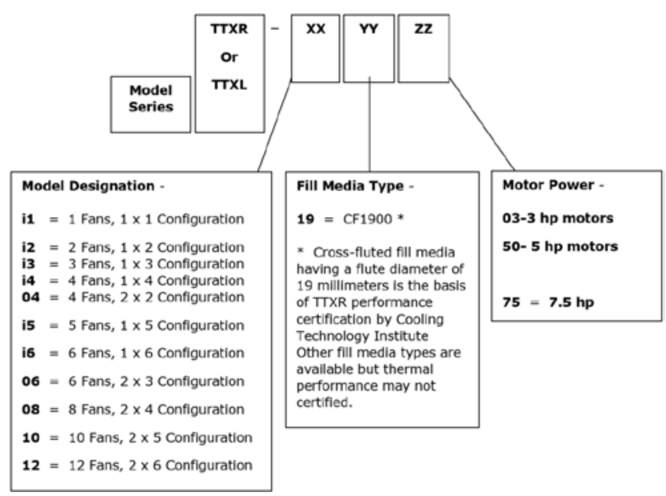


Tower Tech modular cooling towers (three)

Tower Tech nozzles respond to flow changes while keeping a constant pattern—a square pattern that avoids overlap. For example, you might specify a 2/3 water flow turndown to allow the most efficient chiller-tower-pump staging, thereby allowing one chiller to flow over three tower cells at part load conditions.

Model nomenclature

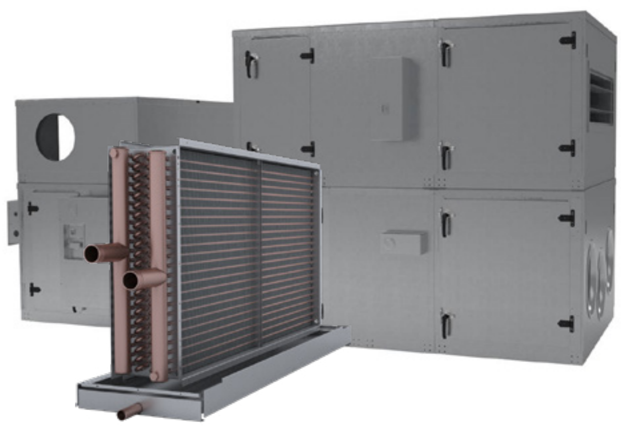
A single-fan tower is nominally 100 tons. A 10-fan tower is 1,000 tons. For an example 4,000-ton application, four Tower Tech 10-fan 1,000 ton modules or five, 8-fan 800-ton modules could be used, among other combinations. There are eleven module sizes.



For more information

- https://www.youtube.com/channel/UCQQYRUBGrX049vfmwVJJbuw
- www.towertechusa.com
- https://towertechinc.com/resource-library/

Coil Selection



When it comes to selecting the coils in air-handling units, whether cataloged or custom, there are (too) many choices. This excerpt from an Engineers Newsletter[1] goes through some of the ways judicious coil selections lead to superior chilled water system performance, both at full load and part load/airflow, while meeting energy and indoor air quality code requirements.

Consider the task of selecting a chilled-water coil for a mixed-air VAV air handler that cools 7000 cfm to 53°F leaving the coil. The entering chilled-water temperature is 42°F, with a 15°F ΔT at design conditions.

Coil #1 has six rows of 3/8-inch diameter tubes and turbulators. These are devices mounted inside the tubes that increase fluid turbulence to improve heat transfer.

Coils #2 and #3 have six rows of 1/2- inch tubes, one with turbulators and the other without. Notice that turbulators allow coil #3 to provide the required capacity with fewer fins than coil #2. This reduces the air pressure drop, but increases the water pressure drop. Whether or not this additional water pressure drop impacts the size of pumps, or pump energy use, depends on whether or not this coil is located in the "critical circuit" of the piping system.

Coil #4 has six rows of 5/8-inch tubes and turbulators.

For this example, coil #1 is the least expensive option. Coil #4 is the best choice for minimizing both air and water pressure drops, but it costs more than the other options. Coil #2 or #3 might be selected to better balance cost and pressure drops.[2]

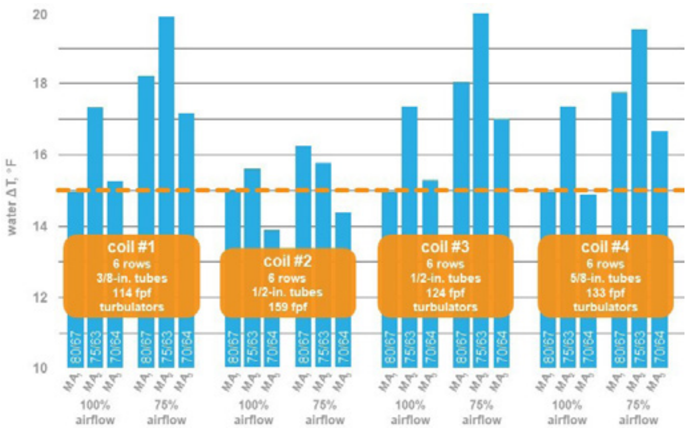
1 Trane. Selecting Chilled-Water Coils for ASHRAE 90.1's New 15°F Delta T Requirement. Engineers Newsletter. 2019

2 Trane. Chilled-Water Coil Selection and Optimization white paper. CLCH-PRB062A- EN. 2016.

	coil #1	coil #2	coil #3	coil #4
entering-water temperature, °F	42	42	42	42
leaving-water temperature, °F	57	57	57	57
water ΔT, °F	15	15	15	15
tube diameter, in.	3/8	1/2	1/2	5/8
coil rows	6	6	6	6
fin density, fins/ft	114	159	124	133
fin design	high capacity	high capacity	high efficiency	high efficiency
turbulators	yes	no	yes	yes
water flow rate, gpm	40	40	40	40
water velocity, ft/s	2.7	2.8	2.8	2.1
water pressure drop, ft. H_2O	11.2	4.7	11.1	5.2
air pressure drop, in. H_2O	0.81	0.95	0.71	0.71
cost of coil	base - 30%	base	base + 8%	base + 15%

Based on size 14 Performance Climate Changer air-handling unit with coils constructed of copper tubes and aluminum fins.

Example coil selections



Coil performance at design and off-design conditions

Effect of part-load operating conditions. ASHRAE Standard 90.1 requires a minimum 15°F ΔT at design conditions. This allows for a lower water flow rate (gpm) and a reduction in installed cost due to smaller valves, pipes, and pumps. But the other motivation is to reduce pump energy use, for which part-load operation (off-design conditions) also matters.

For the mixed-air VAV system in this example, the entering-air conditions will change as the outdoor conditions change, and the airflow across the coil will change as the zone-level VAV dampers modulate. Figure 2 shows the resulting water ΔT of these same four coils—each selected to achieve a 15°F ΔT at design conditions—at three different entering-air conditions at which the cooling coil will still be active, and at two different airflows.

At part-load conditions, the coils with turbulators (#1, #3, and #4) are able to maintain, or even increase, the water ΔT. However, for the coil without turbulators (#2), the water ΔT starts to drop at the third part-load condition. And in all cases, the ΔT is not as high in coil #2 as it is in the coils with turbulators.

Turbulators increase fluid turbulence, which improves heat transfer. This allows a coil to provide the required capacity with a lower water flow rate (higher ΔT), leading to reduced pumping energy at part-load conditions. After analyzing many coil configurations, this is a consistent trend.

Impact of laminar flow. The ASHRAE Handbook suggests that chilled-water coils are best selected with water velocity between 2 to 4 ft/sec, at design conditions.[3] This recommended range is intended to provide a good balance between coil size and minimizing both air and water pressure drops.

But water velocity is also important because it is one of the key factors for determining flow turbulence, depicted by the Reynolds Number. As the turbulence of a moving fluid increases, so does its ability to transfer heat from the tube wall to the fluid.

Some in the HVAC industry express concern that coil heat transfer deteriorates rapidly if the Reynolds Number falls into the laminar flow region. The performance prediction methodology prescribed by AHRI Standard 410 was refined in 2001, allowing coil performance to be accurately predicted well into the laminar flow region, without fear of large discrepancies between predicted and actual performance.[4]

Laminar flow does not cause a severe drop-off in capacity. And the AHRI prediction methods allow coils to be rated accurately well into the transitional and laminar flow regions.

More fins or tubulators? To achieve the 15°F minimum ΔT, some designers may choose to select the coil with more fins. This will increase the air pressure drop. Other designers may choose to select the coil with turbulators. This will increase the water pressure drop, but results in higher water ΔTs at part-load conditions, which leads to pump energy savings. And designing the system with a slightly lower entering-water temperature can allow the coils to be selected with little or no impact on air pressure drop and fan energy use.

3 ASHRAE. ASHRAE Handbook—HVAC Systems and Equipment, Chapter 23 (Air- Cooling Coils). 2016.

4 Air-Conditioning, Heating, and Refrigeration Institute (AHRI). AHRI Standard 410-2001: Standard for Forced-Circulation Air-Cooling and Air-Heating Coils. 2001.

Effect of Water Temperature on Coil Selection

Warmer versus colder water temperatures

This new requirement in Standard 90.1 requires the leaving-water temperature be no colder than 57°F, allowing it to be warmer.

Table 2 compares coils selected for a 15°F ΔT, but with different entering-water temperatures. Coils #2 and #3 are from the previous example, with 42°F entering water. Coils #5 and #6 are selected with a 45°F entering-water temperature.

The coils selected with warmer water (#5 and #6) require eight rows of tubes to provide the necessary capacity. This results in much higher air and water pressure drops than the six-row coils selected with colder water (#2 and #3). And not only will the coil be more expensive due to these additional rows, the air-handling unit will likely need to be longer, which increases the cost of the casing as well.

Even though the chiller has to work a little harder to make the 42°F water versus 45°F in this example, this is typically more efficient than making the fans and pumps both work harder to overcome these higher pressure drops.

Water ΔT higher than 15°F

Note that Standard 90.1 requires the water ΔT to be 15°F or higher. There are many in the industry who recommend ΔTs even higher than this.

In the table below the two right-most columns show the impact of selecting for higher water ΔT. Coil 7 reverts to 42°F entering water like coils 2 and 3, but with a 20°F ΔT. Coil 8 is selected with 40°F entering water and a 25°F ΔT.

The larger water ΔTs reduce the water flow rate even further—from 40 gpm down to 30 gpm or 24 gpm—and also reduce the water pressure drop. This significantly lowers pump energy use. However, in this example, the higher ΔTs require more coil surface area, so air pressure drop does increase.

	coil #2	coil #3	coil #5	coil #6	coil #7	coil #8
entering-water temperature, °F	42	42	45	45	42	40
leaving-water temperature, °F	57	57	60	60	62	65
water ΔT, °F	15	15	15	15	20	25
tube diameter, in.	1/2	1/2	1/2	1/2	1/2	1/2
coil rows	6	6	8	8	8	8
fin density, fins/ft	159	124	153	113	114	135
fin design	high capacity	high efficiency	high capacity	high capacity	high efficiency	high capacity
turbulators	no	yes	no	yes	yes	yes
water flow rate, gpm	40	40	40	40	30	24
water velocity, ft/s	2.8	2.8	2.8	2.8	2.1	1.6
water pressure drop, ft. H2O	4.7	11.1	5.8	15.1	8.4	5.8
air pressure drop, in. H2O	0.95	0.71	1.2	1.0	0.88	0.92
cost of coil	base	base + 8%	base + 30%	base + 35%	base + 30%	base + 35%

Effect of entering water temperature on coil selections and higher ΔT options

Coil Selection for Cleanability

ASHRAE 62.1 Limit on Air Pressure Drop

As mentioned, the Standard 90.1 committee stated in their foreword to this addendum that their intent was to encourage the use of coils with more heat transfer surface to achieve higher ΔT. In some cases, this might result in a higher air pressure drop.

ASHRAE Standard 62.1 includes a requirement intended to ensure that coils can be properly cleaned. Deeper coils with more rows, and coils with a higher density of fins, can be more challenging to clean.

The Standard 62.1 committee addressed this issue by prescribing a limit on coil air pressure drop, as a surrogate measure for clean-ability. In other words, coils with higher air pressure drops are, in general, more difficult to clean properly.

5.11.2 Finned-Tube Coil Selection for Cleaning. Individual finned-tube coils or multiple finned-tube coils in series without intervening access spaces of at least 18 in. shall be selected to result in no more than 0.75 in. H2O combined dry-coil pressure drop at 500 fpm face velocity.

But notice that this is at a specific air velocity (500 fpm), and this limit is based on the air pressure drop when the coil is dry (not dehumidifying).

	coil #2 (wet)	coil #2 (dry)
coil airflow, cfm	7000	6820
coil face velocity, fpm	513	500
entering dry-bulb temperature, °F	80	80
entering wet-bulb temperature, °F	67	55
entering dew point temperature, °F	60	30
leaving dry-bulb temperature, °F	53	53
tube diameter, in.	1/2	1/2
coil rows	6	6
fin density, fins/ft	159	159
fin design style	high capacity	high capacity
turbulators	no	no
air pressure drop, in. H2O	0.95	0.70

Air pressure drop of a wet versus dry coil

For this example, the entering-air conditions are 80°F dry bulb and 67°F wet bulb, which equates to a 60°F dew point. The air is being cooled to 53°F, which means that water vapor will be condensing out of the air and onto the coil surface. Therefore, the air pressure drops listed are for a wet coil, not dry.

To ensure that a selected coil complies with this requirement, use the manufacturer's selection program to re-run the performance of the coil, but change the entering-air conditions so that the coil will be dry, with no condensation. In this example, by lowering the entering wet bulb from 67°F to 55°F, the entering dew point drops to 30°F—well below the coil surface temperature, so the coil will operate dry.

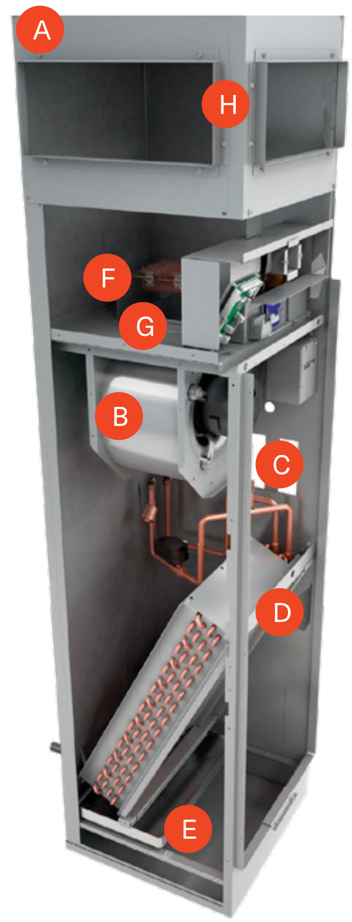
The first column in Table 4 shows coil #2 from the previous example. The air pressure drop is 0.95 in. H2O, but this is when the coil is wet. The second column shows the same coil, with the entering wet bulb changed to 55°F, so the coil will operate dry. (Note that the airflow was also changed slightly, so that the air velocity is exactly 500 fpm.) Under these dry conditions, at the prescribed air velocity, the air pressure drop is 0.70 in. H2o, so this coil does comply with the Standard 62.1 limit on air pressure drop.

