HVAC

SUMMER EDITION

CONSULTING - SPECIFYING engineer eBOOK

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Chiller energy optimization systems versus building automation systems

Learn the nuances of a chiller energy optimization system operates contrasted with a building automation system

Chilled water systems are a significant portion of a building's energy use, sometimes accounting for up to 40% of peak electric demand and 15% to 25% of annual electrical energy usage for a large building. As such, efforts to reduce the amount of energy used by a chilled water system are worthwhile.

Control sequences in the building automation system are written to identify and respond to variables that impact chilled water system energy. Engineers write and BAS vendors implement control sequences that are intended to meet the system demand, operate within safe parameters, protect the equipment and perform those tasks as efficiently as possible within the capability of the BAS.

Another software tool for controlling system operation is a chiller energy optimization system. Consulting engineers hear from the chiller vendors that the chiller not only meets system demand and protects the equipment, but does so more efficiently. They also hear from many BAS vendors, "We can do that."

What's the difference? And is a separate chiller energy optimization system worth the investment?

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Typical BAS control

In a simple overview, a BAS comprises several levels:

- **Management level:** Makes systemwide adjustments from external input, provides user interface.
- **Control level:** Receives input, sends instruction to output devices based on the control loops.
- **Application level:** The sensors, transmitters and devices that measure input and apply output.

The sequences are written to measure an input, make a decision, then instruct the output to be implemented. Each sequence for a control loop is focused on one or a few variables and one output. For example: If the building chilled water demand exceeds 90% of operating chillers capacity or the chilled water supply temperature exceeds setpoint for five minutes, next lag chiller shall be started.

In this example, the BAS monitors two variables, chilled water system demand and supply temperature. The BAS compares the current values to the maximum operating capacity and chilled water temperature setpoints then, if either condition is true, the BAS initiates one output (start next chiller).

There are many other control loops operating simultaneously that are monitoring and controlling the chilled water pumps, the condenser water pumps, cooling tower fans, valve positions, water temperature setpoints and pressure differentials across piping

mains. Each control loop is focused on a single piece of equipment; having multiple control loops trying to control the same piece of equipment often results in sending conflicting output instructions to the equipment. The sequences consider a limited number of factors, compare to a setpoint or decision value, then adjust to meet that setpoint or value.

Information flows up from the application level to the control level, where programmed responses are then sent back to the application level for implementation. The management level provides interfaces for both users and other systems (fire alarm, security, etc.).

While the sequences can be complex, they are still mainly "static" — that is, the sequences themselves don't change. For example, they don't consider changes in equipment operating efficiency that happen over time and don't recognize changes to the operation of the system due to lack of maintenance, all factors affecting the overall operating performance of the system. In other

Figure 1: Any chiller that serves a hospital, which is a 24/7 critical load with a heavy energy demand, is a viable candidate for a chiller energy optimization system because chiller energy is a significant part of its operating costs. Courtesy: Smith Seckman Reid

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words, BAS control comprises multiple control loops acting simultaneously but independently, each focused on a particular part of the chilled water system. However, the parts of a chilled water system don't act independently; they affect each other.

By contrast, a chiller energy optimization system takes a global view of the chilled water system. It not only monitors all of the various control loops for each particular device or piece of equipment as the BAS does, but it also has the capability to understand how the various loops affect each other and can make adjustments to the control loops based on that understanding. This capability to make changes automatically to control loops — to make a control sequence "dynamic" — is what differentiates a chiller energy optimization system from a BAS. In fact, it can be argued that a chiller energy optimization system is a low-level form of "internet of things" in which one system controls and makes dynamic changes to another system without direct human evaluation or intervention.

Factors that impact system operation

In a chilled water system, there are four major equipment types that consume electrical energy: the chillers, chilled water pumps, condenser water pumps and cooling tower fans. As noted above, there are control loops and sequences that control the operation of each piece of equipment. In doing so, the control sequences directly affect the resultant power consumed by operation of that equipment.

With the installation of electrical energy usage meters for real time data collection, the chiller energy optimization system can monitor the individual power consumption for every separate piece of equipment and can attempt to tune or trim the power used for a specific piece of equipment. The total amount of electrical energy used by all of the

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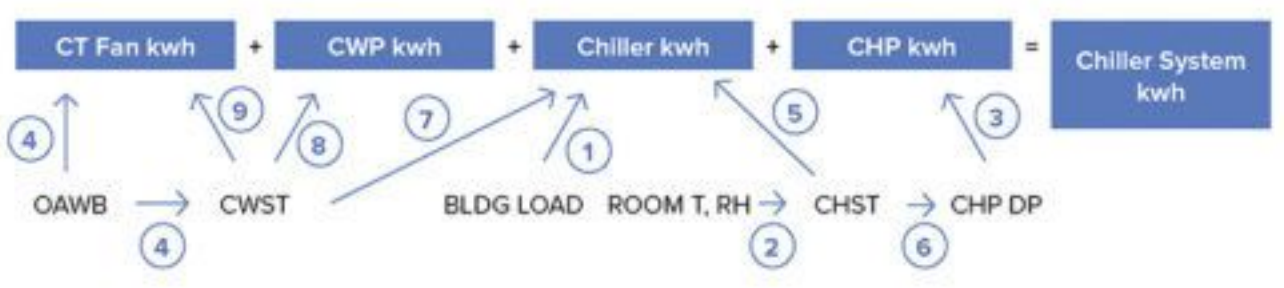

Figure 2: A schematic diagram shows how different input variables affect not only equipment but other inputs. Courtesy: Smith Seckman Reid

equipment, the overall chiller plant kilowatt/ton, is the sum of the simultaneous demands of all of the equipment. This is the purpose of a chiller — to minimize overall chiller plant kilowatt/ton in real time.

Figure 2 illustrates how various inputs and variables affect not only the intended piece of equipment, but how the resultant action affects other pieces of equipment.

Direct inputs from external sources:

1. Building load affects number of chillers and individual chiller loading to maintain enough capacity online to meet cooling demand.

2. Space temperature and relative humidity affect chilled water supply temperature setpoint to obtain chilled water sufficiently cold enough to provide required sensible cooling and dehumidification.

3. Chilled water delta P across the mains affects chilled water pump speed to maintain sufficient flow to all chilled water-cooling coils.

4. Outside air wet-bulb temperature affects condenser water temperature setpoint that can be produced by the cooling towers. It also affects cooling tower fan speed needed to meet the CWST setpoint.

Control sequences are written to take the input above and stage chillers on and off to match cooling demand, change CHST setpoints if space temperature or relative humidity is too high, increase or decrease chilled water pump speed to maintain sufficient flow as chilled water control valves modulate open or closed to maintain required supply air temperature and change CWST setpoint to obtain lower CWST when possible.

These individual actions, however, affect each other and become indirect inputs to other equipment:

1. CHST affects chiller efficiency. Chillers are more efficient at higher CHST but require more energy per ton of cooling at lower CHST (lower CHST require more compressor work for a larger "lift" from evaporator temperature and pressure to condenser temperature and pressure).

2. CHST also affects chilled water pump operation. Lower CHST can result in less chilled water needed, which reduces pumping energy; in contrast, higher CHST may require more chilled water flow and, therefore, more chilled water pump energy.

3. CWST affects chiller efficiency. Higher CWST increases compressor lift (between evaporator and condenser), which increases chiller work and energy required.

4. CWST also affects CWP operation. Higher CWST can result in more condenser water needed, which increases CWP energy.

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5. CWST also affects CTF operation. Lower CWST requires more evaporative cooling, which requires more airflow through the cooling tower and, therefore, more CTF energy.

