Holistic Controls for Superior Cooling System Efficiency, Part 1

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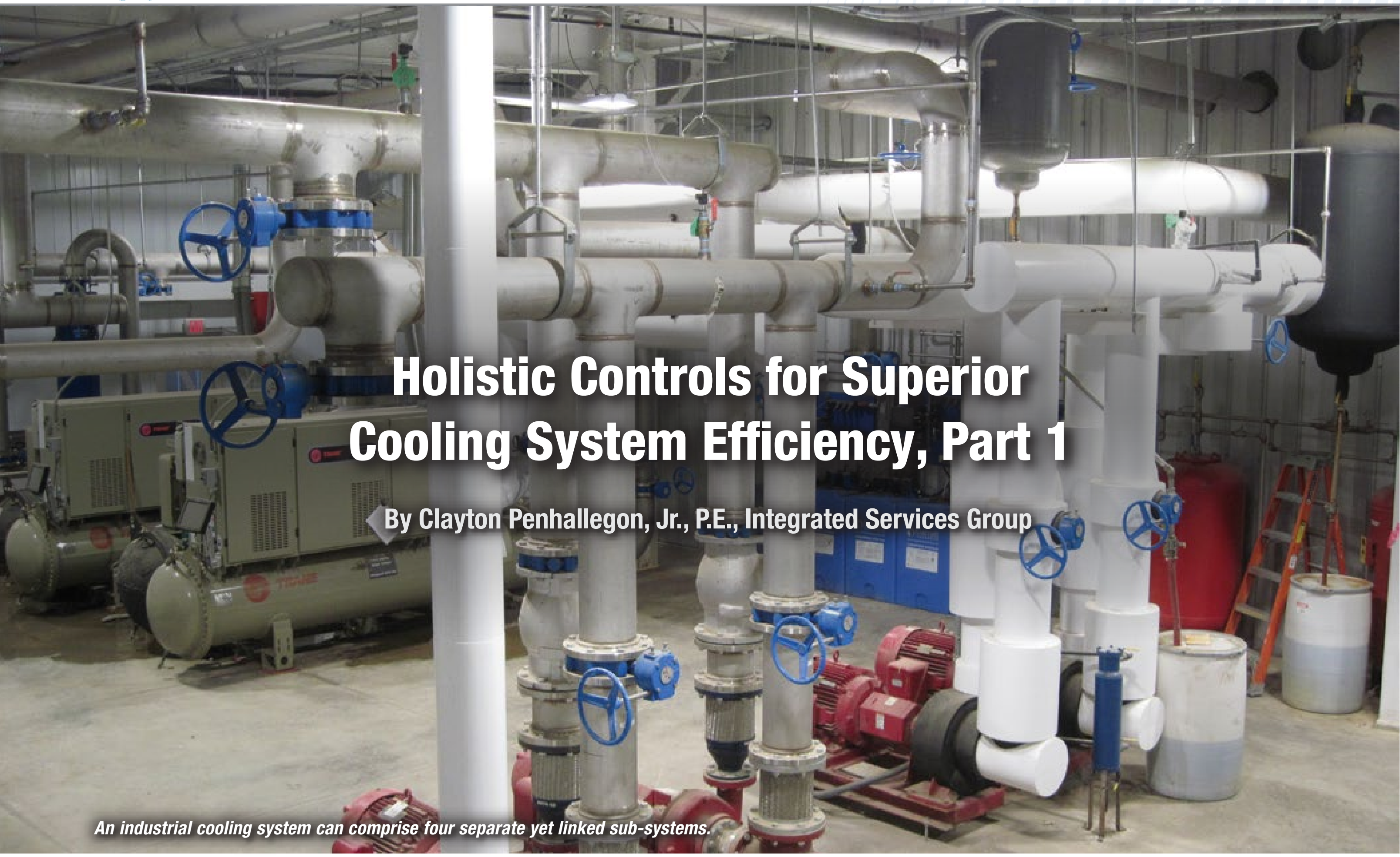

An industrial cooling system can comprise four separate yet linked sub-systems.

NOTE: This article in two parts will present the inescapable importance of holistic system controls in providing superior cooling systems operating efficiency. Part 1 will present an introduction to why controls play such a critical role in cooling system operation and will review general control definitions and applications, as well as common deficiencies found in many systems. Part 2 will describe holistic system controls and give examples of advanced control system functions and benefits; this part will also provide tips on to assess your existing controls.