This section of the standard requires that the air pressure drop of a finned- tube coil cannot exceed 0.75 in. H_2O.

UniTrane® Vertical High-rise Fan Coil

Key components

- A 18 ga. galvanized cabinet with acoustical liner
- B Direct-drive centrifugal fan - EC fan motor with sealed bearings standard
- C Piping package factory installed (hot water reheat)
- D Chilled or hot water coils, 2-pipe or 4-pipe
- E Drain pan - stainless steel or polymer, positive sloped to outlet
- F Optional electric heater (behind panel)
- G Electrical box for unit-mounted thermostat
- H Supply air opening (multiple openings available)



UniTrane Advantages

- Latest technology for efficiency and sound
- Lower operating and installation costs
- Improved end-user satisfaction and comfort

UniTrane vertical high-rise fan coils[1] are in-room heating and cooling units for applications such as hotels and office buildings. When paired with single-zone VAV controls from Trane, these units offer better energy efficiency, acoustical performance and comfort for your high-rise buildings.

The units come in six sizes, ranging from 300 to 1,200 CFM. With their compact size, these units are ideal for applications where accessibility or footprint is limited.

Also available

- Pipe risers
- Double deflection supply air grille
- Return air panel
- Filter
- Pressure-independent control valves

1 Product catalog

Flexible connectivity

Unlike competitive offerings, UniTrane vertical high-rise fan coil units offer building connectivity through multiple controls options. Pre-programmed Air-Fi® wireless controls can offer plug-and-play connectivity and work seamlessly with other building systems by using a terminal strip or factory-provided thermostat connectivity option.

Support from Trane

Trane's outstanding reputation for high-quality products and service, as well as dedication to innovative solutions, extends to the UniTrane vertical high-rise fan coil units. Trane offers an up-to-five-year extended warranty for parts and labor coverage for the units. Trane also offers an option to order a demo unit for mock-up installations at a competitive price with a short lead time.

UniTrane® Vertical High-rise Fan Coil (cont.)

Improved tenant satisfaction

- Electronically commutated motor (ECM) softly ramps motor speed, helping reduce audible distraction
- Return-air door minimizes unit acoustics for quiet operation
- Cleanable insulation with dual-sloped, slide-out drain pan option allows for easy cleaning, helping to eliminate mold and improving air quality

Lower total operating costs

- Factory-provided ECM with single-zone VAV controls up to 66 percent more efficient than a traditional higher-efficiency option, meeting capacity requirements at the lowest operating costs
- Brushless ECM technology and higher quality valves don't wear easily and have longer service-lives
- Trane Air-Fi® wireless controls with lifetime batteries reduces service costs associated with changing out batteries

Quick-and-easy installation

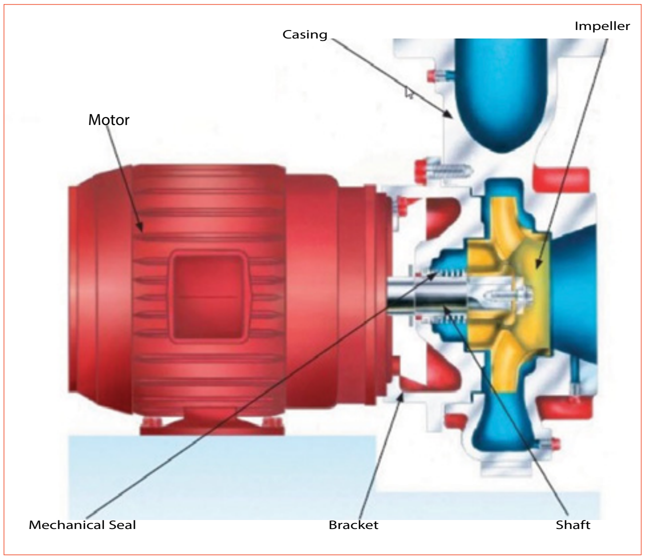
- Pre-programmed Air-Fi wireless controls reduce installation costs and time
- Flexible ship schedule put units in your hands more quickly
- Improved unit labeling and tagging, including build floors and risers, makes for easier job coordination and faster installation time.
- With multiple possibilities for outlet locations, customers have many options with discharge configurations, making these units easier to integrate in your overall design and keeping install time to a minimum.

Improved maintenance and ease of use

- Easy-access return-air door provides quick exposure to serviceable components.
- VelociTach™, an ECM control board that features an LED screen exclusive to Trane, provides real-time feedback to installers and maintenance staff, eliminating the use of a separate service tool.

Pumps

In hydronic systems, pumps develop the pressure necessary to circulate fluids through the various system components at the desired flow rate. In HVAC systems centrifugal pumps are typically specified to meet heat transfer fluid flow needs. Centrifugal pumps increase fluid pressure from the pump suction side to the discharge side by imparting kinetic energy into the fluid and subsequently transforming the kinetic energy into static pressure energy by reducing the fluid velocity. Within the pump casing, a rotating impeller rapidly accelerates fluid radially and outward, which increases its dynamic pressure. The fluid then proceeds through stationary elements inside the pump casing (e.g. diffusers and volutes) which reduce the fluid velocity, converting the dynamic pressure into a higher static discharge pressure. The impeller is typically mounted to a shaft which is in turn driven by an electric motor.

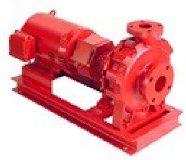


Typical centrifugal pump package cutaway

(image courtesy of Armstrong Fluid Technology)

Pump Types

There are many types of centrifugal pumps including end-suction, vertical in-line and horizontal split casing. End-suction pumps have horizontal pump shafts with suction water flow aligned with the “end” of the pump shaft and water discharge at a right angle to the pump shaft. In horizontal split casing pumps the pump shaft is oriented horizontally and the inlet and outlet water flow are oriented along a common horizontal axis at a right angle to the pump shaft and the pump casing is split for ease of pump service. For vertical in-line pumps the pump shaft is oriented vertically and the inlet and outlet water flow are oriented along a common horizontal axis for ease of piping and mounting. The pump can typically be supported by the piping system providing for significant space savings. Multiple impellers are used in parallel for higher flow capacity and in series for higher head capability. Pumps are connected to motors either directly or with couplings. Close-coupled pumps either have the pump impeller directly connected to an extended motor shaft or the pump shaft is connected to a standard motor shaft using a rigid or spacer coupling. Long-coupled pumps incorporate a flexible coupling between the pump shaft and motor shaft. Longer arrangements with flexible couplings tend to provide for easier pump servicing.

Pump Type	Characteristics
	• Compact, right angle in to out • Floor mounted • Close-coupled or flexible coupling which allows more motor options • < 5000 gpm and 600’
	• Maintenance ease • Floor mounted • Single or double suction which reduces hydraulic imbalance • Close-coupled or flexible coupling • Multiple parallel impellers for increased flow • < 7000 gpm and 600’
	• Pipe supported for lower installed cost, do not require inertia base • In-line suction and discharge • Close coupled • Multiple parallel impellers for increased flow • < 25,000 gpm and 300’

Images Courtesy of Armstrong Fluid Technology

Pump Performance

Pump performance is characterized by a series of curves depicting the relationship between flow and pressure for various impeller speeds and diameters. Mechanical efficiency and brake horsepower are commonly included. The Best Efficiency Point (BEP) refers to the zone of highest efficiency on the pump curve and typically occurs near the midpoint of the head and flow range. Pump energy consumption is determined by the pump mechanical efficiency, the motor efficiency and the efficiency of the motor controller (e.g. VFD.) Equations for water hydraulic horsepower (PH), pump brake horsepower (BHP) and wire-to-water horsepower (WWHP) are given below for water flow (Q) in gpm and total dynamic head (TDH) in feet. TDH is the height of a water column equivalent to the sum of fluid friction losses in all system components such as heat exchangers, pipes and flow controls. For fluids other than water the equations are multiplied by the fluid's specific gravity.

Net Positive Suction Head or NPSH is an important parameter in pump selection and system configuration and includes both NPSH available (NPSHA) and NPSH required (NPSHR). NPSHA is the sum of all static pressure and friction losses on the suction side of the pump. NPSHR is specified by the pump manufacturer

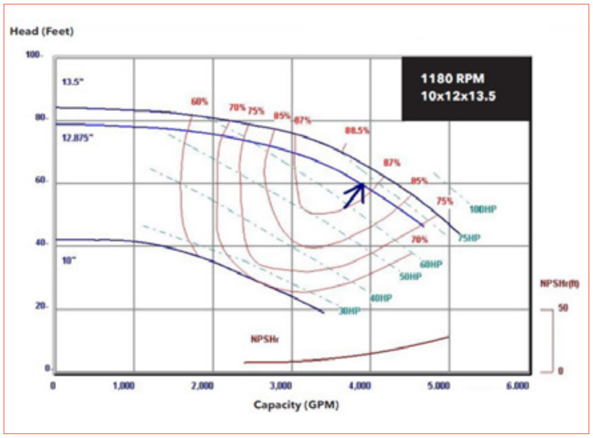
$$P_H = Q \times TDH \div 3960$$

$$BHP = P_H \div \eta_{pump}$$

$$WWHP = BHP \div (\eta_{motor}\ x\ \eta_{vfd})$$

and is the minimum head pressure required at the pump inlet to prevent fluid from flashing into a vapor. If fluid vapor bubbles are formed at the pump suction, they will subsequently collapse violently within the impeller causing surface erosion known as cavitation. Cavitation can significantly degrade pump performance and sound quality. By ensuring NPSHA is greater than NPSHR, cavitation can be avoided.

A typical manufacturer's pump chart includes pump head, flow, pump mechanical efficiency, brake horsepower and NPSHR.

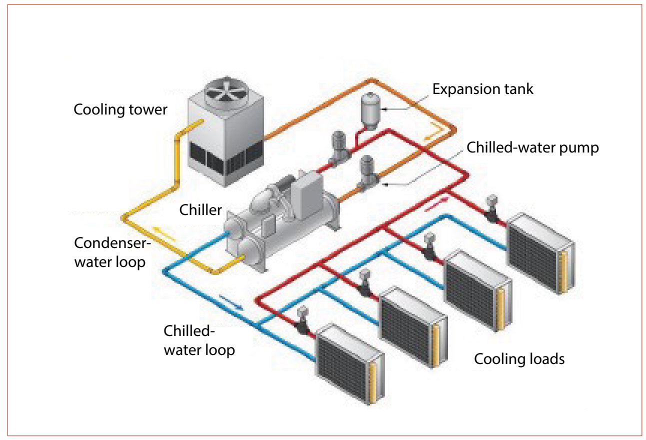


Typical pump chart

Open- and closed-loop systems

Central plants may include open-loop and/or closed-loop hydronic circuits. In closed-loop circuits the fluid has only one interface with a compressible gas and elevation does not create system flow. In open loop systems the fluid has multiple interfaces with a compressible gas and/or an elastic surface and elevation may create system flow. Compressible gas interface points can include cooling tower basins and discharge nozzles as well as the bladder inside an expansion chamber. Note that elevation differences only need to be considered in system curves for open-loop systems. In closed loop systems the discharge elevation and suction elevation head cancel each other.

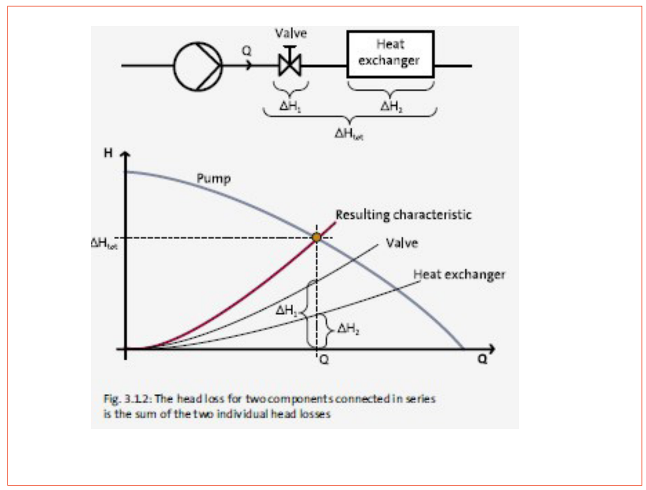
An example system with both an open-loop and closed-loop system is shown at right. Open loop system components are also subject to more severe chemical conditions, in which case pump materials of construction become even more important in the selection process. Be sure to consult the specific pump manufacturer's material specifications to ensure compatibility with the fluid chemical and electrolytic properties.



Open loop (yellow/orange), closed loop (red/blue) system

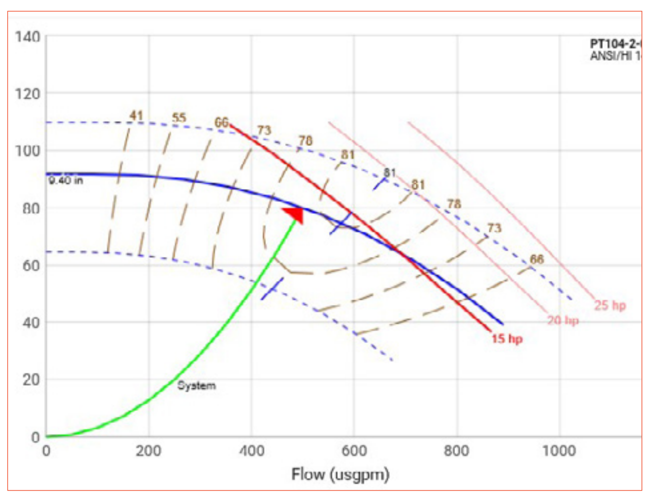
System curve and duty point

The system curve depicts the system TDH over a range of fluid flows. As noted earlier, TDH includes the sum of fluid friction losses in all system components such as heat exchangers, pipes and flow controls. An example of developing a system curve is shown at right.



System curve and duty point determination

With the system curve and pump curve in hand, the system duty point can be determined. The duty point is the flow and head at which the system operates and is found at the intersection of the pump curve and system curve as shown.