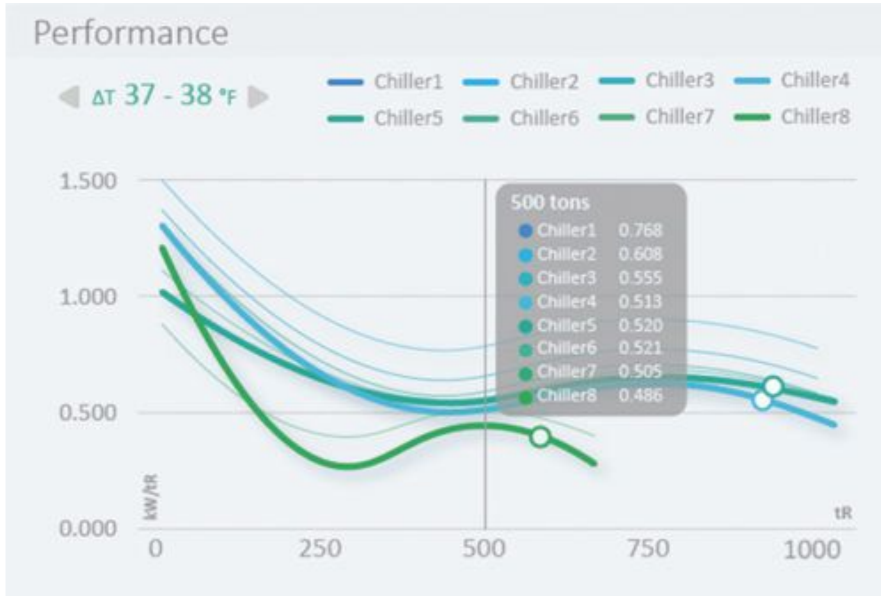

Figure 3: A chiller energy optimization system can use the actual part-load efficiency curves of installed equipment to select the most energy-efficient combination for that particular demand at that particular time. This information, based on the equipment specifications when new, is part of the "predictive" analysis of the chiller. In addition, the chiller will monitor, record and store the resultant energy usage. As equipment wears over time, which may affect efficiency, the chiller will recognize and update this information. This update to the information, based on operating history, is part of the "adaptive" analysis of the chiller. Courtesy: tekWorx

Common control loops for equipment operation in a chilled water system include:

- Chiller staging based on load; sometimes monitoring CHST is also included in chiller staging.
- Chilled water pump speed to maintain delta P across the coil and control valve at an AHU.
- Cooling tower fan speed to maintain CWST setpoint.
- Sometimes a control loop to vary condenser water flow and CWP speed is used as the

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first stage of CWST setpoint; at part load, condenser water from one chiller might flow through two cooling towers to take advantage of available heat transfer area. In addition, condenser water flow might vary from 50% to 100% before starting fans.

There are also control loops that seek to optimize setpoints to minimize energy:

- CHST setpoints can be increased slowly until space relative humidity exceeds setpoint.
- CHST setpoints can also be lowered to try and increase the chilled water system delta T, which reduces chilled water flow and pump energy.
- Chilled water pump delta P setpoint can be decreased until some chilled water air handling unit control valves are open past 95%.
- CWST setpoint can be decreased slowly based on the projected available CWST from the cooling towers as outside air wet bulb temperature drops.

Each of these reset control loops, which are intended to save energy, can also have unintended consequences:

- Increasing CHST setpoint increases chiller efficiency. However, it may also result in more chilled water needed at the cooling coils to obtain required cooling, which would increase pumping energy, so there's a trade between increased chiller efficiency (decreased chiller energy) and increased chilled water pump energy. The increase in required flow at the coils will also result in more chilled water control

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valves opening, which will cause the chilled water pump delta P setpoint to be reset to a higher value.

- Lowering the CHST setpoint may reduce chilled water pump flow and energy but increases chiller energy per ton because the chiller works against a higher compressor lift.

- Lowering the CWST increases chiller efficiency. It also may require more CTF energy, which is a trade-off against the lower chiller energy. The sequence could also affect CWP energy if varying the condenser water flow is part of controlling the CWST setpoint.

The big question is, how do you control the chilled water plant equipment to operate as efficiently as possible and ultimately consume the least amount of energy, while meeting the building needs?

What an optimization system chiller offers

A chiller energy optimization system continuously looks at all of the operating equipment and seeks to minimize the overall chiller plant electric demand. It may adjust the CHST and CWST setpoints up or down. It may reduce CWP speed while increasing CTF speed or do the opposite. It constantly monitors and adjusts setpoints and equipment speeds to respond to changes in the chilled water system demand. It is this readjusting of established control loops that a chiller acts as a low-level smart device — one system working in conjunction with the BAS to optimize the operation of the chiller plant without human intervention. The system can be installed and operate on local servers for security, if desired.

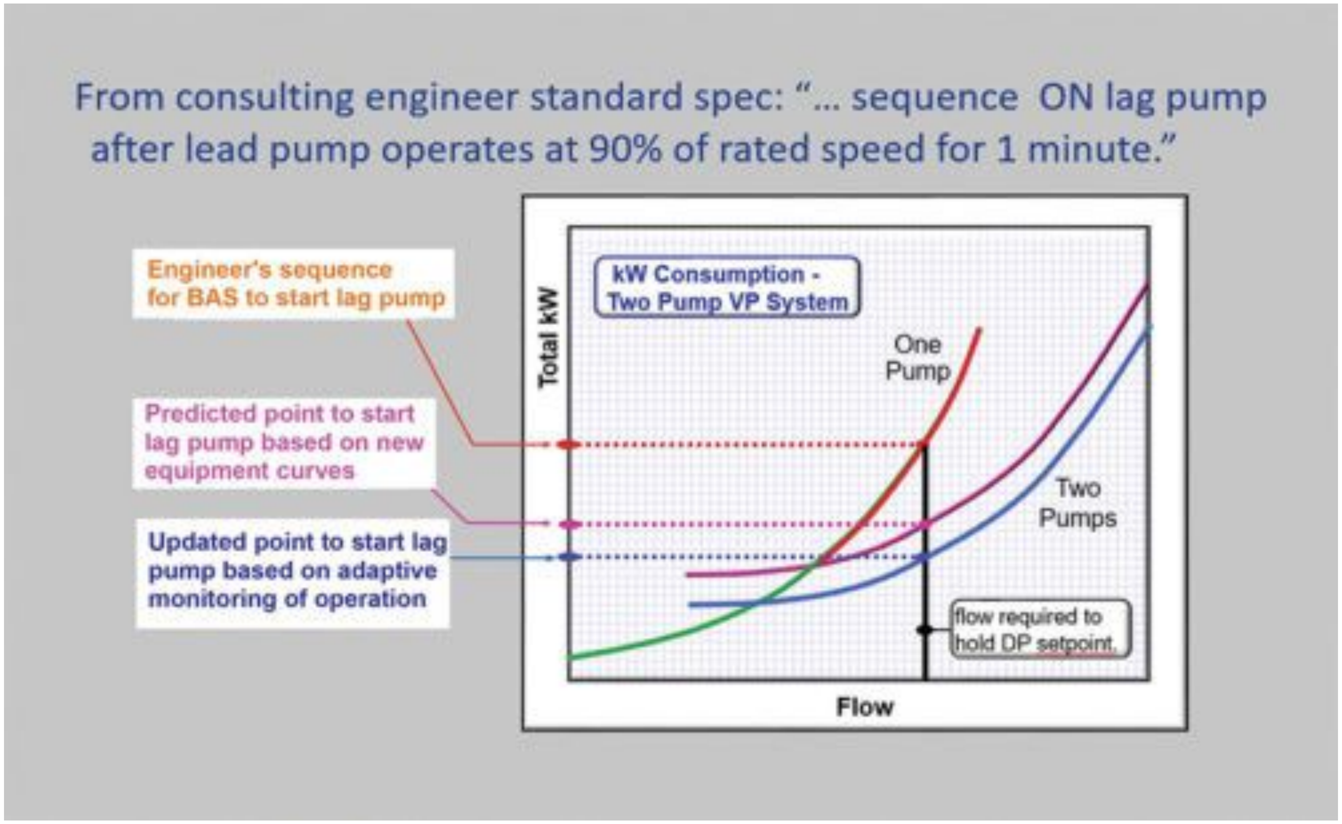

Figure 4: The chiller energy optimization system uses efficiency curves of the newly installed equipment to predict the most efficient time to start the lag pump. After building a database of operating equipment and the resultant energy use, the optimization system adapts to the actual operating characteristics to fine-tune to the most optimal point. Courtesy: tekWorx

How does it do that? Different chiller vendors use their own software and proprietary algorithms to reach the goal of minimizing real-time kilowatt/ton, but one common aspect is that they all build a "library" or type of database that reflects project-specific equipment performance data. The operating characteristics for all equipment in the chiller system and the resultant electric demand are cataloged for comparison. This collection of empirical data becomes the basis for the chiller to know the best combination of equipment and settings for a particular load.

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As an example, a common BAS control sequence might be: "When lead chilled water pump reaches 90% rated speed for five minutes, start lag chilled water pump." A chiller energy optimization system will look at the operating curves of the pumps and sequence two pumps online where traditionally there may only be one. This would happen because two pumps operating at a lower frequency may use less energy than one pump operating at 60 hertz.

Another example would be where the chiller knows the part-load operational characteristics of each chiller in a system and uses that information to determine the best combination of chillers for the real-time demand.

One factor that is inherent in this method is that the part-load efficiencies of the specific equipment installed becomes a factor in the analysis. Power is the cube of flow for both water and air, so the energy used by pumps and tower fans during part load conditions becomes a major input to the overall plant energy usage. Chiller efficiencies, as well, are not linear but are functions of the installed equipment and change over time due to wear.

In effect, the chiller energy optimization system "learns" about the installed system then uses that data to select the most energy-efficient combination of equipment and settings. The chiller uses predictive methods at first to determine equipment operation, observes the resulting energy usage then adapts to tune the settings. (This process is similar to when a patient goes for an eye exam for corrective lenses. As the patient looks through the lens device, the eye doctor will select then reselect the proper lens, asking, "Is this better or worse?" until the patient sees no difference, at which point the doctor has found the right prescription.)