Process cooling systems are mandatory components of the production infrastructure in many plants. System efficiency is second only to operational performance (i.e. meeting the process requirements) in the design and operation of these systems[1], and many companies go to great lengths to attain system efficiency. Many times, unfortunately, the actual system performance is well below the hoped for efficiency target.

This is in part because cooling systems are uniquely complicated compared to most other plant utilities. Other systems like compressed air and vacuum typically have a single variable that is controlled (PSI or inches of vacuum, respectively)[2]; some other systems are only controlled on or off as long as they perform adequately (for example, resin conveying systems, trim scrap blower systems, etc.).

It is widely recognized by cooling systems efficiency engineers that cooling systems consist of a series of linked sub-systems. Consequently, controlling the sub-systems' operation in a manner that effectively leverages the different aspects is crucial to realizing the highest potential efficiency. "Holistic" system controls, i.e. controls that incorporate the interaction effects of the linked sub-systems, are the critical ingredient in realizing the highest system efficiencies.

Cooling Systems Complexity Distinctions

For many users who are not cooling system experts, the idea of linked, interconnected sub-systems may be unfamiliar. As an example of these connected sub-systems, consider a water-cooled system with a cooling tower, tower water pumps, chiller, and chilled water pumps. This system comprises at least four separate processes:

- Tower water heat rejection to atmosphere
- Tower water cooling of the chiller
- Internal refrigerant flow within the chiller
- Chilled water cooling of the process[3]

If the cooling system uses hot well / cold well tanks on both tower and chilled water, then there are six loops (i.e., tower water ([TW] cooling of the chiller becomes TW to the tower, TW to the chiller, chilled water cooling becomes two loops, etc.). If there are other separate applications the list grows even further, such as tower water for machine cooling like air compressors, etc. separate from the chiller condenser cooling.

Even a "simple" air-cooled chiller system has several loops (condenser coil heat rejection to atmosphere, refrigerant flow within the chiller, chilled water to process, and possibly hot well / cold well loops). Even in this simple application there are efficiency impacts of condenser fan control strategy[4] , compressor design and operation (compressor type, compressors quantity, and other design characteristics), and chilled water flow design and control.

Simply put, cooling systems are different. And while this is daunting, leading many system operators to simply throw up their hands and say something like "screw it, we'll get what we get", the truth is **this is the heart of the opportunity.**

This very complexity provides the potential for significant differences in system efficiency. Done correctly, implemented across a company's multiple facilities, and maintained intentionally, cooling system efficiency can be a significant competitive advantage for organizations that seize the opportunity to set themselves apart from their competitors.

"…cooling system efficiency can be a significant competitive advantage for organizations that seize the opportunity…"

Three Factors of High Efficiency

Achieving high efficiency in cooling systems requires a combination of factors that include both physical and logical aspects. These broadly fall into three categories: Equipment Selection, System Implementation, and System Operation.

Equipment Selection, meaning technology type, single or multiple units, etc., is the most straightforward aspect. When considering purchases, buyers can readily determine the most efficient options for their particular