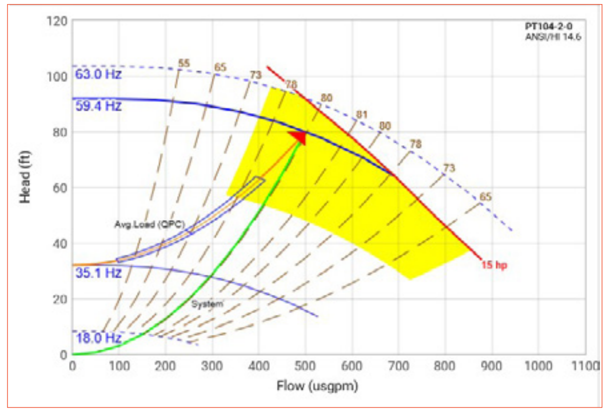


Pump selection for duty point

Maintain NPSHA greater than NPSHR to ensure proper pump performance. Suction piping should follow pump manufacturer guidance for straight pipe lengths, using flow straightening devices if needed to ensure the net positive suction heat available is greater than required at all operating conditions.

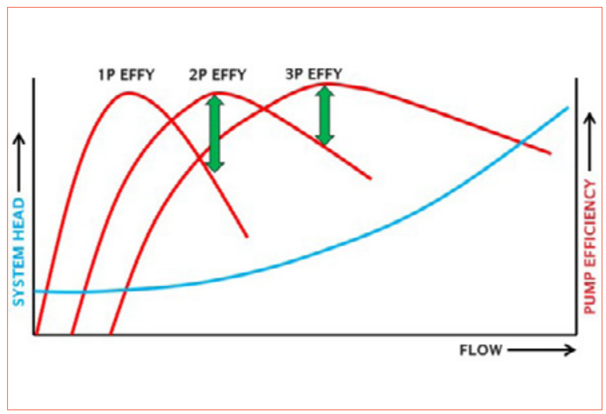
Pump Application Considerations

Constant versus variable speed. Centrifugal pumps can be applied as constant speed or variable speed, depending on the application. As with other centrifugal fluid flow devices, centrifugal pumps follow the affinity laws so changing speed has a cubic effect on BHP. Pump mechanical efficiency tends to scale well with speed and depending on motor and motor controller efficiency, and the application needs significant energy savings may be achieved with a variable-speed pump. Variable-speed pumps also provide advantages for both flow balancing and flow control which will be discussed in later sections. A typical variable-speed pump and system curve is shown at right.



Typical variable-speed pump and system curve

Series versus parallel pumps. Pumps can be configured in series to increase pressure rise or in parallel to increase flow. Pump staging can have considerable impact on system efficiency. The illustration at right depicts a system served by multiple parallel pumps, showing system head on the left axis and pump efficiency on the right axis, with flow on the horizontal axis. The green arrow bars indicate potential energy savings when using control strategies that stage pumps based on pump efficiency versus control strategies based solely on pump flow. Parallel pump configurations can also provide system pumping redundancy.



Efficiency benefits (green) by staging for efficiency not flow

Manifolded versus dedicated pumps. The table at right summarizes the pros and cons of this choice. Dedicated pumps are easier to control as they simply run when the piece of equipment they are connected to runs. However, if the pumps require variable-speed control there is still coordination of control that must be implemented.

Manifolded pumps are typically viewed as providing for greater system operating reliability including N+1 redundancy at lower cost. Manifolded pumping typically requires isolation valves on the equipment they are serving. Another benefit of manifolded pumping is more flexible and efficient system operation through optimal pump sequencing.

Dedicated Pumps	Manifolded Pumps
• Sometimes simpler control • Straightforward pump selection • Simple for operators	• Redundancy • Lower cost N+1 • Selection flexibility • Optimized sequencing opportunity • Greater flow turndown
• N+1 more expensive • Control may not be simpler	• Control remote from equipment served • Isolation valves required on equipment

Pump location

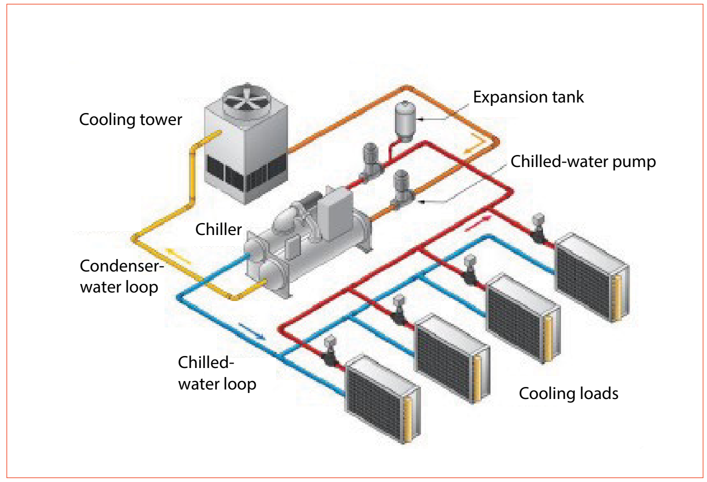
In open loop condenser water systems the pumps are most often installed immediately downstream of the cooling towers, upstream of the chillers' condensers. In closed loop chilled water systems the pumps serving the chillers are most often installed upstream of the evaporators. But these locations are not required based on a chiller requirement. The following is the rationale for this norm; there may be significant advantages to different locations depending on the system conditions.

System impacts. The location of the pumps has no direct impact on the efficiency of the chiller itself. Two primary factors to consider when deciding on the relative location of the pumps are meeting pump NPSHr and not exceeding the pressure rating of the chiller heat exchangers. A secondary factor is the impact of pump heat on the system operation and efficiency.

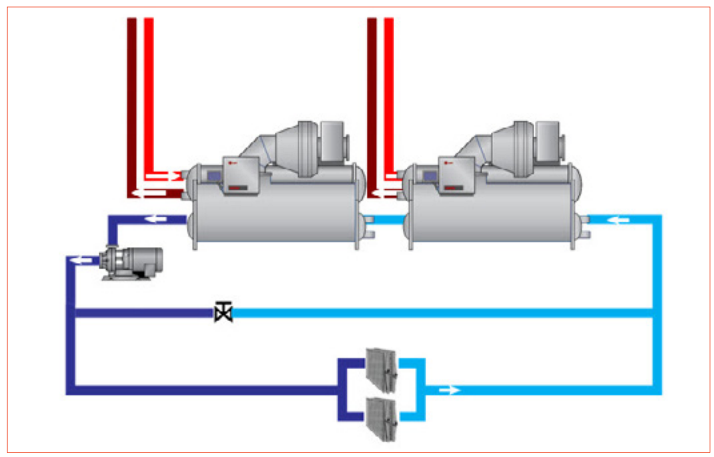
Open-loops and NPSH. If the condenser pump is on the same level or only one or two floors below the cooling tower, the static pressure created by the water column and therefore the ultimate NPSH available is very limited. Locating the pump upstream of chiller condenser means the heat exchanger pressure drop does not further impact the pump NPSH and it is easier to select a pump that will not cavitate.

Closed loops and NPSH. In closed loop systems the NPSH at the pump is controlled by the height of the system, the location of the system expansion tank and the pressurization of the system. Because the pressure at the pump inlet can be controlled by system pressurization, the required NPSH is easier to achieve.

Downstream of chiller evaporator. A common standard pressure rating for heat exchangers is 150 psi, sometimes with options for 300 psi or even 450 psi ratings. These higher ratings increase the chiller price. If the height of the building above the chillers is such that the water column static pressure approaches the heat exchanger's pressure rating, the additional dynamic pressure of the pumps upstream of the chiller may exceed the chiller's standard rating. In that case locating the pumps downstream of the heat exchanger adds the pump pressure downstream of the chiller so the chiller is never subject to the additional pressure. The height



Pump downstream of tower, upstream of chiller evaporator



Pump downstream lowers chiller pressure in tall buildings

of the water column above the pumps provides plenty of NPSH, despite the chiller pressure drop, to prevent cavitation. When the pumps are downstream of the chiller evaporator, pump heat is added after the water is chilled and the chiller setpoint is lowered. This cooler temperature requirement increases chiller power draw.

Upstream of chiller evaporator. In low-rise buildings where the system static pressure is low, the chilled water pumps are typically located upstream of the chiller evaporator. This way the pump heat is extracted from the chilled water stream before it is distributed throughout the system.

Pump Selection Considerations

System curve. In all cases the system curve determines the operating conditions of the pump, the flow and required pressure. To determine the pump(s) operating point the system curve must be overlaid on the pump curves. Only then can the impact of various pump selection options be properly evaluated.

Pump speed. 1780- and 3600-rpm are typical motor-speed selections. While 3600-rpm pumps are smaller and lower cost, 1780-rpm pumps typically have lower required NPSH and higher efficiency. 1780-rpm pumps are less likely to produce a sympathetic system harmonic vibration with other 3600-rpm devices, i.e. chillers, although this is less of a concern with variable-speed operation.

Steep- versus flat-head pumps. Although somewhat arbitrary, pumps that have a pressure rise of greater than 20% from design to shutoff flow are described as having a "steep curve". Pumps with less than that are called "flat curve" or "flat head."

Flat-head pumps are in common use in HVAC systems, but there are places where steeper-headed pumps are better applied. Flat-head pumps are recommended for constant-speed pumps in variable-flow systems for energy efficiency and system control. Steep-head pumps provide more pressure response as system flow conditions change. Therefore, they can be controlled to more precise flows in applications where pump speed rather than control valves modulate the flow. Steep-head pumps are appropriate in filtration circuits because the flow will not vary as rapidly as the filter clogs and pressure drop rises.

Pump over-or under-sizing. Excessive over-sizing equipment should be avoided in all cases. Negative impacts of over-sizing include lower operating efficiency, less turndown, higher installed costs and higher maintenance costs.

However, with the wide application of variable-speed operation and variable-flow systems, there are new considerations for pump sizing. Variable-speed control reduces the energy penalty and may help increase the allowed flow turndown of oversized pumps. Newer considerations in pump selection include overpumping, number of pumps intended to operate, flow turndown, and selecting to the left or right of the best efficiency point (BEP.)

Overpumping. In variable-primary flow systems, it's desirable to have the ability to overpump chillers beyond their selected flows to better match system requirements or to enable optimization. Remembering that the pressure drop through heat exchangers and pipes varies to the square of the flow change so to increase flow not only must a higher flow be selected but the corresponding higher pressure capability.

In manifolded systems more pumps may be operated to achieve high flows but in order for that to work, each of those pumps must be able to produce the higher pressure drop required by the device or system. Said another way, turning on more pumps provides the potential for more flow, but more flow can only happen if those pumps can also produce the required pressure.

Flow turndown. If greater flow turndown is required it may be beneficial to select multiple pumps that meet the required pumping pressure and flow. Properly selecting two pumps to do the duty of one can provide deeper flow turndown, over pumping, higher efficiency and redundancy. If each pump is selected at 60-70% of the system design flow, one pump can still deliver enough flow to support 90%+ of the design thermal load.

Left or right of BEP? Depending on the application either can be preferred. During commissioning and normal operation, the actual operating point often drifts right or left on the pump curve. Anticipating that, the pump is selected to the left or right so that its actual operation moves closer to the BEP.

Some recommend that pumps, particularly constant speed, be selected with their Duty Point (selection point) left of the BEP because their operation is likely to drift to the right. It tends to give the pump a little more capacity for flow increase without a large loss of efficiency. Left-side selections give the pump more operating margin before the NPSH required rises enough to cause cavitation or other issues. Doing this limits pump flow turndown.

In systems that use multiple, variable-speed pumps, selecting pumps to the right of the BEP allows for better operating efficiency with optimal staging. Optimal staging causes the pumps operating point to move to the left on the pump curve with the pump efficiency rising at it approaches the BEP. Care must be taken to prevent the runout of the pumps further to the right on the pump curve. That is handled through smart staging of additional pumps.

Pump Control

For a given pumping system, pump control can involve speed control, sequencing, pumping energy optimization as well as failure recovery.

Constant-speed pump control

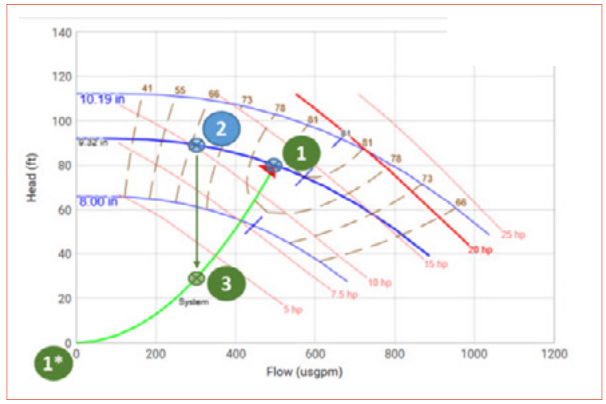
Of course, for pumping systems with constant-speed pumps there is no speed control. That does not mean constant-speed pumps have not and are not in use in variable flow applications. The upper figure in the next column shows a system equipped with quality 2-way control valves on the loads. As they modulate closed, the pump flow decreases along the path of the pump curve, in this case from the full load flow or "Duty Point" of the pump, point 1, to whatever the valves control the flow to, point 2. The reduction in flow decreases the power consumed by the pump, which is somewhat offset by an increase in the pump differential pressure. In this example, the flow decreases by 40% while the pump pressure rises by approximately 12%. The pump efficiency also changes as the flow changes and in this case there is a reduction in efficiency. Given these changes, the pump energy savings would be in the range of 25% at this new operating point.

However, the green system curve line shows that its pressure requirement at this operating flow, point 3, is actually much less. This represents a significant opportunity to save energy.

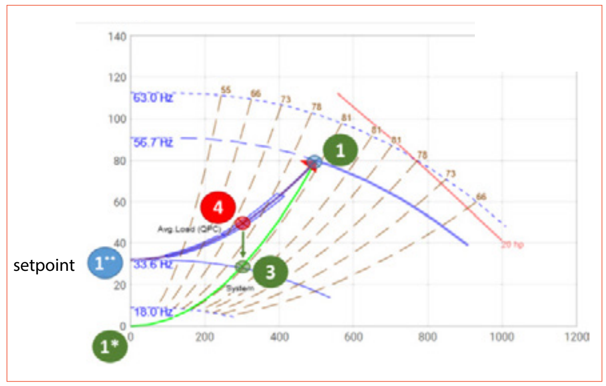
Constant-speed pump systems benefit proportionally more by using low flow rates (15°F ΔT or higher) and chilled water temperature reset.

Variable-speed pump control

When equipped with variable-speed control, typically a variable-frequency drive, the goal of the speed control is to match the system pressure and flow requirements as closely as possible at the lowest pumping energy possible.