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Because the chiller energy optimization system incorporates specific equipment efficiency data, building the database takes time. It will use various combinations of equipment and it may take several months to optimize the most effective plant operating scenarios. As it continues to run, the database continues to grow, with more accumulated history of operating combinations and associated energy usage.

Relationship of optimization system and BAS

It is important to recognize that a chiller energy optimization system does not replace a BAS. Rather, it complements and enhances overall chiller plant operation. The chiller energy optimization system is an optimization of chilled water system control. It takes the available inputs and outputs of the BAS and optimizes their use.

The chiller energy optimization system does not directly command a pump on or off, nor does it directly change a temperature setpoint. It tells the BAS to start or stop a pump or to change a temperature setpoint. The BAS retains direct control of sensors, transmitters and actuated devices and equipment at the application level.

Because they communicate so closely, the BAS and the optimization system must "speak the same language." They must use the same protocol (BACnet, Modbus, etc.). The BAS and chiller energy optimization system are communicating constantly; they need to have compatible network speeds. There need to be sufficient interfaces in the management level of the BAS with which the chiller can communicate.

Just because there is an optimization system, the engineer should not abdicate design and intended operation of the chilled water system. There is always the chance that communication will be lost between the chiller and the BAS; if that happens, how is the

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chiller system supposed to work? There need to be sufficient control sequences for the system to operate properly without an optimization system.

As mentioned earlier, some BAS vendors may not agree with the advertised benefits of a chiller energy optimization system. The optimization system and BAS installer need to coordinate details of "tuning" the systems, such as valve closing speeds and time durations to ramp up or slow down pump speeds. It's important that both system installers work closely together to bring their best products and installation practices to a successful project for the owner.

When does energy optimization make sense?

A chiller energy optimization system is an added expense and is not crucial to the operation of a chilled water system. There is a practical lower boundary of when an optimization system adds value above its cost. Therefore, it "needs to pay for itself." For a custom written specification with site-specific installed equipment, some general guidelines are:

- There are at least three chillers in the plant, totaling at least 1,500 tons.
- Electricity costs are above national norms, either in energy or demand charges.
- A chiller energy optimization system is more likely to prove its worth when the chiller system operates year-round, as opposed to a system that does not run in the winter because the air handling units have airside economizer and do not use chilled water when the outside air temperature is below 50°F.

Recently, some chiller vendors developed standardized systems applicable to chilled water plants smaller than 1,500 tons with three chillers.

Asking "How much does it cost?" is akin to asking, "How long is a rope?" because systems differ in size, number of chillers, characteristics of the BAS, location of the project, etc. For example, a chiller for a chiller plant with three 500-ton chillers and variable primary flow costs in the range of $90,000 to $140,000 to install and start up. (These costs would be for a new installation with a new BAS that is prepared to interface with a chiller. Cost to add a chiller as retrofit may be higher if modifications to the existing BAS are needed to interface with the chiller.) Additionally, annual maintenance costs average 15%, depending on vendor,

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to provide continuing services, such as software updates or implementation on other host equipment.

When comparing systems and selecting a chiller energy optimization system, a presentation in person or in print is helpful to understand the scope of what will be provided. Important points to consider include:

- Features and advantages of the system. Ask what the system does that a BAS won't do. They won't tell you their proprietary algorithms but they should provide enough information that shows they are making real-time decisions based on-site specific equipment operating characteristics. Ask for an example, such as the pump or chiller examples above.

- A sample report or screen shot. See if they show a dynamic, real-time "dashboard" or something similar that shows current chiller plant kilowatt/ton.

- A list of equipment and control points that are monitored and adjusted.

- First cost and what is included in that scope. What requirements must already be on-site (such as BAS interface) for them to communicate? What else will be needed outside of the scope included in the first cost?

- Are there any annual system maintenance or upkeep costs? If so, how much and what is included?

- References for systems in buildings of similar size and occupancy.

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Chiller energy optimization systems versus building automation systems

A chiller energy optimization system is appropriate when the owner prioritizes long-term operational cost savings over first cost of installation. For the three 500-ton chillers example, the simple payback would range from three to four years assuming year-round operation and electricity costs 10% above national norms.

There are many successful optimization system installations with which owners are very satisfied. There are also installations that have not been successful. The consulting engineer needs to evaluate the owner's priorities, plant capacity, expected time of plant operation and electric utility rates to advise the owner accordingly. The engineer should also enlist the owner's influence with the BAS and chiller energy optimization system installers to work together.

Rick Wood

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Controlling multiple chiller plants

A chiller energy optimization system can control multiple plants that are connected together A chiller energy optimization system can provide control optimization not just of a single plant, but can help optimize the combined operation of multiple plants that are interconnected.

A chiller energy optimization system can provide control optimization not just of a single plant, but can help optimize the combined operation of multiple plants that are interconnected.

There are two unique aspects of operating multiple plants "as one":

- Coordination required on the chilled water distribution and pumping.
- Ensuring the chillers in both plants load evenly in chilling capacity.

The chilled water pumps will still control to a delta P setpoint but there are multiple setpoints at the air handling units in the various buildings. There are also multiple pumps from each plant, now simultaneously trying to meet those setpoints.

The chillers in the plants also need to load evenly in capacity, which means the chilled water return temperature to each plant needs to be as close as possible (to avoid one chiller plant with a delta T of 5°F and another plant with a delta T of 15°F across the chillers).

The ability of a chiller to monitor multiple delta P settings as well as know the CWRT at each plant enables the chiller to constantly adjust delta P setpoints to direct the chilled water back to the plants to maintain, as closely as possible, even loading on the plants.

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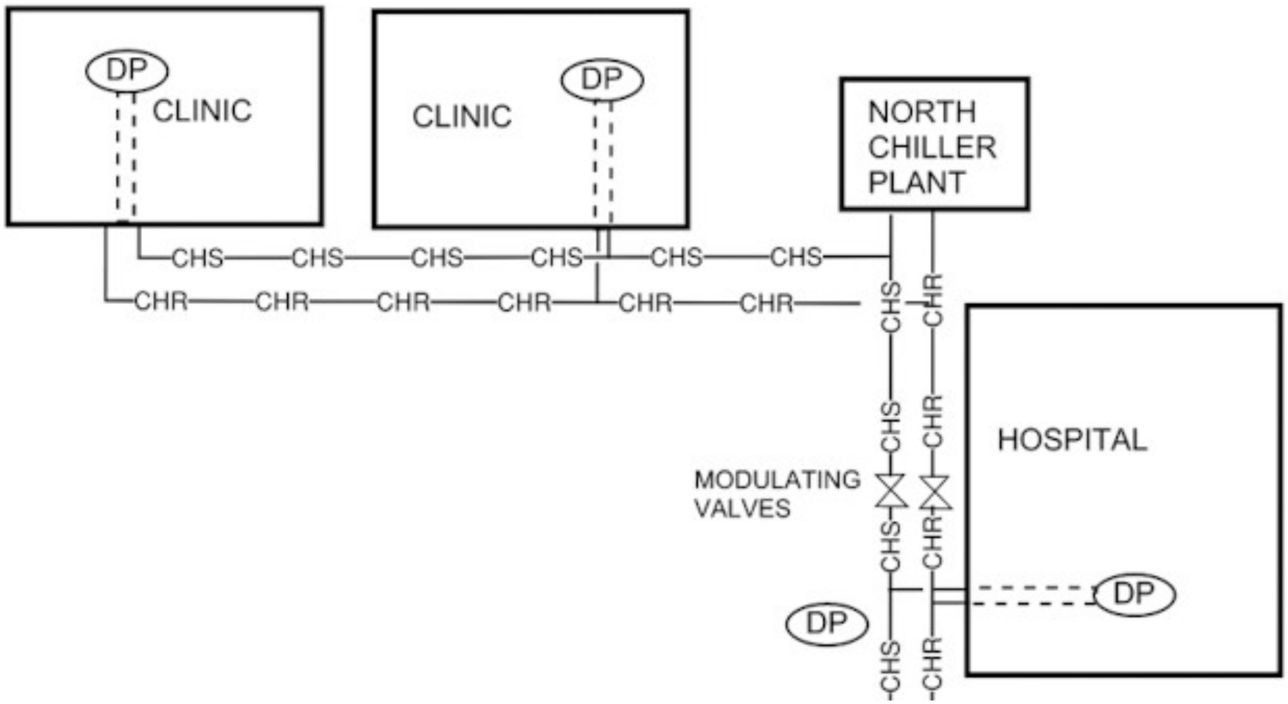

Figure 5: Campus Chiller system layout with two chiller plants serving four loads — two hospital buildings and two clinic buildings. Courtesy: Smith Seckman Reid

In Figure 5, the north and south chiller plants feed into the same campus distribution system. The chiller can adjust pump speeds and start/stop chillers in each plant to best meet the load at the lowest kilowatt/ton. For example, the chiller might operate two chillers from each plant, adjust the delta P setpoints and modulate the valves so that the clinic and hospital buildings are served by the north and south plants, respectively. Alternately, at low load, the chiller may dictate a single plant to serve the entire campus.