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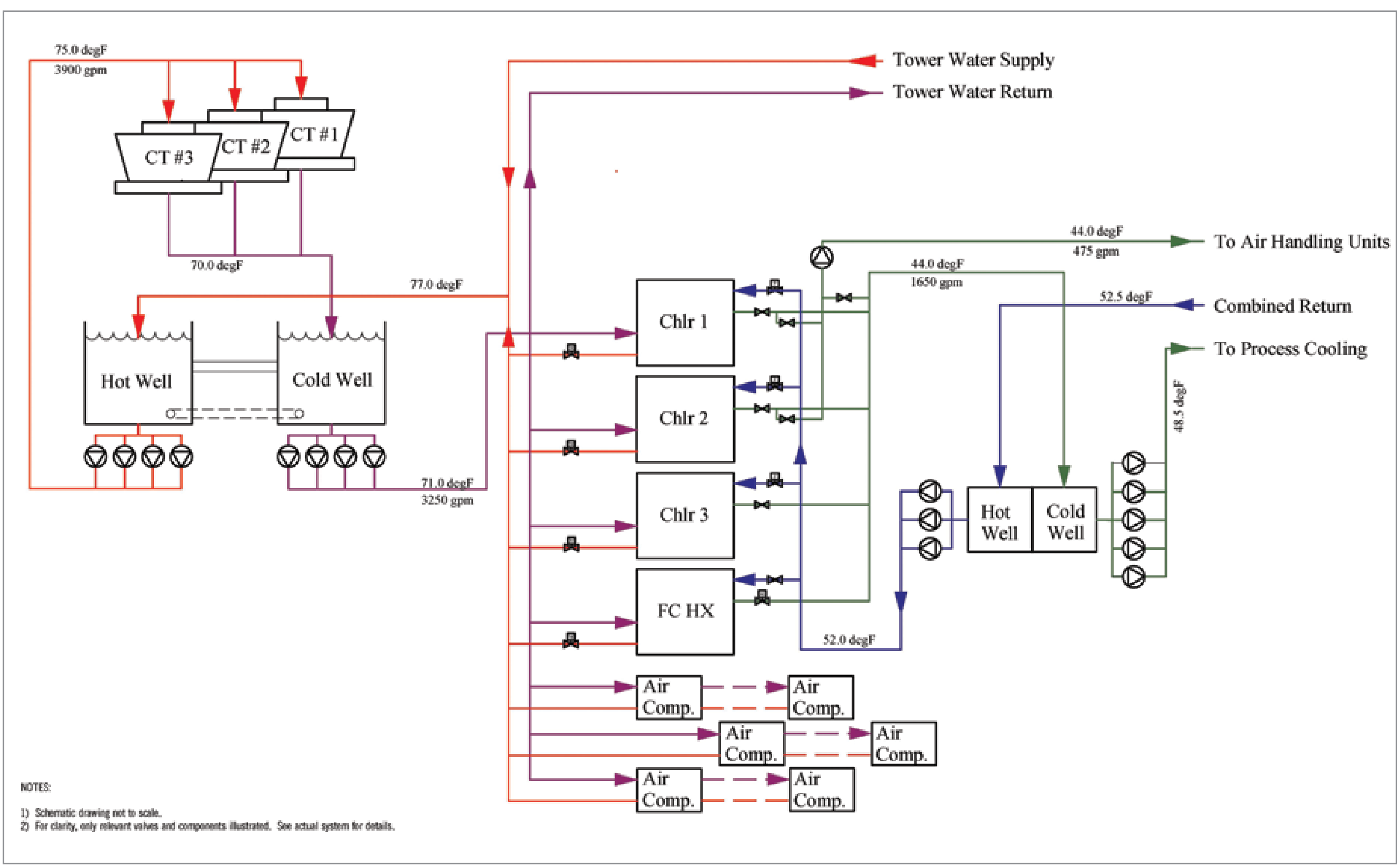
situation and then acquire the components they need. Obviously, these analyses are made in the appropriate context – how big is the load, what temperatures are required, etc. – and the application specifics point users to these types of chillers, those styles of pumps, and so on. Once the general parameters are set, the exact equipment selection (manufacturer, model, options, etc.) becomes the typical cost-benefit decision with the efficiency being just one of the factors in the final purchasing decision.

System Implementation comprises both the conceptual design and the physical installation. For example, a chilled water system may be a process and recirculation design with hot well and cold well tanks, a single loop variable-flow design, or some other flow pattern. For any given conceptual design, there is then the actual built system installed in the plant. This physical realization of the design may schematically match the intended concept while having installation details that differ from the plans and unfortunately negatively impact the operating performance[6].

Pumps choked both in and out.

Furthermore, the plant is already built in many cases when operators are seeking to improve system efficiency. There may be component replacements that provide an opportunity to increase overall efficiency but the underlying design may limit the potential ultimate performance. Even with specific high efficiency components added over time, the system can only be so efficient.

System Operation is the final component of the efficiency triad. Operation is a combination of the system controls and the operating practices of the plant. Operating practices include such activities as system maintenance, plant specific practices and habits (such as always running multiple pumps, etc.), and setpoint selection for cooling towers and chillers.



How many loops are in this system? Did you include the tower-to-atmosphere linkage and the chillers' internal refrigerant flows (as a single loop type)? Answer provided at endnote[5].

System controls are the keystone element of the operation component. These can range from systems with no overarching controls (i.e., controls on individual pieces of equipment but no system-integrating controls) to comprehensive functions that operate the full plant. It must be recognized that controls serve a range of operational functions which are important but they are also pivotal to the efficiency of the plant.

To fully understand the impact controls have on efficiency, it is necessary to review the types of controls available, their capabilities, and features required for good performance.

Controls Basics Review

Cooling *system* controls generally fall into three broad categories – No Controls, Standalone Controls, and Standard System Controls. These articles will present a 4th category: holistic system controls.

No systems truly have no controls as even in the cases where there are no overall system controls, as there are still unit controls or device controls such as motor starters and individual chiller on-board controls. These are referred to as **"No Controls"** systems in that there are no system level controls – plant operators start and stop individual components either using manual MCC start and stop buttons or pressing soft key buttons on chillers.