"Riding" a pump curve



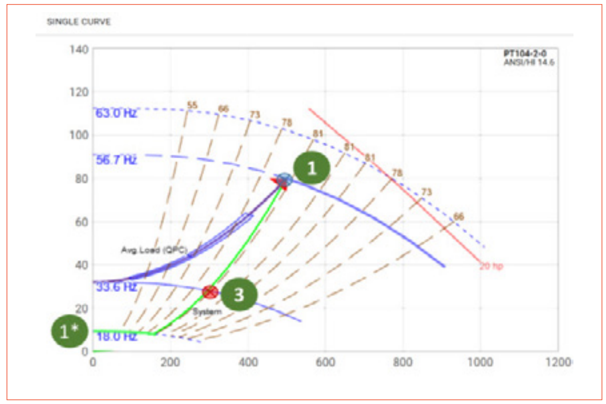
Variable speed pump operation

Based on end-of-loop pressure. The most common method used for pump speed control uses a differential pressure measurement at the "most hydraulically remote load." The setpoint (1**) used for control is the design pressure across that load's coil, control valve and associated piping. This results in pump operation along the control curve from 1 to 1**. At our example flow, the pump flow decreases to the flow through the AHU valves and the pressure decreases along the control curve to point 4.

The flow decrease is again 40% but the pump operating pressure is reduced by approximately 50%. There is only a slight reduction in pump efficiency, resulting in a pumping energy reduction of about 70%. While this an incredible savings there is still more than could be achieved, between points 4 and 3, if the pump were instead controlled along the system curve.

"Sensorless Pump Control" is offered by several manufacturers and is used to mimic end-of-loop pressure control, without the need for an actual pressure transducer. This is very useful in systems where installation and wiring of a remote pressure transducer is difficult or expensive.

Based on critical valve. Since the 2010 version, ASHRAE 90.1 requires the application of "Critical Valve Reset" to variable-speed pump control. This results in a control curve that theoretically follows the system curve to the pump minimum speed. The upper figure in the next column shows the potential pump operating point with this type of control. It should be noted that this idealized control seldom occurs unless all system loads decrease together. If there is uneven unloading, the operating point will be somewhat higher than indicated here. Assuming idealized unloading, the flow would decrease by 40%, the operating pressure would decrease by 64% resulting in a pumping power savings of 78%. Because ideal conditions are rarely achieved, actual pump pressure and power savings are lower in most applications.

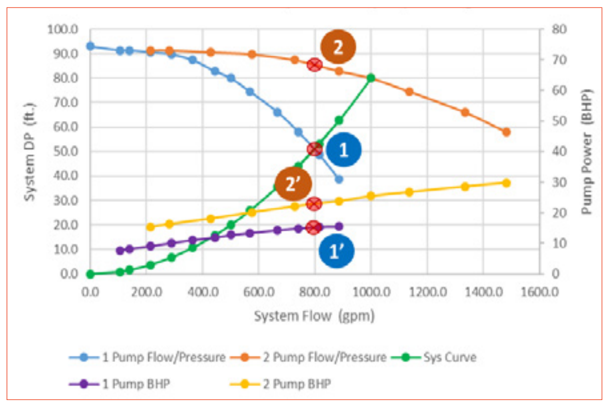


Critical-valve-reset based pump-pressure optimization control

Multiple pump staging

In many systems multiple pumps are applied in "pump banks." This can provide redundancy, better pressure turndown and energy savings. Properly staging pumps is essential for delivering these benefits.

Constant-speed pump staging. Multiple constant-speed pumps are often sequenced based on system differential pressure. When the operating pumps cannot provide adequate pressure, an additional pump is sequenced on. When the pumping pressure rises to the point that n-1 pumps would provide adequate pressure, a pump is turned off.



Operating curves of one and two, constant-speed pumps

The figure at right shows the operating curves of one and two, constant-speed pumps. Notice the one pump and two pump operating curves. From the one pump pressure/flow operating curve it is seen that since these pumps were selected to be "non-overloading" the one pump curve crosses the green system curve at about 750 gpm. Said another way, one pump selected for 500 gpm at design conditions can actually satisfy the system pressure and flow requirement for as much as three quarters of the system flow. Next notice the one- and two-pump power curves. One pump operation always uses less power than two pumps. When the second pump is started, the pressure rises, requiring more pump work. In this example the second pump would be staged on at a pressure approximately where the single pump curve crosses the system curve or about 55 ft. The second pump would be cycled off at a pumping pressure point about 90 ft.

Pump Control (continued)

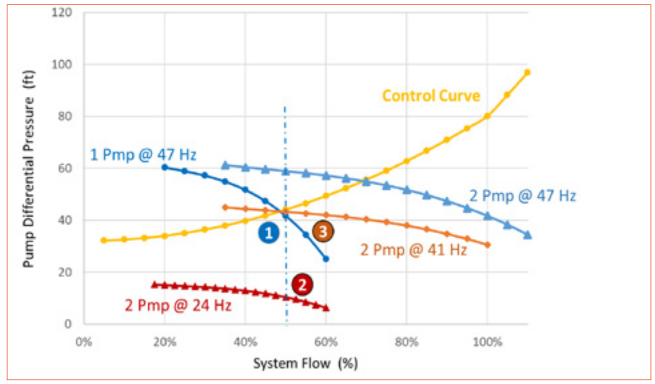
Variable-speed pump staging. Just as differing methods of pump speed control result in varying energy consumption, various approaches to staging the number of operating pumps results in differing energy consumption. Unfortunately, the approaches that have the potential to provide the lowest energy operation are also typically the more complex to implement. The good news is that more and more pump and BAS system manufacturers are building sophisticated staging logic into their products as a standard feature.

When staging variable-speed pumps, whether one, two or N pumps are operating, the flow and pressure operating point will be at the same point on the system control curve; that is, the speed control will provide the exact same flow and pressure regardless of the number of pumps operating.

Proper speed control of variable-speed pumps, discussed previously, results in control along the system control curve. Lower pressure at part-load flow reduces the inefficiencies introduced when control valves throttle flow. Unlike staging of constant-speed pumps, where avoiding excessive pump pressure dominates the staging logic, with variable-speed control the pump/motor/drive efficiencies are the most important factors in determining when to stage pumps for best efficiency.

Therefore, the decision to run more or fewer pumps requires an analysis or prediction of pumping efficiency at each actual system operating point.

Staging on differential-pressure for constant-speed pumps. Differential-pressure-based staging is often applied to constant-speed pump banks. The reason for this is that constant-speed pumps exhibit different pumping curves based on the number of operating pumps. For a given system, the pumping pressure will be higher as more pumps are operated. This results in greater pumping work and therefore higher pumping power. This can be seen in the lower graphic on the previous page, which shows the single pump operating at power points 1 and 1' versus the two pumps operating at points 2 and 2'. This can also be viewed from the control valve throttling losses point of view. For a given load and flow, if more pumps are operating, the pressure to the loads is higher, meaning the control valves must throttle more. Excess throttling is a pure waste of energy. Throttling valves at the outlet of the pump are not allowed by the energy codes.



Operating one versus two variable-speed pumps

The fewest number of operating pumps that can meet the required system pressure and flow results in the least pump work, the lowest throttling losses in the system and the highest pumping efficiency. This dominates the determination of efficient constant-speed pump staging. While differential-pressure based staging works well and efficiently for multiple, constant-speed pumps, it is not as applicable to variable-speed pumps.

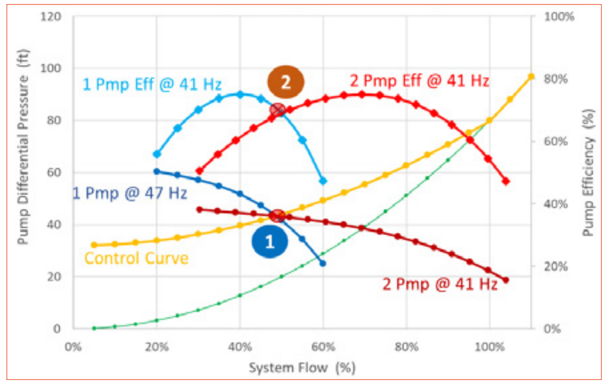
Staging for maximum number of variable-speed pumps. Some misapply the Affinity Laws and conjecture that for best pumping efficiency the most pumps possible should be run at any load. The error in this idea is in ignoring the fact that the pressure available from a pump decreases to the square of the decrease in speed. Because the required system pressure does not change with the number of operating pumps, the pressure required from each pump is very close to the same, no matter how many pumps are operating. As a result, the Affinity Laws "cube of the speed savings" concept does not apply.

In the next graph, point 1 is the system operating point required on the control curve. This condition is required regardless of the number of pumps in operation. Running one pump at 47 Hz meets this system requirement. However the speed of the two pumps is approximately cut in half to 24 Hz, resulting in operation along the red curve, crossing the required flow at point 2. Reducing the pump speed by half cuts the pressure to one quarter of the 47 Hz value (per the pump affinity laws), resulting in a pumping pressure that is far below the required condition. In this example, the speed required for two pumps to achieve the required pressure and flow is approximately 41 Hz (point 3.) The hoped-for outcome of cutting the pump speed in half and therefore power to 1/8 is but a myth.

Staging on flow or speed for variable-speed pumps. Variable-speed pumps can be sequenced based on either measured flow (gpm) or pump operating speed (Hz or rpm). Both of these methods assume that pump flow and speed are indications of pump efficiency at all operating points. Neither value alone is a perfect predictor of pump efficiency at any given operating flow or speed. While flow is typically a better indicator, the accuracy of the indication across the full system operating range is a function of the pump selection, control, and specific system operating characteristics.

In a 2012 ASHRAE Journal article[2], the author recommends modeling the pumping performance to determine a pump flow ratio to design flow setpoint that results in near-optimal pump sequencing. The model necessarily takes into account the selected pump performance characteristics and the specified pump speed control method. This modeling is available in some pump manufacturer's pump selection programs. Those programs provide predicted near-optimal pump staging points. It must be noted that as the system control or operating conditions vary from the theoretical model the staging efficiency will trend away from the optimal point.

Staging for best wire-to-water efficiency. Efficiency-based staging uses a combination of pump operating variables to predict actual pump operating efficiency and/or power consumption. These predictions are then used to determine when to add or subtract a pump. It is not enough to measure the current operating pump power or efficiency, the system must also have algorithms to predict what the new pumping power would be after pump were added or subtracted. There are various combinations of operating parameters that can be used in the prediction algorithm depending on the data available to the control system; flow and speed, power and speed, flow and pump differential pressure, etc. Predicting the expected pump power or efficiency requires significant knowledge of the selected pumps' operating curves, as well as the accurate measurement of the variables being used in the prediction algorithms.



Efficiency-based pump staging

The figure above illustrates the efficiency of running one pump at 47 Hz versus two pumps at 41 Hz to meet a specific system pressure and flow control requirement. In closely examining the operating point on the pump efficiency curves it can be seen that running one pump is slightly more efficient at this combination of system flow and pressures. However, given a slightly different control curve, such as one resulting from pump-pressure optimization, or with different pump selections, running two pumps might be more efficient. Every system point and each pump selection results in differing optimum pump staging points. Responding to this on a real-time basis is the goal of efficiency-based pump staging.

The sensorless- and sensored-control offered as an option by many pump manufacturers includes Efficiency Based Staging as well as control of pump speed for pressure or flow control. Since the pump manufacturers are obviously knowledgeable of their pump performance they can build the pump characteristics into their controls from the factory. Some use characteristic pump data based on predicted pump performance while other manufacturers factory test each pump to determine its as-built performance for even more accurate control and optimization.

Because different control suppliers can use slightly different variables and modeling methods to achieve efficiency based pump staging, a specification sequence may be used to allow various control vendors to provide their solution.

2 Taylor, S., " Optimizing Design & Control Of Chilled Water Plants - Part 5: Optimized Control Sequences", *ASHRAE Journal*, 2012.

Design Envelope® Pumps from Armstrong Fluid Technology®

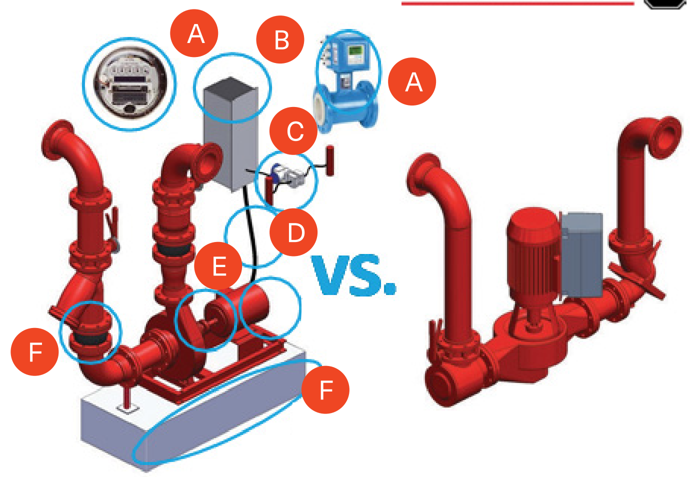
The Design Envelope pump is a unique solution, available with integrated controls up to 450hp. Integrated controls have many advantages over a traditional pump controlled by a VFD mounted on a wall, with a separate pressure feedback sensor for pipe mounting. Other advantages from Design Envelope pumps include:

- Energy and cost savings
- Impeller trim
- Superior control
- Smaller motor and control sizes
- Wiring and VFD mounting bracket savings (B, D)
- Reduced harmonic distortion (D)
- Emission and immunity requirements (B)
- Eliminated reflected wave voltage (D)
- Reduced risk and cost through better envelope selection
- Energy and flow metering (A)
- Reduced wall or floor space (B, F)
- DP sensor installation, calibration and commissioning (C)

Design Envelope pumps are selected to minimize annual energy costs. This generally results in pump selections with the design point to the right of the best efficiency point (BEP) so that during part-load (where the pump operates most the time), the pump operates at higher efficiencies by being closer to the best efficiency region for the pump. A traditional pump selection ignores energy costs and may not meet modern code requirements.