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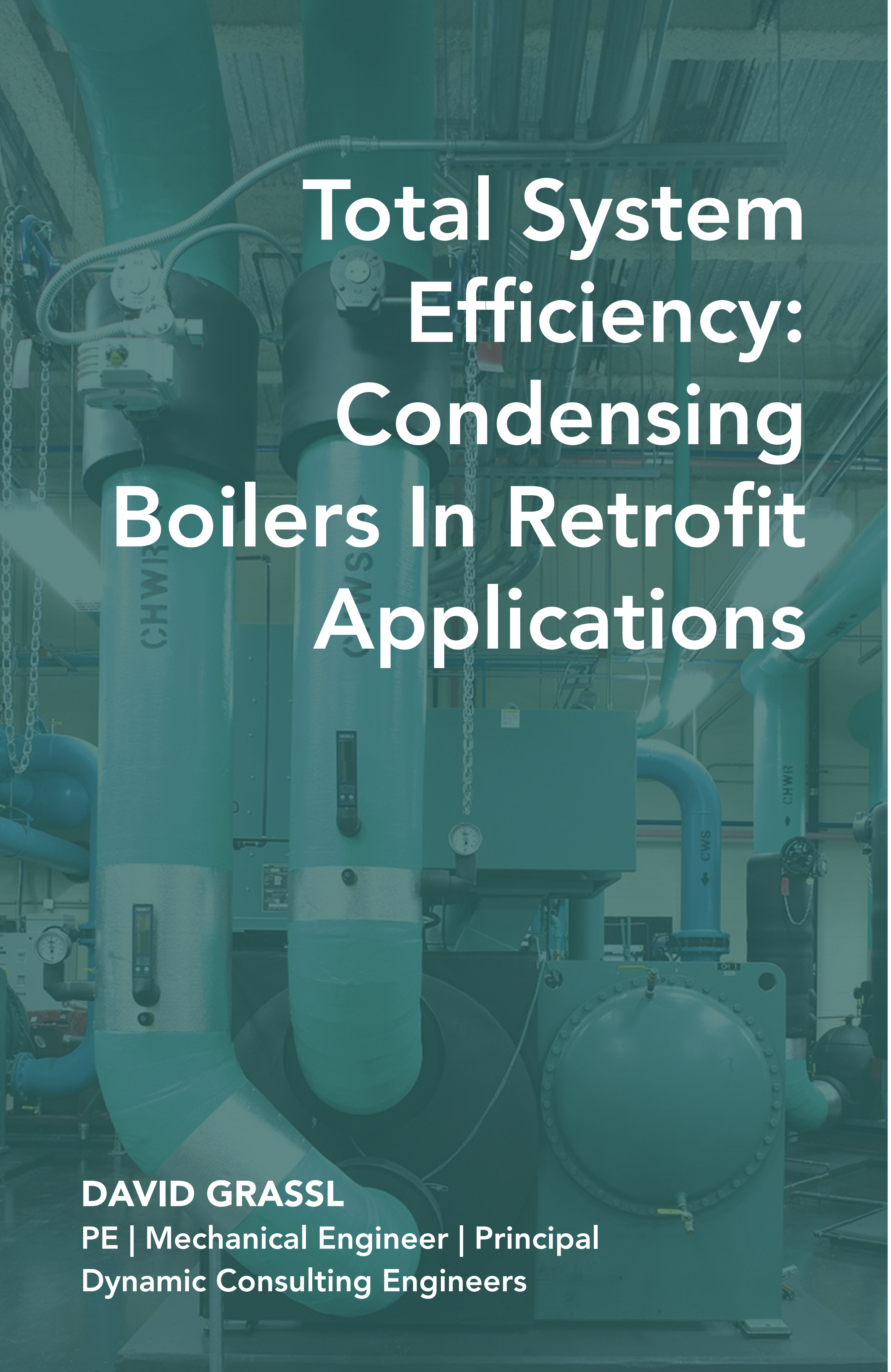
ClearFire Boilers - The Dual Return Advantage

The dual return design of the ClearFire condensing boilers helps achieve true condensing performance, even in applications with non-condensing temperature heating loops, resulting in 6%+ increase in system efficiency.



Total System Efficiency: Condensing Boilers In Retrofit Applications

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Each retrofit has its own set of challenges, but having a solid understanding of the various pumping and piping configurations available will lead to the correct design for each project. Following are the steps necessary to evaluate piping applications, pumping configurations and control strategies necessary for a successful retrofit that increases overall hot-water-system efficiency.

Common Items in All Retrofits

The first step in the retrofit process is to evaluate the building loads, including any potential loads that are suitable for low-temperature applications such as domestic water heating, pool heating, or radiant applications including snow melt or in-floor heating. Once the loads are fully identified, the next step is to evaluate the system design temperatures currently in use to determine if they may be modified to increase efficiency, remembering that the goal is to reduce the hot-water-return temperature as much as possible while still meeting the building load to increase boiler efficiency. When converting traditional, non-condensing systems, it is standard for the hot water system to be designed with a hot-water-supply temperature in the range of 180°F to 200°F. Since it is customary for heating systems to have redundancy and safety factors included in the calculations that overestimate the true load, it is important to determine the actual boiler capacity required.

Similarly, the minimum and maximum loads should be observed over time to assist in boiler sizing and selection to match system turndown and redundancy with the required loads.

Next, the control used at the heating coils should be reviewed to determine the method of coil and pump control. Traditional, non-condensing boiler systems typically have three-way temperature control valves at each coil in the system, which allows for variable flow at the coil as the load varies; however, any flow that is not required by the coil is bypassed around the coil and creates constant flow in the system. By using two-way control valves, the wasted water that bypasses the coil is eliminated while reducing the flow in the system when it is not required. The temperature-control-valve conversion literally can be a replacement of the valves, or it can be accomplished by fully closing the balancing valve in the bypass piping circuit and keeping the existing piping in place. Remember, in the conversion from three-way valves to two-way valves, it is important that the system minimum flows be maintained for the pumps and/or boilers by one of the methods described.

To maintain maximum system efficiency, as the control valves are converted to two-way control valves, the distribution pumps should also be converted to provide variable flow. Variable speed pumping can be accomplished by adding a variable frequency drive to the existing pump, providing a new pump with either a remote VFD or an intelligent pump with a built-in VFD or microprocessor. Regardless of the method used to vary the pump speed, note that it is important for pumps with variable speed drives to have shaft grounding rings. The use of variable frequency drives has the potential to induce harmful electrical voltages on the motor shaft, which can lead to pitting and premature failure of the shaft.

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Piping & Pumping Modifications

In a retrofit application, the existing hot water system can be piped in a variety of different configurations, including constant volume, variable volume, variable-flow-primary, or primary-secondary. Regardless of how the system was previously piped, almost always there will be a need to adjust the piping configuration to maximize system efficiency. Although it is impractical to attempt to cover every application, this paper will discuss some of the more common retrofit configurations.

The first and likely most-common retrofit condition is converting a primary-secondary system with non-condensing boilers into a fully condensing boiler plant. This system is a cost-effective way to incorporate condensing boilers, but it uses low-mass boilers, which have a reduced life expectancy compared to high-mass boilers. In this configuration, all the existing non-condensing boilers can be replaced with similar condensing boilers in the same primary-secondary configuration. Low-mass condensing boiler systems typically require a design ΔT of 20°F to 30°F due to the amount of water in the system. At the same time, if the hot water system does not have the overall system volume necessary, it may be necessary to expand system volume, which can be accomplished by adding a primary-secondary buffer tank. With this approach, a few different functions can be accomplished with a single device. The primary and secondary systems can interact at a pipe common to both systems such as an air separator, buffer tank, or the common pipe. Remember, it is important to analyze each condition, especially in a retrofit condition, by comparing the style of boilers removed from the system with the new boilers being added. For example, if high-mass boilers are removed and replaced with low-mass boilers, the system water volume may be significantly reduced and require a buffer tank. However, if the reverse were true, a buffer tank may not be required in the new system. A second method to accomplish the same task is to use