The next step is isolated or focused controls which are very common in plant cooling systems. These are characterized by limited functional spans such as dedicated cooling tower controls that stage several cooling towers or a pump skid controller controlling several pumps to maintain discharge pressure from the pump package. These are **Standalone Controls** that are not tied into any other control aspects of the cooling system. These systems are typical in small to mid-sized manufacturing plants with medium sized cooling systems.

Standard System Controls are controls that functionally span the entire system with a traditional range of control. This commonly includes starting and stopping pumps, tower fans, and chillers, speed control for secondary chilled water differential pressure control, and some reliability and maintenance support functions such as rotating lead / lag equipment and staging chillers. These systems are usually found in larger plants that warranted an overarching control system when the cooling system was installed, and they are often supplied by familiar cooling equipment manufacturers like Carrier or Trane as well as building controls vendors such as Delta Controls, Johnson Controls, or many others.

Typical standalone control examples.

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Unsurprisingly, these common control system types have limitations that make them less than ideal.

No Controls or Standalone systems both generally have these characteristics:

- high operator workloads to run and manage equipment, such as manual on / off operation, manual restarts after power events, and other operating requirements
- relatively poor efficiency due to system design and limited operator knowledge of efficient practices
- little leverage of adjacent process efficiency opportunities

Standard System Controls, while reducing the operator workload, still have shortfalls:

- vendors oriented toward commercial building systems vs. process cooling applications and requirements
- generally constrained in control design by typical commercial system control approaches that are not optimal for process cooling
- system costs are as much as more capable systems while leaving untapped potential savings

Why Have System Controls?

Occasionally someone will ask why system controls are necessary since the cooling equipment can operate without them. Tower fans can run with a set point controller, chillers can run with their front panel setpoints, and everything else can be turned on and off by hand. No confusion, no complexity, all good, right?

In fact, having a complete cooling system control capability offers a variety of benefits for plants. Proper controls will provide more stable process conditions, reduced equipment wear, improved equipment reliability, automated fault response, and significant energy efficiency over running a system without overarching controls. These advantages will be covered in some detail later

Non-Industrial Controls Specialist Limitations

Standard System Controls are very often provided by companies who primarily work in commercial facilities such as offices, hotels, municipal and institutional facilities, and other non-industrial systems. While the components used in these systems are often identical to those in an industrial cooling plant, the actual operation of the different system types is quite different.

Commercial systems are significantly characterized by widely varying loads from daily operating schedules typical of office and retail facilities, and seasonal weather-based loading factors affect even 24 hour systems like hotels, dormitories, hospitals, etc. Traditional control practices that are quite reasonable in these applications do not translate well to industrial cooling. Most process loads are essentially unaffected by outdoor conditions and cooling system loads often change more rapidly due to lines turning on and off than would be typical in daily weather-based building load swings. Consequently many commercial-grounded vendors fail to appreciate benefits of control approaches normally discounted in commercial cooling when the load is high year round.

Moreover, industrial systems include various requirements such as multiple pressures, intentionally low delta-T processes (which correlates to high flow for the net tons load), different temperature processes, etc. that exceed the normal scope of commercial system requirements. Unfortunately, the building control contractors and technicians who end up tasked with implementing systems in these environments are unfamiliar with these aspects and consequently either limit the control approaches applied to those they know, which leaves opportunities unfulfilled, or they attempt to implement measures with which they have no experience and must learn while implementing the job. Neither of these are good outcomes for the plant hosting the system.

Experienced industrial systems controls contractors will bring control methods and strategies to the user and will challenge and encourage users to implement more advanced approaches that provide opportunities for higher efficiency along with other benefits such as improved process conditions and reduced equipment maintenance costs.

One other unfortunate consideration with non-industrial controls vendors is the long-term support of systems. Even if a commercial vendor is able to staff an initial installation with a technician who quickly grasps the opportunities inherent in the industrial application, typical staff turnover makes it likely that person will leave and not be available to support the system long term. Dedicated industrial cooling controls vendors are good partners who will provide knowledgeable and consistent support through the years due to their business focus, notwithstanding the inevitable evolution of personnel.

in this article series but for now, it is enough to say that they are significantly beneficial for cooling system operations.

When reviewing cooling systems in a range of roughly 200 to 2000+ refrigeration tons, it is our experience that the system control types break down appropriately as shown in Table 1.