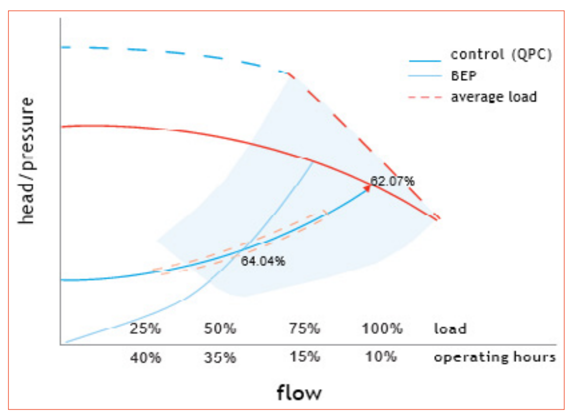
Design Envelope pumps are designed with impellers trimmed to optimize efficiency and capacity by using the load-limiting ability of the controls. Where a traditional pump impeller is trimmed to the customer's design point, with the motor 'non-overloading' for the whole curve, the impeller in a Design Envelope selection is generally trimmed close to the pump best efficiency point [BEP] for a power draw matching the motor size, which cannot overload over the operating range of the unit. This offers two key benefits:

- Increases the capacity of the pump by up to 10% such that a smaller pump can be selected
- Increases efficiency by over 5% with larger impeller trim and reducing speed to meet the design point

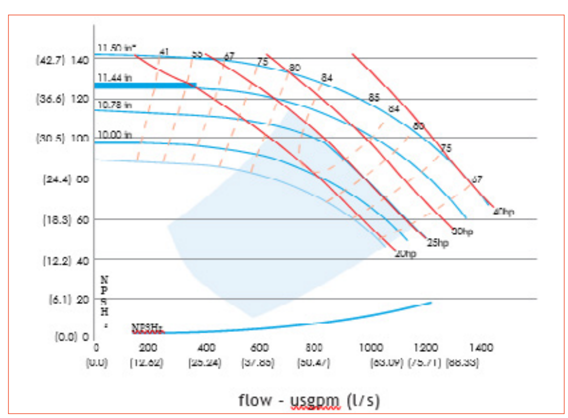


Design Envelope pumps include/eliminate

- A Flow and energy metering
- B Wall-mounted VFD
- C Differential pressure sensor
- D VFD wiring
- E Shaft alignment
- F Concrete pad, flex connectors



Design Envelope selection to the right of BEP



Trimming impellers saves first and operating cost

Armstrong Fluid Technology® Pumping Solutions

Pump	Image	Type	Description	Material	Applications	Performance range	Max Temp	Power Range	Size
Design Envelope 4300		Vertical in-line	Pipe-mounted pump unit with integrated intelligent controls for space-saving installation, superior energy performance	Ductile iron e-coated casing Stainless steel impeller Sintered silicon carbide mech. seal	HVAC, general purpose, industrial/ process pumping and control Suitable for use with water, brine or glycol based fluids.	25 to 25,000 gpm 10 to 300 ft composite curves available	300°F	¾ - 10 hp	1¼" to 20"
Design Envelope 4300				Cast iron or ductile iron casing Cast iron or bronze impeller Sintered silicon carbide mech. seal				15 -1250 hp	
Design Envelope 4322 Tango		Vertical in-line, twin type	Pipe-mounted 2-pump unit with integrated intelligent controls for space-saving installation, superior energy performance, and parallel-pumping or full redundancy operation	Ductile iron e-coated casing Stainless steel impeller Sintered silicon carbide mech. seal		Up to 900 gpm in parallel flow and 160 ft composite curves available		¾ - 10 hp	
Design Envelope 4382 dualArm			Pipe-mounted 2-pump unit with integrated intelligent controls and suction and discharge isolation valves for space-saving installation, superior energy performance, and full redundancy or parallel-pumping operation	Cast iron or ductile iron casing Cast iron or bronze impeller Sintered silicon carbide mechanical seal	HVAC, general purpose, industrial/ process pumping water or glycol based DE pumps with integrated controllers are OSHPD pre-approved	Up to 1000 gpm Up to 140 ft	250°F	1 - 7.5 hp	3" to 8"
Design Envelope 4302 Twin						Up to 1250 gpm Up to 250 ft		1 - 40 hp	2" to 6"
Design Envelope 4200H End-Suction Pumps with Integral Vibration Isolators		Horizontal, end suction	Base mounted end-suction horizontal pumping unit with integrated intelligent controls for easier installation and superior energy performance	Ductile iron e-coated casing Bronze or stainless steel impeller Sintered silicon carbide mech. seal	HVAC, general purpose, industrial/ process pumping and control water or glycol based	25 to 450 gpm 10 to 160 ft composite curves available		1 - 10 hp	1¼" to 2½" discharge
4300 Vertical In-Line		Vertical in-line	Space-saving installation, high operating efficiency, and long service life	Cast, ductile iron or bronze casing Cast iron or bronze impeller		25 to 25,000 gpm 10 to 300 ft composite curves available	300°F	15 -1250 hp	1¼" to 20"
4030 End Suction Base Mounted		Horizontal, End Suction	Reduced cost across installation, operation, and maintenance High-efficiency NEMA-premium motors		HVAC-system pumping; light industrial/ process pumping	Up to 5,000 gpm up to 600 ft	250°F	⅓- 300 hp	1" to 8"
4600 Horizontal Split-Case Base-Mounted		Horizontal, Split Case	Split-case (HSC) double-suction pumps, base mounted and engineered to substantially reduce cost over rival designs across installation, operation, and lifetime maintenance.	Cast-iron, or ductile iron casing	HVAC-system pumping and control General purpose pumping Industrial/process pumping and control Suitable for use with water, brine or glycol based fluids.	Up to 7,000 gpm up to 600 ft	225°F	1½ - 500 hp	4" to 10"

Best Practices

- Compare options on installed cost, life cycle costs and carbon footprint.
- Examine multiple quantities of pumps to ensure optimum value.
- Convert standby units into more effective parallel equipment to reduce equipment installed cost, energy consumption, life cycle costs (LCC) and increase control.
- Specify parallel pump staging with best efficiency staging as standard.
- Specify lean parallel pumping systems. For example, two 50% units in a single pipe with 80% minimum flow redundancy for 95% heat transfer. Two-60%, -70%, -80% and -90% may be desired for redundancy level and optimum customer value.
- For full redundancy (hospitals, data centers, etc.) use two 100% units but with parallel pump staging control.

Hydronic System Accessories

Other devices in a hydronic system (sometimes called specialties) typically include expansion chambers, air-separation devices, fluid strainers, flow straighteners, measurement devices and a variety of valves. A typical system schematic for a closed chilled water loop is shown below.

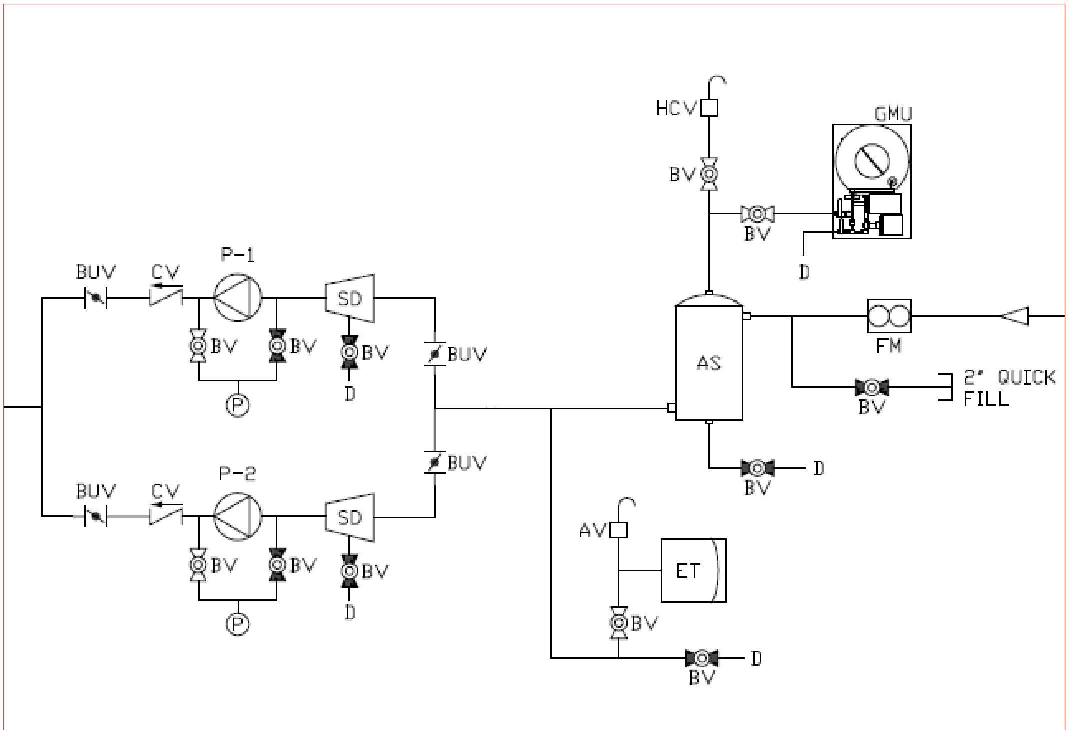
Temperature, pressure and flow measurements are used for system commissioning, operational control, performance monitoring and maintenance. Fluid sampling ports are necessary for monitoring system chemistry. Piping and valving should be designed accordingly for temporary versus fixed measurements as well as ensuring proper fluid flow profiles for the measurement device.

Follow the recommendations of the sensor manufacturers, the ASHRAE Standard 41-series *"Methods of Measurement"* as well as ASHRAE Guideline 22 *"Instrumentation for Monitoring Central Chilled Water Plant Efficiency"* to ensure the measured accuracy achieves the system measurement objectives.

Valves isolate components, balance and control flow, drain fluid, relieve pressure and inhibit/check flow from reversing. In many cases a single valve can serve several of these functions.

Air-separators are used to collect and remove air and other gases from the system. Air and gas accumulation within the hydronic circuit can inhibit fluid flow in terminal devices, degrade pump performance, create noise and lead to corrosion. Air-separation devices are tanks designed to slow the fluid velocity down and include manual or automatic gas-bleed valves. Air-separation devices should be located at the point of lowest air solubility in the fluid system. Refer to system schematics and fluid solubility tables to determine the appropriate location.

Expansion chambers allow for the expansion and contraction of the system fluid over the range of system operating temperatures and act as the reference pressure point in the system. This is accomplished by providing an interface between the fluid and a compressible gas at a controlled pressure. Types of expansion chambers include open, closed and diaphragm tanks. Open tanks are open to the atmosphere and are typically avoided in modern hydronic systems as they contribute to significant air entrainment and subsequent system corrosion. Closed and diaphragm expansion chambers have compressed gas interfacing with the system fluid to allow for fluid expansion and contraction as well as system pressurization. Closed loop systems should only use one expansion chamber in the piping circuit to avoid shock waves or water hammer. Chamber size depends on the system water volume, water properties, compressible gas properties and the type of tank.



Example hydronic accessories

****VALVES/PIPING SPECIALTIES****			
TAG	DESCRIPTION	MANUF.	PART NUMBER
AS	AIR SEPARATOR	ARMSTRONG	VA-5 VLS
AV	AUTO AIR VENT	ARMSTRONG	AVA-075
BUV	BUTTERFLY VALVE	NIBCO	5" LUGGED
BV	BALL VALVE	NIBCO	¾" FP
CV	CHECK VALVE	METRAFLEX	5" SILENT
D	DRAIN	NIBCO	¾" FP
ET	BLADDER EXPANSION TANK	ARMSTRONG	SX-40
FM	FLOW METER	ONICON	F-1210
GMU	GLYCOL MAKEUP UNIT	CALMAC	GMS
HCV	MANUAL AIR VENT	ARMSTRONG	AAE-750
P	PRESSURE GAUGE	WEKSLER	254L4PC
P1	PUMP 1	ARMSTRONG	4280 3X2X8
P2	PUMP 2	ARMSTRONG	4280 3X2X8
SD	SUCTION DIFFUSER	ARMSTRONG	SG-54
V	VENT	NIBCO	¾" FP

Example hydronic accessories bill of materiel

Pipe Sizing

Trane has provided pipe sizing assistance for many years through the Trane Pipe Designer software. There are other requirements in the energy codes or ASHRAE Standard 90.1.

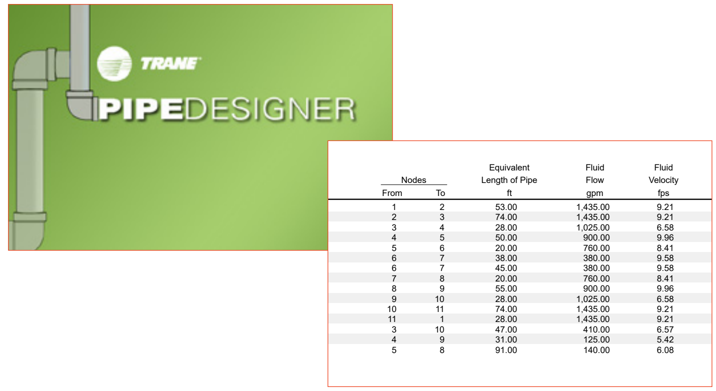
Three main criteria are used for sizing pipes: maximum diameter, maximum velocity and maximum pressure drop. Usually, all three are met before a pipe design is finalized.

The Critical Flow Path represents the circuit with the greatest overall pressure loss in the system. Increasing the diameter of pipes in this flow path reduces the total system pressure drop and reduces pump energy. After increasing its pipe diameter, another path may become the critical path.

Pipe sizing to meet minimum energy codes

A prescriptive requirement for compliance was created by iterating through the economic payback of various pipe sizes. It is structured to show the maximum flow that can be carried by a certain diameter of pipe. Constant flow, variable flow and hours of operation variations are accommodated. For pipes larger than 12 inches, maximum velocities are specified.

There are two ways around this requirement. The first is to show that sections of piping out of compliance are not in the critical circuit, nor are predicted to be in the critical circuit for more than 30 percent of the operating hours. The second is a performance option. This method requires that the designer calculate the system pressure drop with piping and fittings meeting the table requirements, then show that the proposed design has a lower pressure drop.



Nodes From	Nodes To	Equivalent Length of Pipe ft	Fluid Flow gpm	Fluid Velocity fps
1	2	53.00	1,435.00	9.21
2	3	74.00	1,435.00	9.21
3	4	28.00	1,025.00	6.58
4	5	50.00	900.00	9.96
5	6	20.00	760.00	8.41
6	7	38.00	380.00	9.58
6	7	45.00	380.00	9.58
7	8	20.00	760.00	8.41
8	9	55.00	900.00	9.96
9	10	28.00	1,025.00	6.58
10	11	74.00	1,435.00	9.21
11	1	28.00	1,435.00	9.21
3	10	47.00	410.00	6.57
4	9	31.00	125.00	5.42
5	8	91.00	140.00	6.08

Trane Pipe Designer software

Effect of optimized flow rates on pipe sizing

Consider a 500-ton condenser-water circuit that operates a majority of the year at a constant flow. A 3 gpm per ton design of 1500 gpm requires a 12-inch pipe. The same system using a 2 gpm per ton design of 1000 gpm could use 10-inch pipes. Not only can the pipe size be reduced, but so will all of the valves and miscellaneous fittings. This can further reduce the cost of the system.

For higher performance rather than lower cost, consider pipe sizes larger than the minimum.