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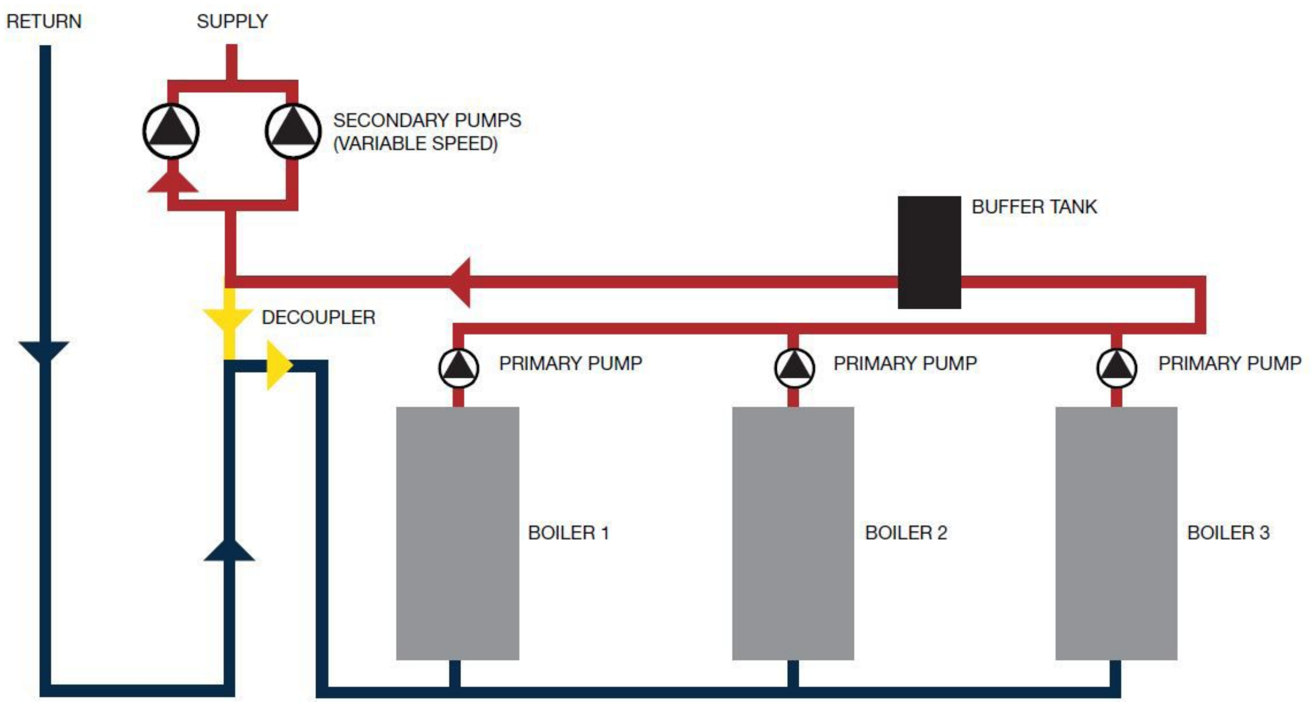

Figure 1: Low-mass condensing boiler system in a primary-secondary configuration with a buffer tank.

a buffer tank in the primary piping as shown in Figure 1.

If high-mass condensing boilers are used in lieu of low-mass condensing boilers, it is possible to eliminate the buffer tank because the system volume is accomplished within the boiler itself. Because of this, it is possible to modify the piping configuration from a primary-secondary system to a full variable-flow-primary system and remove the secondary pumps as shown in Figure 2. Since the boilers are condensing units, any water temperature that satisfies the building load is sufficient for the boilers to operate, and only the necessary flow is distributed to the system to minimize pumping energy. With this system, it is critical to install two-position, two-way isolation control

valves that eliminate flow to the boilers only when they are not in operation to prevent bypassing the boilers and mixing water downstream of the boilers Figure 2: High-mass boiler system in a variable-flow-primary configuration.

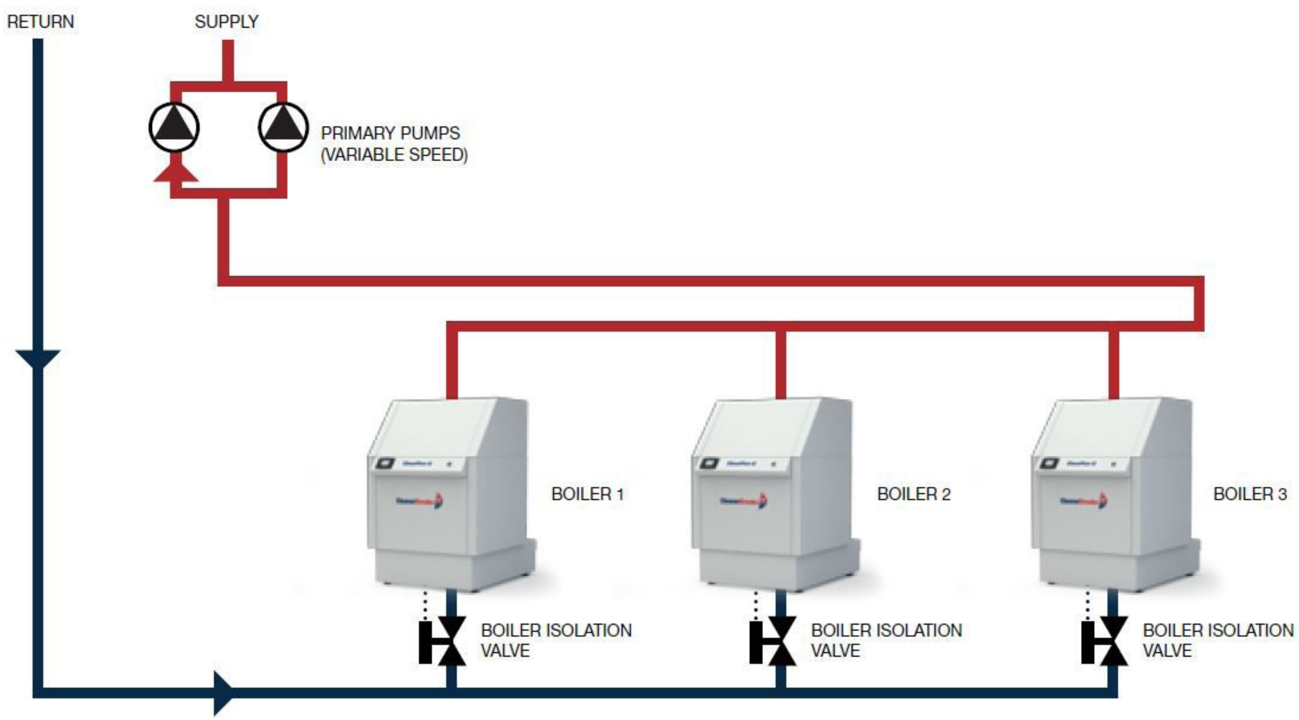

Figure 2: High-mass boiler system in a variable-flow-primary configuration.

A third approach is to use a system with a dual return. Applications for a dual-return system include systems that have a consistent low-temperature return that can be used to condense the boiler flue gases that might otherwise be lost by mixing the low hot-water-return temperature with high-temperature hot water. In a system with consistently low temperatures, the low-temperature hot water return is piped back to the boiler independently of the other hot water return piping to increase system efficiency. This

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allows the boiler to operate in a condensing mode even if a majority of the load requires non-condensing temperatures, increasing the boiler operating efficiency.