No Controls installations are usually small systems, typically around 350 – 400 total nameplate tons and below, with only integral device controls like on-board chiller panels. Pumps are started manually and filter blowdowns and other operations are done by operators when problems occur or other events trigger a response.

Table 1 – System Control Types Break Down

TYPE	DESCRIPTION	APPLICATIONS
"No Controls"	Unit / Device Only	25% - Air-cooled & simple
"Standalone Controls"	Isolated / Focused Controls	55% - Typical
"Standard System Controls"	Typical Function Systems	20% - Larger plants

Standalone Controls are typical of many medium size systems (roughly 400 – 1200 total tons) where there are multiples of key components like cooling towers and parallel pumps on separate loops such as recirculation loops to chillers and separately to the process. A staging controller is often found for multiple tower cells while pumps in a group may be staged on pressure or controlled by VFDs from a single pressure input.

Cooling systems with Standard System Controls have a unified control platform providing a range of control functions for the system, and these are typically found in plants with 1200-1500 tons and above. The onboard controls of major components such as chillers are still included, but the control of components such as pumps and cooling towers will be done by the control system. Other advanced functions like automatic lead / lag rotation and fault recovery are commonly also included, and these serve to reduce the operator workload for basic system operation.

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System Controls Cooling System Efficiency Implications

There are unsurprising correlations between the system sizes, their controls, and their typical efficiencies. This is partly due to the scale efficiency of larger systems but also to the inherent efficiency of the accompanying designs and operation practices. Table 2 illustrates typical system efficiency by control types and sizes.

Note that the ranges depend on system technology and design, e.g. air-cooled vs. water-cooled, recirculation loops vs., single variable flow, etc. Furthermore, the higher efficiency of Standard Controls systems is due mostly to equipment used and system scale rather than control functions in most common cases.

System Equipment Selection Impact on Efficiency

Many system owners work to choose efficient components for their systems, particularly in chiller selections. This matters as the chiller design and associated features (e.g., compressor type, heat exchanger design, capacity control method, etc.) define the potential operating envelope of the chiller, and a given design can only run so efficient and no more. However, as will be shown later, simply having a high efficiency design is not enough – it creates potential for high efficiency but does not guarantee it in operation.

In fact, optimal system controls may cut the energy use of a system by 35 – 50% versus the same major components without the benefit of advanced functional approaches. Unsurprisingly, the highest efficiency requires a combination of high efficiency equipment, efficient system design, and beneficial control operation.

Table 2 – Typical System Efficiency By Control Types And Sizes

TYPE	APPLICATIONS	TYPICAL SYSTEM EFFICIENCY
"No Controls"	25% - Air-cooled & simple	1.2 – 2.2 kW per ton
"Standalone Controls"	55% - Typical	1.1 – 1.5 kW per ton
"Standard System Controls"	20% - Larger plants	0.8 – 1.3 kW per ton

While efficient operation concepts will be discussed further in Part 2, an example of control function benefits would be operating pumps in parallel when a single pump could provide adequate flow. Accurate system analysis may show (assuming advantageous pump curves) that the total power required is less running two together versus a single pump in the same situation.

"…optimal system controls may cut the energy use of a system by 35 – 50% …"

Part 1 Conclusion

This article has stated the importance of system controls for highly efficient process cooling systems and has presented building blocks so those only generally familiar with the cooling controls can understand how this is true. We have reviewed why industrial cooling systems are different from other plant utilities and from commercial cooling applications, the types of cooling controls in use including minimal scope and more capable standard system controls, and the general range of sizes and efficiencies in typical process cooling systems.

The second part of this article will describe holistic cooling controls and will give examples of how their operation can yield significant savings versus conventional scope controls. It will also give tips for assessing the performance of existing controls and offer suggestions for leveraging installed system components for potential improvements. BP

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Endnotes

1. And as will be seen, systems capable of operating efficiently are also nearly always systems that are capable of maintaining the highest operating performance in terms of close temperature control, pressure stability, etc.
2. Compressed air also often has dew point control but that is a separate system control function (the air dryer vs. the compressor[s] and the pressure and dew point variables are only marginally connected.
3. These cooling loops could be broken down even more discretely depending on the specifics but the point is made.
4. Condenser fan control is integral to the chiller controls but potentially met with different efficiency effects by staging of fans, running them with partial VFDs, or running them in parallel with all on VFDs.
5. This system has at least seven separate loops, and could be construed as up to eleven depending on the operating mode. If interested, call or email the author to discuss.
6. It is exceedingly rare for design deviations made in the field to improve a system's performance as they are almost always made to benefit the installation process rather than make the design better.

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