Operating Hours/Year	≤ 2000 hours/year		>2000 and ≤ 4400 hours/year		>4400 hours/year	
Nominal Pipe Size, inches	Other	Variable flow/ variable speed	Other	Variable flow/ variable speed	Other	Variable flow/ variable speed
2 1/2	120	180	85	130	68	110
3	180	270	140	210	110	170
4	350	530	260	400	210	320
5	410	620	310	470	250	370
6	740	1100	570	860	440	680
8	1200	1800	900	1400	700	1100
10	1800	2700	1300	2000	1000	1600
12	2500	3800	1900	2900	1500	2300
Maximum velocity for pipes 14 to 24" in size	8.5 ft/s	13.0 ft/s	6.5 ft/s	9.5 ft/s	5.0 ft/s	7.5 ft/s

ASHRAE 90.1-2019 maximum flow rate (gpm) by pipe size, hours of operation and application

Pipe Insulation

Energy codes and standards also specify minimum insulation thickness. The requirements vary based on the conductivity of the material, the temperature of the fluid, and where it's installed.

There are exceptions for factory-installed piping within HVAC equipment that's tested and rated, with efficiencies covered in the HVAC equipment efficiency tables.

Fluid operating temperature

Piping that conveys chilled fluids below 60°F and hot fluids above 105°F must be thermally insulated. Fluids between 60°F and 105°F, inclusive, require no insulation for energy reasons.

Conductivity

The insulation thicknesses in the table below only apply to insulating materials with thermal conductivity in the range specified by the appropriate temperature. Footnote a shows a formula for calculating insulation thickness for material outside of the conductivity range.

Buried pipe

Directly buried cooling system piping does not require insulation. Hot water piping does (see table footnote d below.)

Other piping materials

Piping materials other than steel or non-metallic pipe with 80 thickness or less may comply by demonstrating equivalent or better thermal resistance than a system using the table values.

Factors other than energy

Energy conservation is not the only reason to insulate piping. Depending on the area where the piping will be installed, additional layers, vapor retarding or jacketing may be necessary.

For example, extra insulation and different types of insulation may be used to combat or manage condensation on piping in areas without sufficiently low dewpoint temperature control.

Fluid Operating Temperature Range (°F) and Usage	Insulation Conductivity		Nominal Pipe or Tube Size, in.				
	Conductivity, Btu-in/h-ft2-°F	Mean Rating Temperature, °F	<1	1 to < 1 ½	1 ½ to <4	4 to <8	≥8
<40	0.20 to 0.26	50	0.5	1.0	1.0	1.0	1.5
40 to 60	0.21 to 0.27	75	0.5	0.5	1.0	1.0	1.0
>60 to <105	No requirements for insulation for energy reasons						
105 to 140	0.22 to 0.28	100	1.0	1.0	1.5	1.5	1.5
141 to 200	0.25 to 0.29	125	1.5	1.5	2.0	2.0	2.0
201 to 250	0.27 to 0.30	150	2.5	2.5	2.5	3.0	3.0
251 to 350	0.29 to 0.32	200	3.0	4.0	4.5	4.5	4.5
>350	0.32 to 0.34	250	4.5	5.0	5.0	5.0	5.0

a. For insulation outside the stated conductivity range, the minimum thickness (T) shall be determined as follows: T = r{(1+t/r)K/k-1}, where T = minimum insulation thickness (in.), r = actual outside radius of pipe (in.), t = insulation thickness listed in this table for applicable fluid temperature and pipe size, K = conductivity of alternate material at mean rating temperature indicated for the applicable fluid temperature (Btu-in/h-ft2-°F), and k = the upper value of the conductivity range listed in this table for the applicable fluid temperature.
b. These thicknesses are based on energy efficiency considerations only. Additional insulation is sometimes required relative to safety issues/surface temperature.
c. For piping smaller than 1.5 in. and located in partitions within conditioned spaces, reduction of these thicknesses by 1 in. shall be permitted (before thickness adjustment required in footnote (a)) but not to thicknesses below 1 in.
d. For direct-buried heating and hot-water system piping, reduction of these thicknesses by 1.5 in. shall be permitted (before thickness adjustment required in footnote (a)) but not to thicknesses below 1 in. For direct-buried cooling system piping, insulation is not required.
e. The table is based on steel pipe. Nonmetallic pipes schedule 80 thickness or less shall use the table values. For other nonmetallic pipes having thermal resistance greater than that of steel pipe, reduced insulation thicknesses are permitted if documentation is provided showing that the pipe with the proposed insulation has no more heat transfer per length than a steel pipe of the same size with the insulation thickness shown in the table.

ASHRAE 90.1-2019 chilled fluid piping insulation requirements

Control Valves

This section discusses automated modulating control valves used to regulate or throttle flow through cooling coils. Other types of valves not discussed allow or stop flow, limit flow, prevent backflow and relieve or regulate pressure.

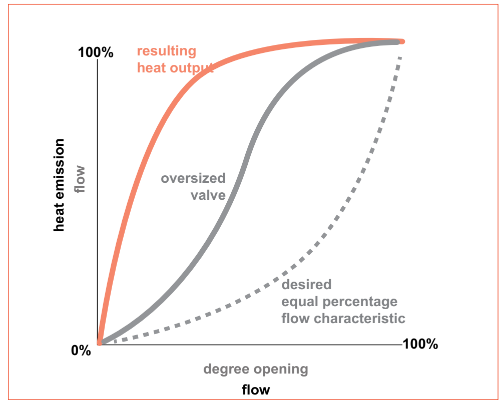
Equal-percentage flow characteristic valves are typically used for hydronic system control. Other valve characteristics (and applications) are quick opening (two-position valves) and linear (steam coils and bypasses).

Authority is the ratio between the valve and branch pressure drop. Its range is from 0 to 1. With higher authority come higher the pressure losses, but also better turndown and control. Higher authority is also preferred to accommodate the pressure shift associated with an installed characteristic vs. the inherent characteristic. Lower authority leads to instability, and results in a larger pressure shift and is only recommended for on/off applications.

Flow coefficient (Cv) is a calculated value derived from the fluid type (specific gravity), flow and pressure drop. It is used to select pressure-dependent valves and varies with the location of the valve within the system.

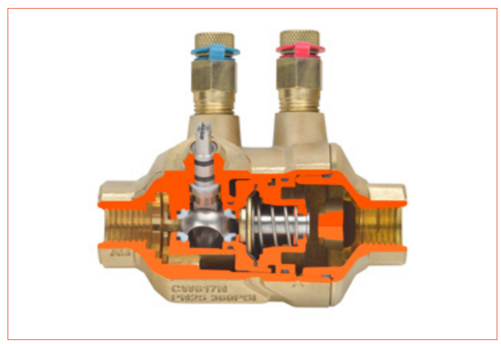
Pressure-dependent (PD) control valves are selected by choosing the valve authority and calculating the proper flow coefficient (Cv). Typically, valve authority is unknown. Pressure-dependent valves are commonly selected using a fixed pressure drop (5 psid) and the desired flow rate to calculate the desired Cv, and the actual valve is chosen from a catalog with a Cv that meets or exceeds the calculated result. This nearly always results in oversized valves.

Pressure-independent control valves (PICV) eliminate variability from pressure fluctuations within the system. This can be done mechanically with a dynamic pressure regulator or electronically with integrated software and measuring devices. Mechanical PICV consist of a pressure regulating section and a flow control section. Electronic PICV consist of a flow measurement section and a flow control section. Selecting both mechanical PICVs and electronic PICVs requires only the design flow rate of the unit. Neither require a flow coefficient (Cv) calculation.

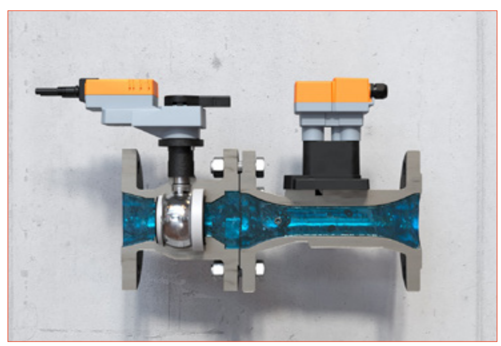


Heat output versus flow, typical PD valve

Pressure-dependent valve



Mechanical pressure-independent valve



Electronic pressure-independent valve

images courtesy of Flow Control Industries and Belimo

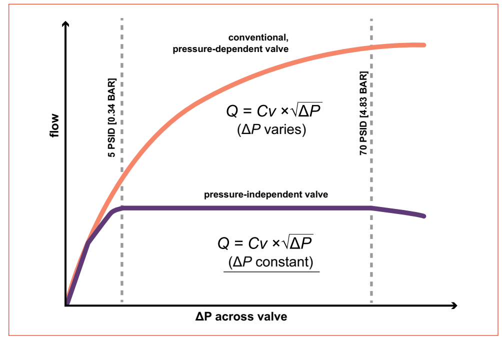
Energy, Comfort and Cost Implications of Precise Control

Besides stability, operational differences exist between pressure-dependent and pressure-independent valves. We can quantify the impact in terms of energy and first costs.

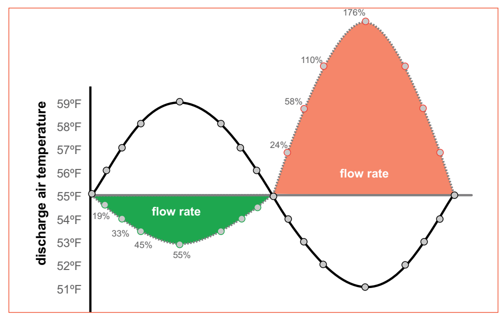
Energy

With pressure-dependent valves, erratic flow control is expected in normal system operation, due to ever-changing differential pressure throughout the system. In addition, pressure-dependent valves are almost always over-sized, may have poorly tuned gains, and experience higher-than-design inlet pressures. As a result, discharge air temperature deviates from setpoint. The effect is not just on comfort but energy. The figure at right shows a simplified view of discharge air temperature over time. If this cycle were held, the average discharge air temperature would be 55°F.

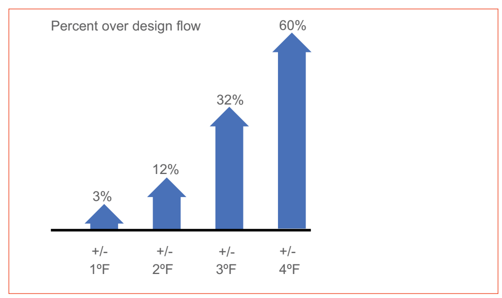
Unfortunately, more flow and pump energy is used to create the colder than 55°F discharge air temperature than is saved when making warmer temperature air. In addition, this higher-than-desired flow contributes to Low Delta T Syndrome. The higher the deviation, the more excess flow and the more wasted energy. In addition, there will likely be flow-starved coils in hydraulically remote locations and added tons due to additional latent cooling being performed than necessary.



Pressure-independent versus conventional, dependent valve



Effect of erratic valve control on deficit/surplus flow



Effect of deviation from setpoint on surplus flow through coils

images courtesy of Flow Control Industries

Installed cost

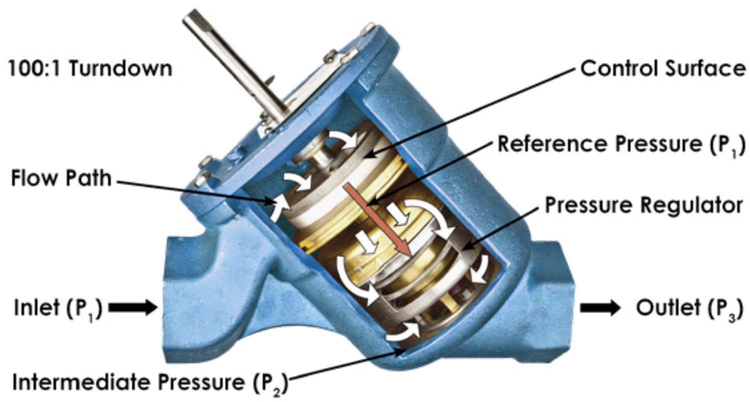
One of the perceived drawbacks of pressure-independent control valves is the upfront cost. The valve alone will likely be more expensive than a traditional control valve. When comparing the first costs of pressure-independent control valves, consider other factors such as commissioning, balancing, and manual balancing valves. Systems perform much better with PICV than without, which also affects the cost (time) for getting the system up and running.[1,2]

Mechanical and Electronic PICV Considerations

Mechanical		Electronic	
Benefits	**Considerations**	**Benefits**	**Considerations**
Easier selection	Optional support for BACnet	BACnet typically standard	Setup software and programming
Near perfect authority for best flow control	Variability in robustness of design between manufacturers	Load measurement	Straight pipe upstream of flow meter - can split flow meter section from valve if installation is constrained
No additional control power, programming, software	Some field setup required depending on manufacturer	Flow limiting and Delta-T limiting operating modes	Potential comfort issues when operating in flow limiting modes
No balancing devices, limited commissioning	Load measurement with optional temperature sensors	Supply temperature and pressure setpoints can be independently reset	Slower control portion response to pressure fluctuations — flow change must be sensed first by flow meter
Position feedback and differential pressure across P/T ports	Specify intermediate P/T port to confirm pressure independence	Position, flow in real-time, glycol concentration, and temperatures	Available data varies by option

[1] Peterson, K., "Considerations for Selecting Modulating Control Valves", *ASHRAE Journal*, Feb 2017.
[2] Taylor, S., "Practical Applications for Pressure Independent Control Valves", *ASHRAE Transactions*, 2018.

Mechanical Pressure-Independent Control Valves



The DeltaPValve® precision control valve from Flow Control Industries is a mechanical PICV available though Trane sales offices. It is ideal for controlling cooling and heating coils.

Warranty All 1/2"to 8" DeltaPValves are covered by a 10-year warranty. FCI has experienced a failure rate less than 0.25% for all customers, and offers a superior warranty as evidence that the DeltaPValve® delivers a lower total cost of ownership than any other control valve on the market.

Valve materials Body: Valves 1.5" [40 mm] and smaller have brass bodies with female NPT connections. Valve bodies 2" [50 mm] and larger are ductile iron.

Internal components: All internal components are high quality brass, carbon steel, stainless steel or Teflon. No plastic internal parts are used.

Seals: EPDM.

Shutoff and leakage The unique design and low internal differential pressure allows the DeltaPValve® to achieve tight close-off, meeting ANSI Class III and IV leakage standards (0.1 to 0.01% of rated valve capacity). Actuators are selected appropriately for the torque required to achieve up to 200 PSID [13.8 bar] shut-off.

Actuation options All DeltaPValves are factory assembled and shipped complete with actuators. The valve is not actuator-specific: different actuation types are available for specific applications, including electric and pneumatic, and both fail-safe and fail-in-place operation.