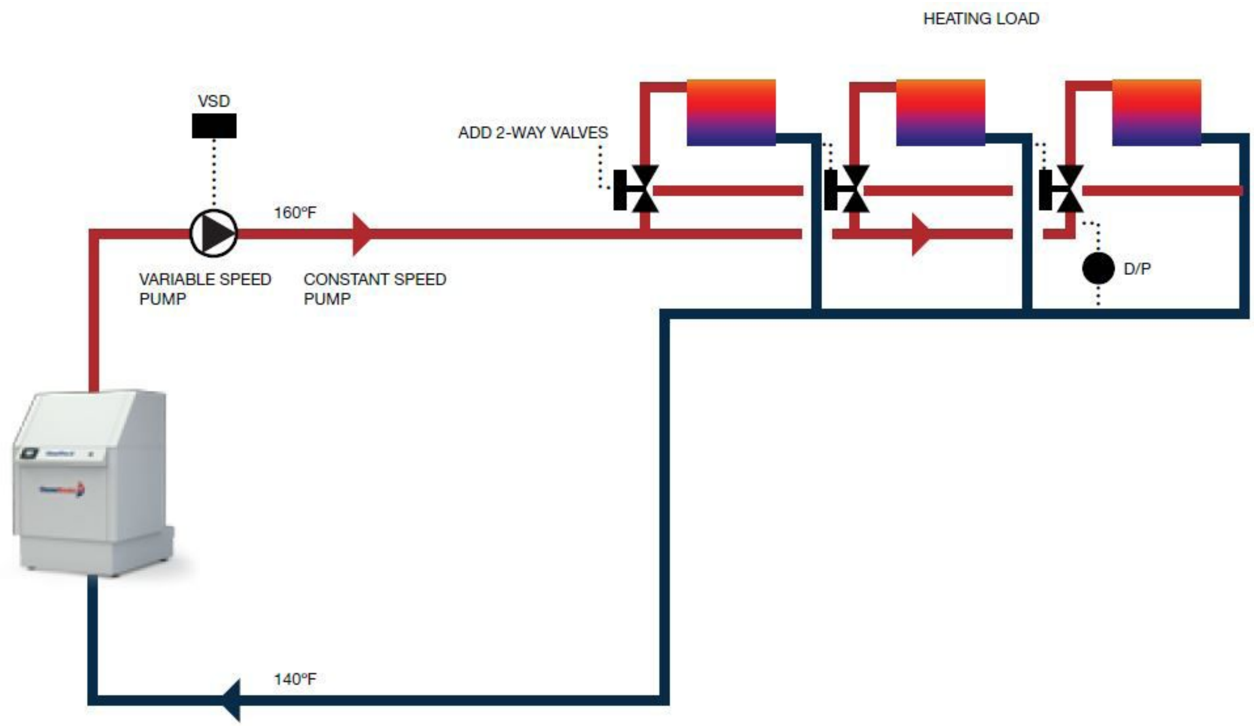

Figure 3: Retrofit option from a constant speed, non-condensing boiler system to a variable speed, condensing boiler system.

Another common retrofit is converting a traditional, non-condensing, constant-speed pumping system to a modern, condensing, variable-speed pumping system. By replacing the boiler with a condensing unit, providing a variable frequency drive on the pump with pump controls, providing two-way control valves, and reducing the hot water supply and return temperatures, the system can be converted as shown in Figure 3. Although this example shows a single boiler, it can be used for multiple boilers in parallel.

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A slightly more complex, but still common retrofit application is converting a larger primary-secondary, non-condensing boiler system with multiple boilers to a configuration that can maximize system efficiency by either partially or fully replacing the non-condensing boilers with condensing boilers. In the existing non-condensing boiler system, each unit has a primary pump that operates when the boiler's primary function is producing hot water for the secondary loop. The primary and secondary loop are connected by a common pipe that hydraulically decouples the loops from each other (also known as a decoupler). Depending on the hot-water-supply temperatures required by the system, this enables a couple of potential piping options.

The simplest configuration is to completely replace all the boilers in the plant with condensing ones and reduce the system hot water supply temperature to meet the load. Under this configuration, with the use of high-mass boilers it is possible to operate a variable-flow-primary system with a single set of primary pumps to distribute water to the entire building. This option will yield the highest efficiency as the entire boiler plant would be condensing and the system would experience only the pumping energy required to meet the load. However, this option has the highest first cost as condensing boilers are more expensive than similar-sized non-condensing boilers. This method also assumes that lower hot water supply temperatures can be used by the system to maximize system efficiency.

A second approach is to maintain the primary-secondary pumping configuration with a hybrid of condensing boilers and non-condensing boilers as shown in Figure 4. In this configuration, condensing boilers are installed upstream of the non-condensing boiler to allow the coldest water to come in contact the condensing boilers first. The condensing boilers can then heat the hot water for the non-condensing boiler, or in some

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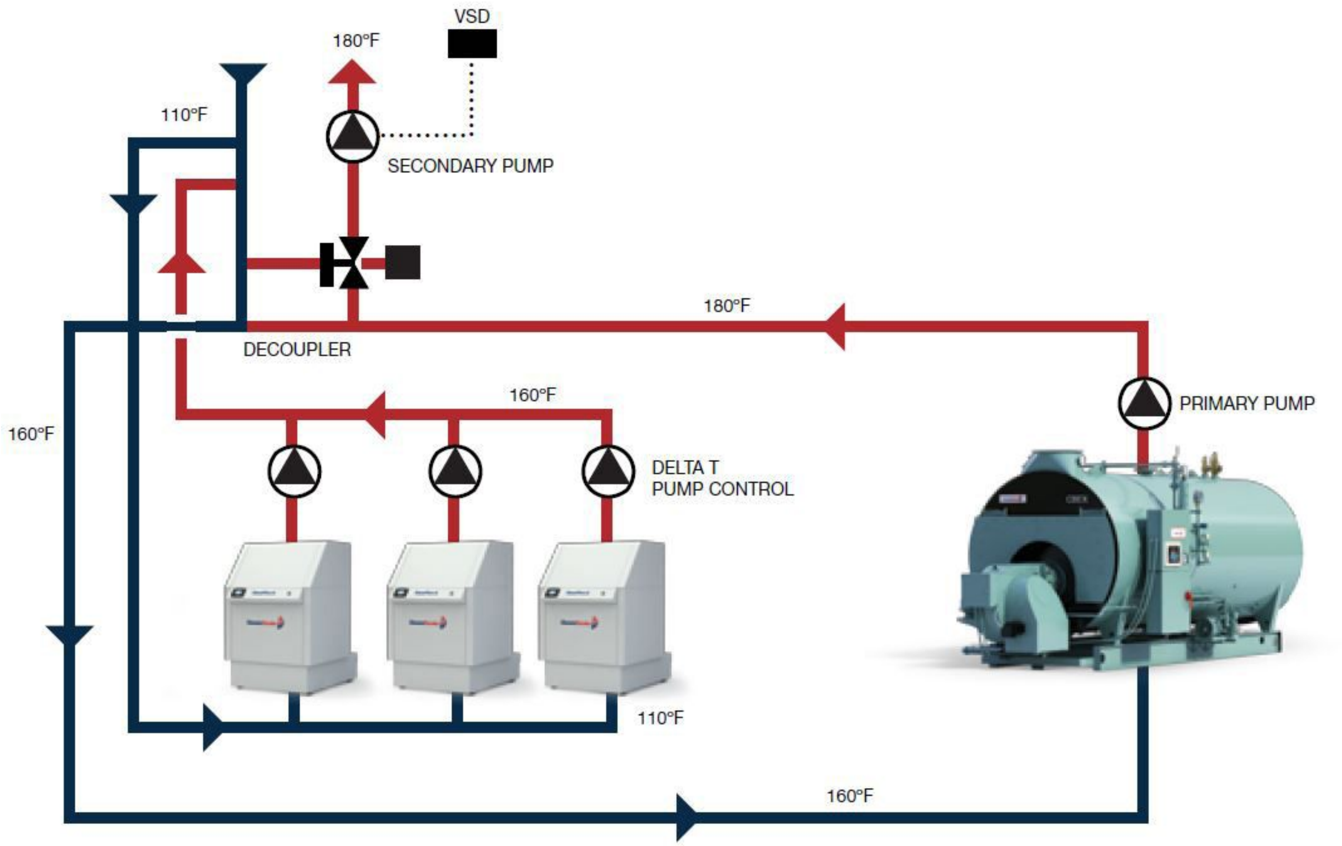

Figure 4: Hybrid plant with primary-secondary pumping.

cases during low loads, to satisfy the entire load required for the building. The pumping configuration at the condensing boilers should be set up to operate based on a ΔT pumping configuration to maintain a hot-water-return temperature to the non-condensing boiler appropriate to prevent condensing. One advantage of this system is the primary-secondary pumping configuration is maintained for simplicity and familiarity, but it enables higher efficiencies since the condensing boilers are upstream of the non-condensing boiler.