Actuators from most major manufacturers are acceptable. Contact Trane or FCI for more information on actuator options or for specific requests.

Maintenance All seals can be replaced in valves 3" [80 mm] and smaller without removal from the piping system. Valve flow characteristics can be modified in valves 8" [200 mm] and smaller without removal from the piping system.

Installation The DeltaPValve® can be used for control with chilled water, heating water and glycol fluid systems. Orientation can be horizontal or vertical, with the recommendation to keep the stem and actuator above horizontal.

There are no requirements for straight pipe lengths before or after a DeltaPValve®.

Field verifiable performance

Inlet, intermediate, and outlet P/T ports are vital to verify pressure independent operation, validate flow rates, confirm valve shutoff, and troubleshoot system issues. The DeltaPValve® is the only pressure-independent valve with 3 P/T ports standard for every size, 1/2" [15mm] thru 16" [400mm].

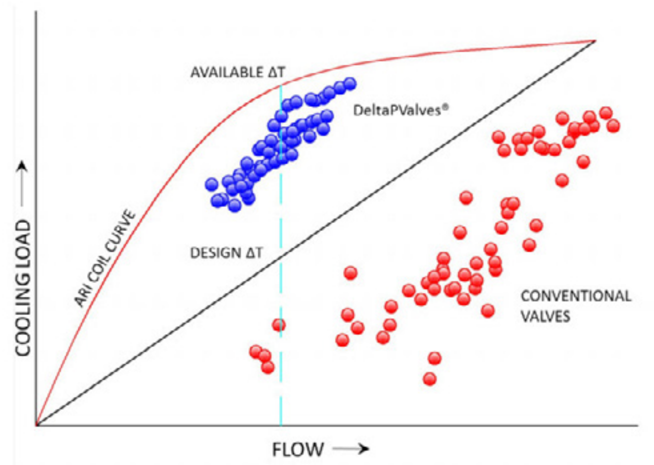
Conventional piping systems experience wide pressure fluctuations, even with variable-speed pumps and complex controls. This results in imprecise control and low delta T, and limits the benefits of the drives on the pumps.

DeltaPValves stabilize system flow, resulting in high delta T at each heating and cooling coil, as shown in the chart at right. DeltaPValves experience higher than design delta T at all load points.

Guaranteed delta T

Because precise control has such a profound impact on coil performance, Flow Control Industries extends a guarantee that your coils will deliver at least the design delta T at all load points. Performance is maintained through stable flow control, without controlling to delta T or sacrificing comfort.

Part-load coil performance (Delta T)



Made in the USA

The DeltaPValve® is manufactured and assembled in Woodinville, Washington, and meets the Buy American requirements in Section 1605 of the American Recovery and Reinvestment Act of 2009 (ARRA).

For more information

https://www.flowcontrol.com

<table>
<tr><th colspan="2">DELTA VALVE</th><th colspan="8">Max GPM [liters per second]</th></tr>
<tr><td rowspan="15">DeltaPValve® Series</td><td></td><td colspan="8">5 to 70 PSID [0.34 to 4.83 bar]</td></tr>
<tr><td>½" MDP [15 mm]</td><td>0.5 [0.03]</td><td>1.0 [0.06]</td><td>1.5 [0.09]</td><td>2.0 [0.12]</td><td>2.5 [0.15]</td><td>3.0 [0.18]</td><td>4.0 [0.25]</td><td>5.0 [0.31]</td></tr>
<tr><td>¾" LDP [20 mm]</td><td colspan="2">6 [0.37]</td><td colspan="3">8 [0.50]</td><td colspan="2">11 [0.69]</td><td></td></tr>
<tr><td>1 ¼" LDP [32 mm]</td><td colspan="2">18 [1.13]</td><td colspan="3">24 [1.51]</td><td colspan="2">32 [2.01]</td><td></td></tr>
<tr><td>1 ½" LDP [40 mm]</td><td colspan="3">40 [2.52]</td><td colspan="4">50 [3.15]</td><td>10 to 90 PSID [0.69 to 6.20 bar]</td></tr>
<tr><td>2" HDP [50 mm]</td><td colspan="2">52 [3.2]</td><td colspan="3">75 [4.7]</td><td colspan="2">90 [5.6]</td><td>112 [7.0]</td></tr>
<tr><td>3" HDP [80 mm]</td><td colspan="2">126 [7.9]</td><td colspan="3">150 [9.4]</td><td colspan="2">180 [11.3]</td><td>209 [13.1]</td></tr>
<tr><td>4" EDP [100 mm]</td><td colspan="2">248 [15.6]</td><td colspan="3">308 [19.4]</td><td colspan="2">326 [20.5]</td><td>430 [27.1]</td></tr>
<tr><td>6" EDP [150 mm]</td><td colspan="2">400 [25.2]</td><td>500 [31.5]</td><td colspan="2">590 [37.2]</td><td colspan="2">650 [41.0]</td><td>800 [50.4]</td></tr>
<tr><td>8" IDP [200 mm]</td><td colspan="2">700 [44.0]</td><td>900 [56.0]</td><td colspan="2">1130 [71.0]</td><td colspan="2">1320 [83.0]</td><td>1750 [110.0]</td></tr>
<tr><td>10" NDP [250 mm]</td><td colspan="2">2200 [138.0]</td><td></td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td>12" NDP [300 mm]</td><td colspan="2">3000 [189.0]</td><td></td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td>14" NDP [350 mm]</td><td colspan="2">4400 [278.0]</td><td></td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td>16" NDP [400 mm]</td><td colspan="2">5500 [347.0]</td><td></td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
</table>

Electronic Pressure-Independent Control Valves

The Belimo ePIV is an electronic pressure independent control valve that incorporates a flow meter and a 2-way control valve. The actuator has an algorithm that modulates the control valve to maintain the flow, regardless of variations in system differential pressure. In addition, the ePIV provides a feedback as a 0-10 VDC or 2-10 VDC to the BMS system, or it can also communicate via BACnet, Modbus or MP Bus to the BMS system. Depending on the system requirement, this feedback can be configured to be either flow control (pressure independent) or position control (pressure dependent).

Flow and control tolerances of the ePIV:
flow measurement +/- 2% of the actual flow.
flow control: +/- 5% of the actual flow.
V'nom = flow rating of valve as listed in catalog

The ePIV has an equal percentage flow curve. The equal percentage curve offers a more stable control for heating and cooling applications. The flow characteristic and feedback can be changed from equal percentage to linear (e.g. for bypass valves) using the Belimo PC-Tool.

Actuator & flow sensor removal. To replace the flow sensor, isolation valves need to be closed or the system needs to be drained. On ½" to 6" ePIV, the flow sensor cannot be separated from the flow housing. However, it can be separated from the valve using the coupler/union connecting both.

Installation requirements. The ePIV requires a section of straight pipe on the valve inlet to guarantee sensor accuracy. The length should be at least 5 diameters long. If the inlet length is less than 5 diameters, the valve can still control and measure, but with less accuracy.

No requirements for outlet length. Elbows can be installed directly after the valve, and the unit can be split to accommodate tight installations, for example, valve in the return side, and sensor on the supply side.

Warranty. Belimo ePIVs have a 5-year warranty.

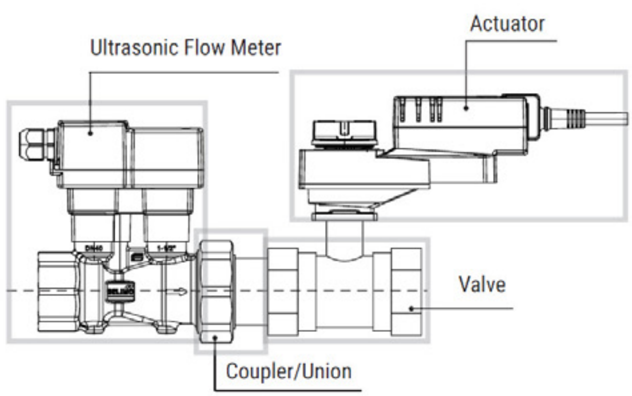
For more information
https://www.belimo.us/en_US/solutions/valves/product-documentation/pressure-independent-control-valves

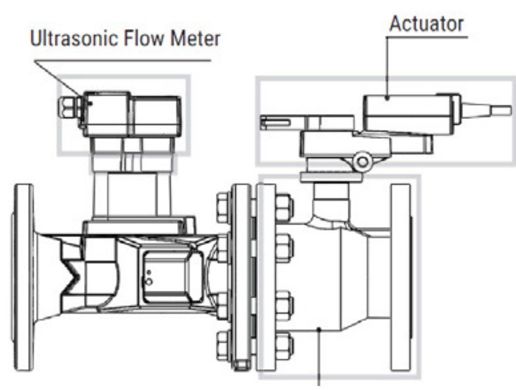
Innovations

- Pressure independent valves compensate for pressure variations, performing a continual balancing function to maintain system performance at varying loads.
- Precise flow control eliminates over-pumping and provides favorable energy savings.
- Equal percentage flow characteristic leads to system controllability.
- Pressure independent valves prevent energizing additional chillers by maintaining desirable Delta T.

Features

- Simplified valve sizing and selection, no Cv calculations required
- Ultrasonic flow sensor, no maintenance required with no moving parts
- True flow feedback or valve position feedback is available as 0-10 VDC or 2-10 VDC
- Settings can be viewed or changed using the optional ZTH US, or with a computer using the PC-Tool software or via bus communication
- Glycol compensation for the entire range
- Bus communication - BACnet, Modbus and MP





<table>
<tr><th colspan="2">Product Range</th><th colspan="2">Nominal Size</th><th colspan="2">Suitable Actuators</th></tr>
<tr><th>Valve Type</th><th>Flow (GPM)</th><th>Inches</th><th>DN (mm)</th><th>Non-Fail-Safe</th><th>Electronic Fail-Safe</th></tr>
<tr><td rowspan="7">ePIV and Energy Valve</td><td>5.5</td><td>½</td><td>15</td><td rowspan="3">LRX24</td><td rowspan="9">AKRX24</td></tr>
<tr><td>10.3</td><td>¾</td><td>20</td></tr>
<tr><td>18.2</td><td>1</td><td>25</td></tr>
<tr><td>28.5</td><td>1¼</td><td>32</td><td rowspan="2">NRX24</td></tr>
<tr><td>39.6</td><td>1½</td><td>40</td></tr>
<tr><td>76.1</td><td>2</td><td>50</td><td rowspan="4">ARX24</td></tr>
<tr><td>100</td><td>2</td><td>50</td></tr>
<tr><td rowspan="6">ePIV and Energy Valve
ANSI 125
ANSI 250</td><td>127</td><td>2½</td><td>65</td></tr>
<tr><td>180</td><td>3</td><td>80</td></tr>
<tr><td>317</td><td>4</td><td>100</td><td rowspan="3">GRX24</td><td rowspan="3">GKRX24</td></tr>
<tr><td>495</td><td>5</td><td>125</td></tr>
<tr><td>713</td><td>6</td><td>150</td></tr>
</table>

Tracer® Chiller Plant Control

Operating a chiller plant to balance demands for efficiency and reliability can be complex, even for experienced plant operators. Tracer chiller plant control delivers efficiency and reliability through pre-engineered applications that embed our advanced systems expertise into your facility.

Efficient, Reliable Performance

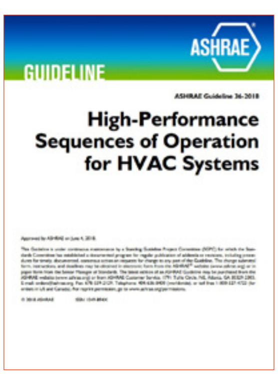
Trusted algorithms, proven in tens of thousands of installations worldwide, operate your plant with fewer risks—and greater rewards:

- Simplified operation that's easily mastered.
- Optimization strategies that align with business priorities.
- Full documentation that empowers your operators to take control.
- Flexibility to manage advanced sequences tailored to any plant.

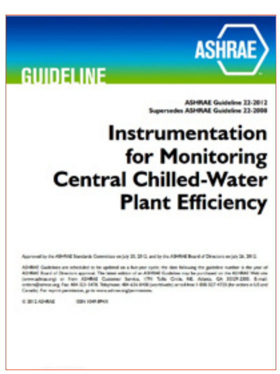
Trane brings industry-leading best practices and Trane engineering expertise into your building to optimize performance.

ASHRAE Guideline Implementation

Industry guidance on controls also comes from ASHRAE. Guideline 36 suggests ways that information be used for coordinating between sub-systems. The new trim-and-respond functions within Tracer control platforms allow for the implementation of these sequences. Guideline 22 suggests the data that should be collected from a chiller plant, which may be used to meet the ASHRAE 90.1 requirements for chiller-plant monitoring.



ASHRAE Guideline 36



ASHRAE Guideline 22

Experience guides every decision

Tracer chiller plant control benefits from decades of proven experience. Our patented algorithms have been developed using a combination of comprehensive modeling tools, lab experiments, and real world installations. The approach we apply today has evolved over several generations of Trane control platforms, and we learn more every day. The more buildings we serve, the better we get.

Easy to understand and operate

Full-screen instructions in plain language, describing "what's next" and "why," use real time data to answer the questions most asked by plant operators. Even less experienced operators will find it simple to complete chiller interactions like forced chiller addition and subtraction, rotations, set point changes and other common adjustments.

Greater operator support

Plant operators have our support to make sure they feel completely confident and in control. Trane provides operator training, application guides and convenient on-screen help. Additionally, our applications are fully documented. There's no mystery behind our sequences, decision branches, or what-if scenarios. Our systems are fully transparent, so your team can operate and maintain the chiller plant with greater confidence. Operators can monitor and manage systems anytime, anywhere, remotely with the BAS Operator Suite mobile app.

Flexible, adaptable and open

Tracer chiller plant control accommodates a wide variety of plant configurations, operating conditions and regional characteristics. Optimization strategies can be selected to provide the best solution for any plant.

Built on the Tracer controls platform, Trane chiller plant control uses open, standard protocols. Total compatibility with BACnet, Modbus® and LonTalk® means our solutions work with many different equipment brands, and they are easily scalable.

Comprehensive in Scope

Every business runs differently. Every chiller plant is slightly different. Pre-engineered settings provide an excellent starting point, but there's always room to do better. Trane Intelligent Services can identify the path to continuous chiller plant improvement.

Trane delivers efficiency gains by applying our industry-leading system knowledge to virtually every aspect of chiller plant operation.

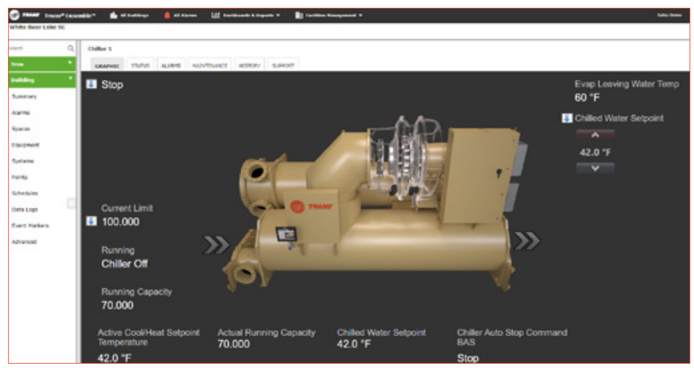
Tracer® Ensemble® plant interface

Chiller staging

Simple to use operator interfaces allow for functions such as: selecting which chiller to run and when, removing chillers from the rotation for service, recovering from failures and rotating lead-lag designations.

Pump pressure or chilled-water reset

These control algorithms adjust the pump setpoint or chilled water setpoint in response to changes in the building loads, indicated by a sensed variable: valve position, remote differential pressure, or another relevant variable such as temperature or humidity conditions in critical zones.



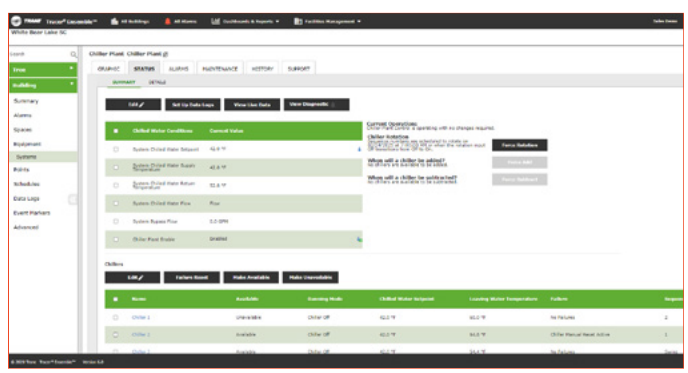
Tracer Ensemble chiller interface

Chiller/tower optimization

Finding the right balance of chiller and cooling tower energy requires quantifying the impact that they have on each other. This control solves for the lowest energy combined in the chillers and towers every 15 minutes to determine the tower temperature setpoint.

Enhanced cooling tower staging

Depending on the flow limits of the chillers and the towers, running more towers than chillers is one way to save energy. This algorithm adds towers based on energy use and limiting conditions.



Tracer Ensemble equipment detail

Thermal storage integration

Most Trane chillers are suitable for ice storage applications and all can be used in chilled-water storage. Getting the controls working properly is a critical factor and Trane brings decades of expertise to this task.

Trane Design Assist™ Application

Trane Design Assist (TDA) is the newest web application from Trane that delivers project-ready Building Automation Control designs and documentation.

This web-based tool gives users the power to design, collaborate, and export project layouts of all sizes and regardless of brand.

Design

TDA allows you to create scalable comprehensive Building Automation Systems on a digital design canvas using industry proven strategies and standards.

The process is straightforward and is available to engineers and designers for free.

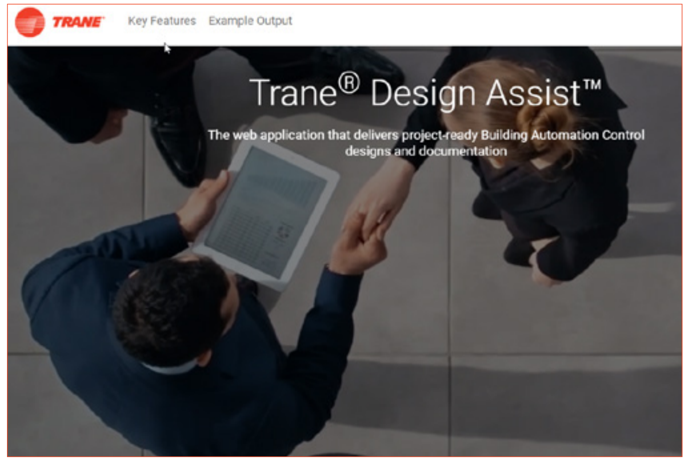
Collaborate

The application allows for the seamless collaboration that we expect from web-based tools. Share project designs and information within the tool to easily collaborate with other stakeholders, colleagues and trusted advisors.

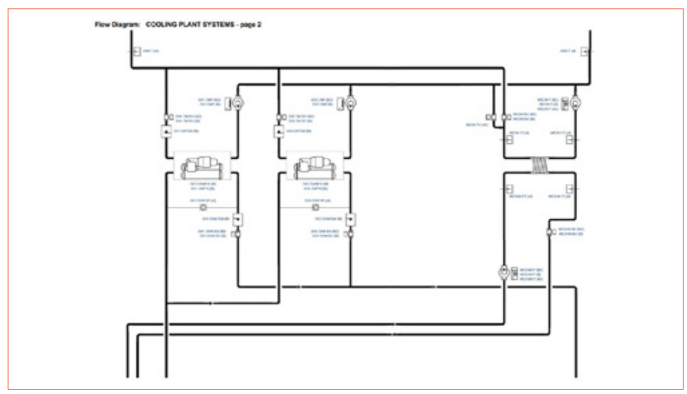
Export

Generate and download project documentation through customized formats DWG, PDF and DOCX.

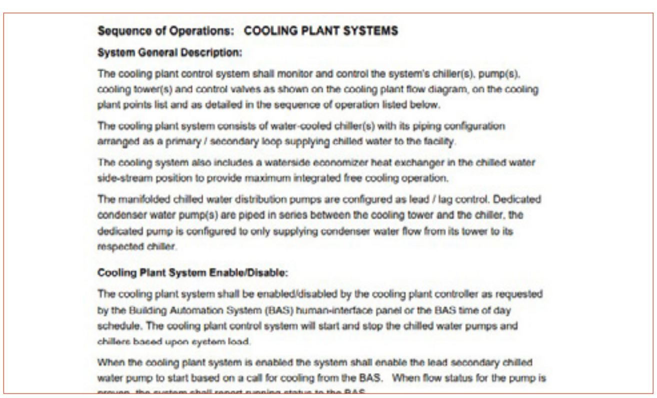
www.tranedesignassist.com



Trane Design Assist



Design



Sequence of Operations: COOLING PLANT SYSTEMS

System General Description:

The cooling plant control system shall monitor and control the system's chiller(s), pump(s), cooling tower(s) and control valves as shown on the cooling plant flow diagram, on the cooling plant points list and as detailed in the sequence of operation listed below.

The cooling plant system consists of water-cooled chiller(s) with its piping configuration arranged as a primary / secondary loop supplying chilled water to the facility.

The cooling system also includes a waterside economizer heat exchanger in the chilled water side-stream position to provide maximum integrated free cooling operation.

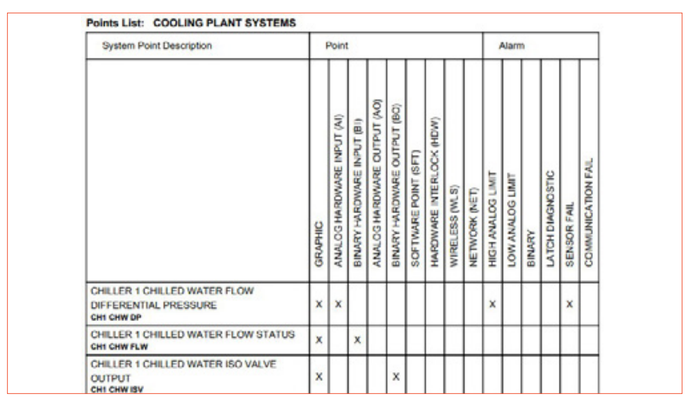
The manifolded chilled water distribution pumps are configured as lead / lag control. Dedicated condenser water pump(s) are piped in series between the cooling tower and the chiller, the dedicated pump is configured to only supplying condenser water flow from its tower to its respected chiller.

Cooling Plant System Enable/Disable:

The cooling plant system shall be enabled/disabled by the cooling plant controller as requested by the Building Automation System (BAS) human-interface panel or the BAS time of day schedule. The cooling plant control system will start and stop the chilled water pumps and chillers based upon system load.

When the cooling plant system is enabled the system shall enable the lead secondary chilled water pump to start based on a call for cooling from the BAS. When flow status for the pump is proven, the system shall report running status to the BAS.

Sequences of operation



Points List: COOLING PLANT SYSTEMS

System Point Description	Point									Alarm					
	GRAPHIC	ANALOG HARDWARE INPUT (AI)	BINARY HARDWARE INPUT (BI)	ANALOG HARDWARE OUTPUT (AO)	BINARY HARDWARE OUTPUT (BO)	SOFTWARE POINT (SFT)	HARDWARE INTERLOCK (HDW)	WIRELESS (WLS)	NETWORK (NET)	HIGH ANALOG LIMIT	LOW ANALOG LIMIT	BINARY	LATCH DIAGNOSTIC	SENSOR FAIL	COMMUNICATION FAIL
CHILLER 1 CHILLED WATER FLOW DIFFERENTIAL PRESSURE **CH1 CHW DP**	X	X								X				X	
CHILLER 1 CHILLED WATER FLOW STATUS **CH1 CHW FLW**	X		X												
CHILLER 1 CHILLED WATER ISO VALVE OUTPUT **CH1 CHW ISV**	X				X										

Points list

Chiller Plant Configurations

Chilled-water configurations are available in TDA.

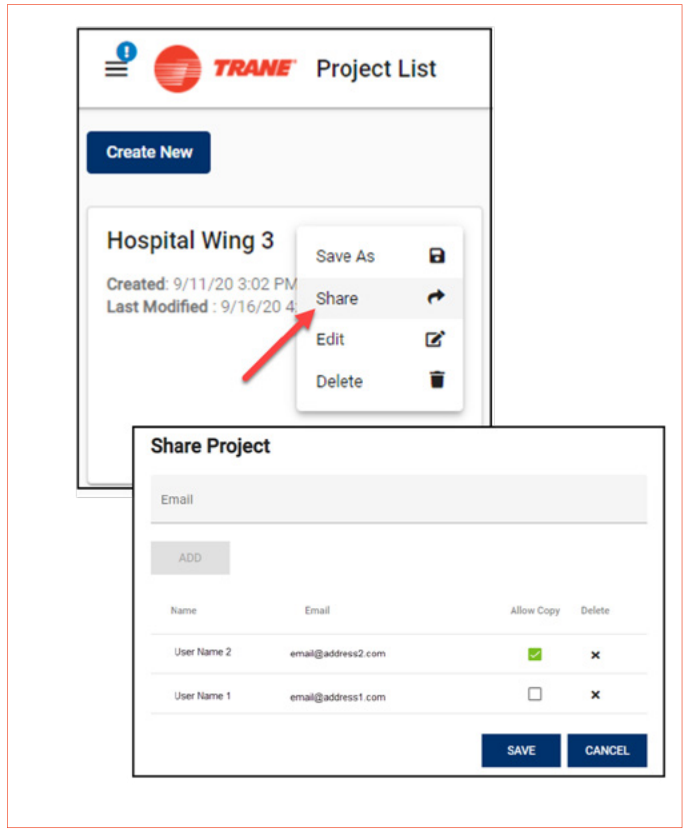
- Constant Flow
- Primary-Secondary Flow
- Variable Primary Flow
- Variable Primary-Variable Secondary

Variations include

- Manifolded or dedicated pumps per chiller
- Variable speed pumps
- Thermal storage in multiple configurations

Condenser-water configurations include

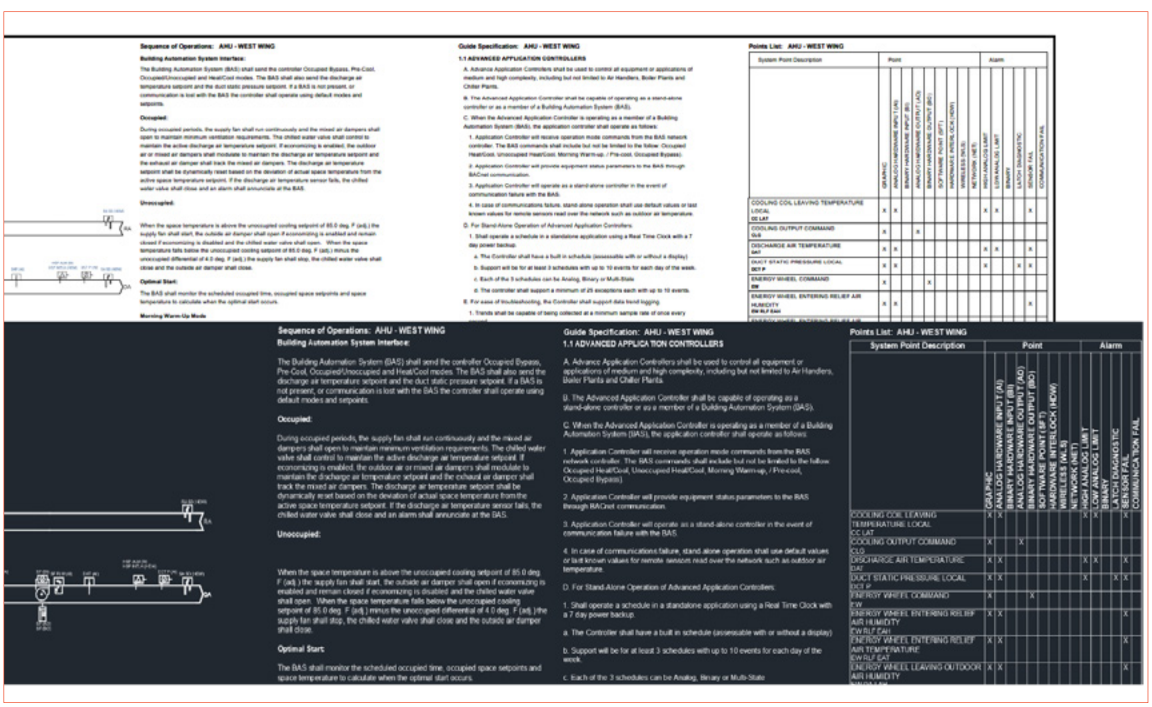
- Air- or water-cooled condensing
- Manifolded or dedicated pumps
- Waterside economizing with fluid or dry cooler
- Waterside economizing integrated into the chiller (air- and water-cooled versions)



Collaborate in real time

Layouts, Sequences, Points Lists

While you make choices, the design documents are generating in the background. The layout tab draws the system as you make decisions, sequences and points lists also update in real time. Once ready, share permissions for your project and publish to generate design documents.



Export project details into your preferred format

Learn more at trane.com

APP-PRC006A-EN
February 2021