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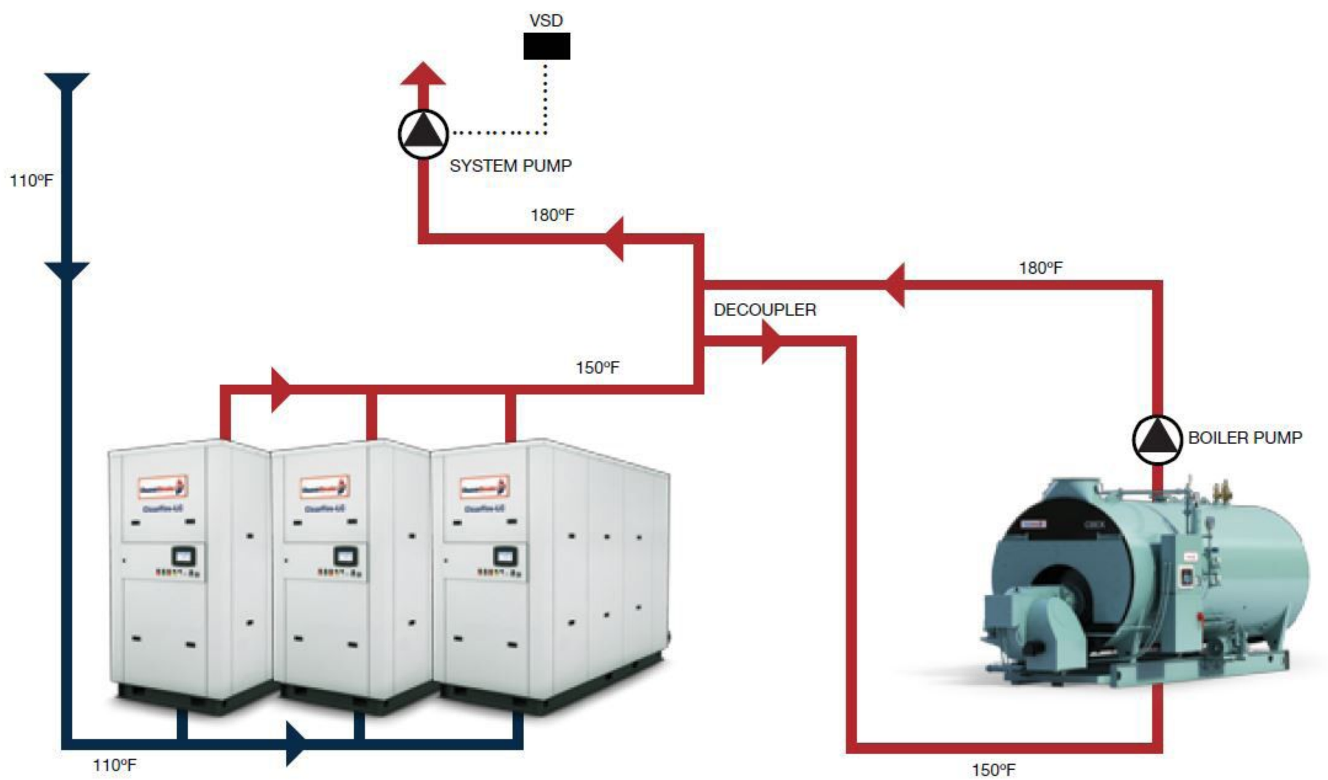

Figure 5: A second hybrid configuration with variable-flow-primary pumping.

Figure 5 shows another hybrid configuration that focuses more on a variable-flow-primary pumping arrangement while using a non-condensing boiler in a side-car configuration. Similar to the first hybrid configuration, the condensing boilers are the first boilers in the boiler plant to see the hot water return so that condensing conditions can be maximized as much as possible while also providing water at a sufficient temperature to protect the non-condensing boiler. By having the non-condensing boiler configured in its own loop with a dedicated pump, should additional heat be required by the system, the control strategy utilized by the primary-secondary configuration can be utilized. As additional heat is required by the system, the non-condensing boiler pump turns on and

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increases the hot-water-supply temperature to the primary loop through a common pipe or decoupler, which maintains its hydraulic independence from the rest of the system.

This configuration, like the other hybrid approach, provides the ability to retain a non-condensing boiler and reduce retrofit costs in lieu of purchasing an entirely new condensing boiler plant. The advantage of this system compared to the first one is the ability to operate in a true variable-flow configuration, which uses less horsepower compared to primary-secondary systems and has less equipment to maintain.

Control Strategies

Similar to pumping and piping configurations requiring modification in a retrofit, the standard control strategy that has been used in non-condensing boilers needs a refresh as well. In traditional boiler systems, it is common practice to operate boilers in a lead-lag staging configuration to maintain the hot-water-supply setpoint. In this setup, the first boiler in the plant operates and stages capacity in order to meet the system setpoint in the main supply header. If the first boiler is unable to maintain setpoint, the control indicated that the boiler could not provide enough capacity, and an additional boiler was brought online to increase the hot-water-supply temperature. In theory this is a good solution, but what actually occurs in the system is that the boilers online operate with uneven firing rates and different hot-water-supply temperatures. Because of this, it is common for the first boiler online to overshoot the hot-water-supply temperature setpoint and produce hot-water-supply temperatures above the setpoint at full load in order to compensate for the second boiler at part load, producing hot water temperatures below setpoint as mixing downstream of the boilers occurs. This leads to unstable and unpredictable hot water temperatures from each boiler in the system, thereby reducing efficiency and increasing boiler cycling.

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In modern condensing applications, boilers typically operate in parallel, regardless of the system load. Contrary to the traditional method of control, system efficiency with condensing boilers improves at part-load condition as more surface area is available for condensing. Similarly, a consistent hot-water-supply temperature can be produced from each boiler in parallel to the distribution system. With the condensing boilers operating in a true parallel configuration at similar loads, controls strategies can be used to further maximize system efficiency. For example, systems that require high hot-water-supply temperatures based on a traditional design can operate with an aggressive hot-water-reset schedule based on outside air to promote condensing during the summer or periods when there are low loads in the system. This can be combined with a night setback schedule to promote the use of lower hot-water-supply temperatures when there may not be any occupants in the space.

Adding VFDs requires new control strategies to provide variable-speed pumping. This can be accomplished in a variety of ways with the most common method being to control the pump speed based on the differential pressure at a defined location in the system. As the system pressure changes based on the control valve position at any given time, the pump speed modulates to provide only the required pressure and flow the system needs, saving pumping energy.

Understanding the principles of condensing boiler technology is required to properly apply it in a retrofit project. For a retrofit application, and even for a new application, it is important to work with the boiler manufacturer to ensure you are designing within the requirements of the boiler. Similarly, it is critical to understand the building load and attempt to reduce the hot-water-return temperature as much as possible to achieve higher boiler efficiency. The pumping configuration and control strategies are just as critical to promote condensing conditions with consistent hot-water-supply temperatures.

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Finally, when selecting a condensing boiler for your new or retrofit application, there are a variety of technologies available. Some condensing boilers require more maintenance than others, or have specific piping, pumping, and flow requirements. High mass firetube condensing boilers have been developed to overcome many of these obstacles, and can be piped in a variety of systems with success. Therefore, it is important to understand each boilers' operating requirements, as well as total cost of ownership, when making a boiler selection.

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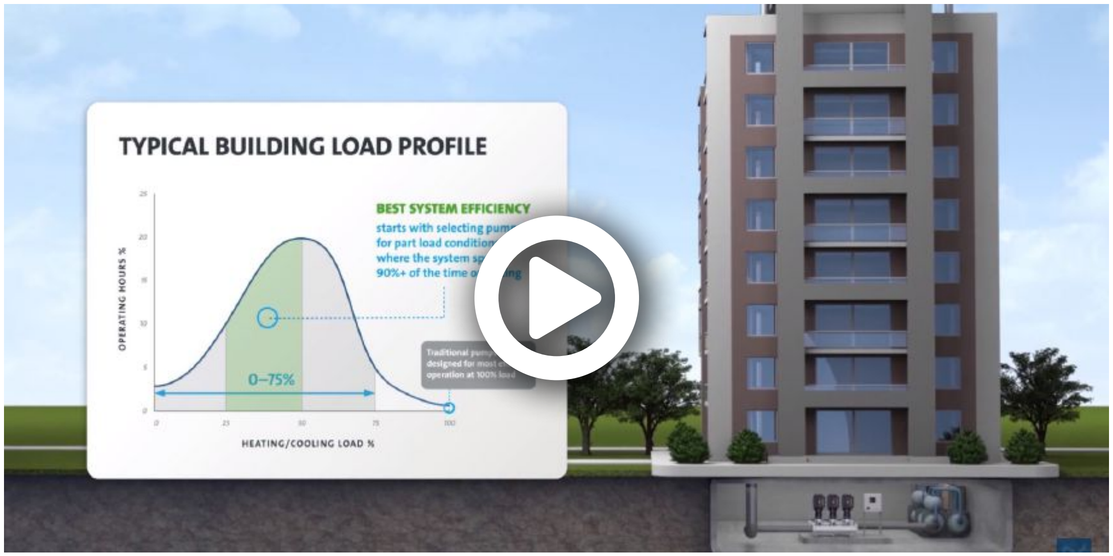
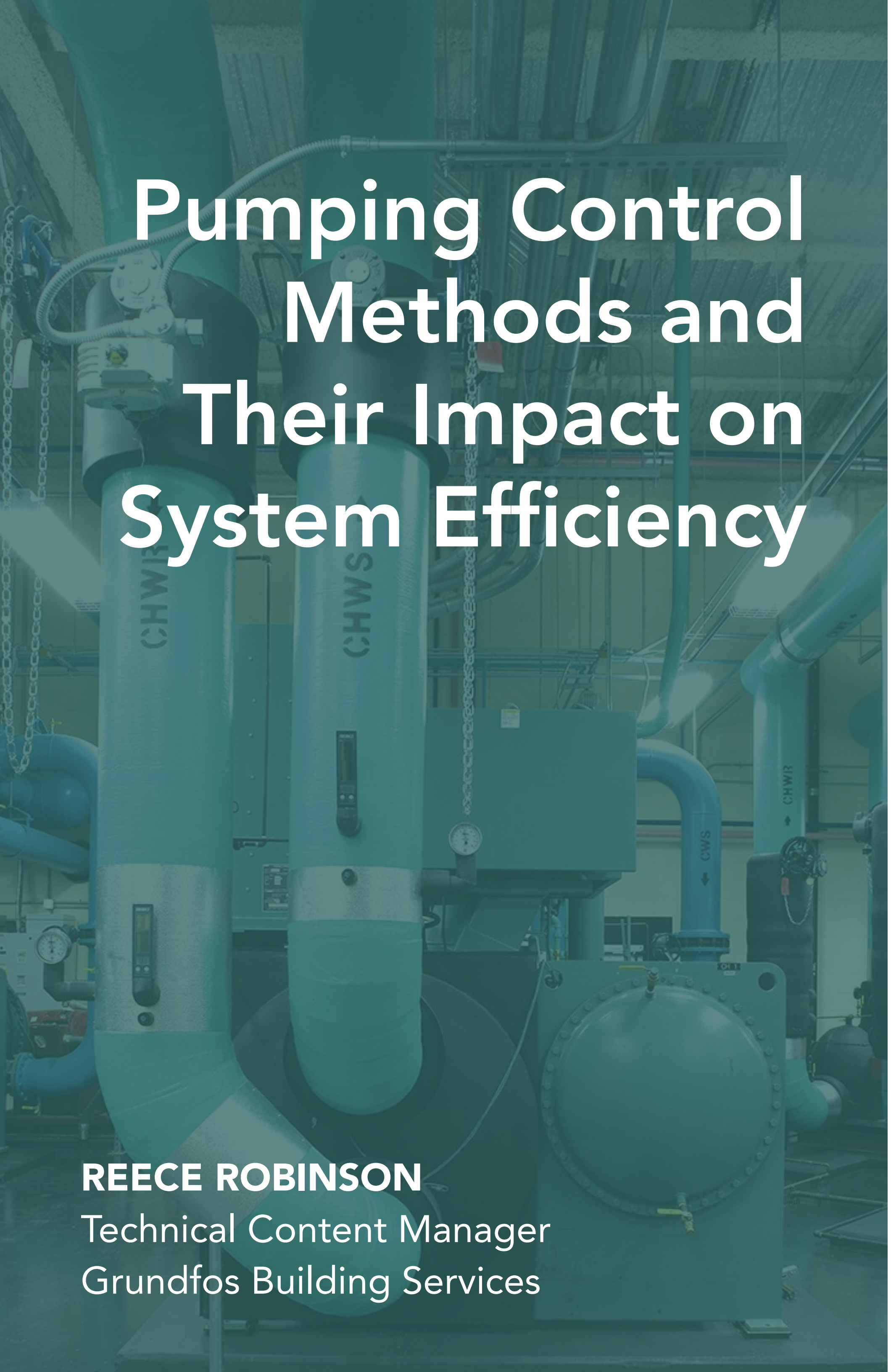


Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Today's engineers face increased pressure to deliver greater building efficiency, with tighter timelines and smaller budgets.



Pumping Control Methods and Their Impact on System Efficiency

REECE ROBINSON
Technical Content Manager
Grundfos Building Services

When it comes to designing commercial HVAC and plumbing systems, engineers have to overcome a number of challenges. While everyone faces perennial budget and timeline issues, system efficiency is becoming a bigger concern every year. In this white paper, we'll discuss the role of pumps in hydronic and pressure boosting applications, as we focus on the various pumping control methods and the significant impact they have on overall system performance and efficiency.

Today's Focus on Efficiency

In recent years, commercial building energy codes have gotten tighter in response to environmental concerns and consumer preferences. The result of national efforts like the ASHRAE code requirements, LEED certification, Energy Star and the Department of Energy's Energy Efficiency Programs is that over a span of nearly 40 years, buildings have become 50% more efficient.[1] At the same time, designing systems to meet the new regulations has become more of a challenge. In states like California, where Title 24 calls for even more stringent efficiency requirements, this focus is amplified.

This means both engineers and contractors have to understand all the tools at their disposal for increasing system efficiency.

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Complex systems may have multiple remote sensors and control logic to adjust pump system set-point accordingly.

The Importance of Pumps

Pumps are the heart of any commercial HVAC or pressure boosting system, so they are the key to how the system performs. Pump manufacturers strive to create pumps that offer the highest possible efficiencies, with mechanical enhancements and permanent magnet motors that deliver energy-saving variable speed pump performance.

In 2015, the Department of Energy (DOE) upped the ante and mandated new pump efficiency standards that will take effect in 2020. As a result of the new measure, the DOE projects that over the course of 30 years, pumps meeting these standards will reduce electricity consumption by about 30 billion kilowatt-hours — the equivalent of the annual electricity use of 2.8 million US households.[2]

As the intended outcome of the DOE mandate demonstrates, pump efficiency goes way beyond the pump itself and extends to the vital role pumps play in the overall energy consumption of the buildings in which they operate. In other words, in both HVAC and plumbing applications, the key to success is overall system efficiency. And that's where pump control methods play an important role.

Variable Pressure Is Key to Efficiency

In a nutshell, variable pressure control is a method used in variable speed pumping that results in reduced pump energy costs. Variable pressure encompasses a number of control modes where pump head is reduced either linearly or quadratically as flow is reduced.

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While the terms "proportional pressure control" and even "quadratic proportional pressure control" are frequently used, combining these words results in an oxymoron. Mathematically, the term "proportional" describes a linear relationship, while "quadratic" describes a non-linear relationship. For this reason, quadratic pressure control should not be a subset of proportional control.

Applications

In HVAC systems, variable pressure control is most common in closed system (hydronic) applications configured as variable / primary or secondary pumping systems, where water is pumped to heating / cooling coils or air handling units (AHUs) with modulating control valves.

In pressure boosting systems, this type of control is used in municipal water supply and service water boosting in commercial buildings.

An illustration of why variable pressure control is preferred in these applications can be seen in Figure 1, which shows what happens when an uncontrolled (fixed speed) centrifugal pump is used instead.

Notice that the pump head rises as flow is reduced. This is quite often the exact opposite of what is needed to provide the required flow. Variable pressure control eliminates this problem, delivering lower pressure as flow reduces. This ultimately results in greater efficiency and lower energy costs.

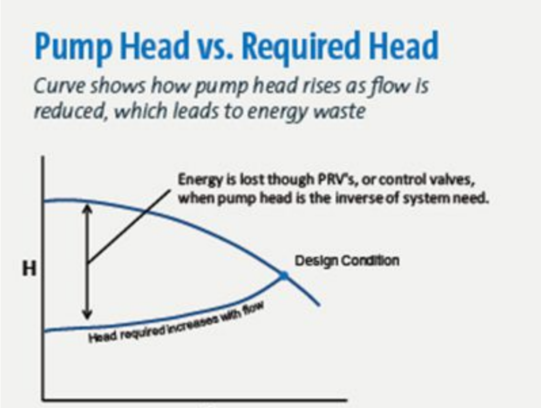

Figure 1

Changing Flow Demand

Variable pressure adapts to changes in flow demand, delivering efficient performance even during partial-load scenarios, which occur much more often than full-load situations. For example, a chilled water circulation system can have low flow demands in the spring and fall months, and a service water booster system can have low flow demands during off-peak hours. The pump head required during these lowflow periods can be significantly lower than what is required at peak (design) flow periods due to the reduced friction losses in the pipes and fittings. Because of the hydraulic relationship between pressure and flow in piping systems, pump operation can be controlled by only measuring pressure, without the need to measure flow.

Measuring Pressure

There are several options for measuring pressure, including type of equipment, and where it's located. Because they are less intrusive and inexpensive, pressure sensors have become more popular than flow sensors. Pump systems with pressure sensors (differential pressure or individual suction and discharge pressure sensors) will calculate flow based on the differential pressure across the pump, or a combination of differential pressure and power. Pump performance data is loaded into the pump control. Power-based pump control, or controls operating without sensors, have gained popularity over the last 10 years as well. Here, pump performance curves are loaded into the pump control and both pressure and flow are estimated using the power consumed by the

Power-based Control and Relation to Pump Performance Curve

Controlling pumps based on the pump's power consumption can intersect the pump curve at multiple points, as demonstrated by points 1 and 2.

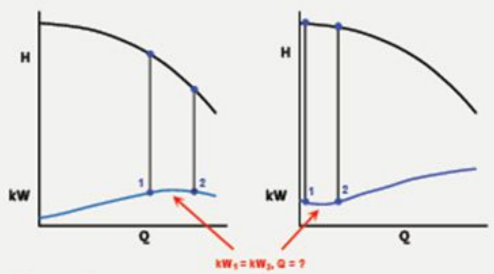

Figure 2

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motor and drive. Caution must be taken when using power-based control, as this method does not work on all pump types. Since the only thing being measured is motor input power (via the variable frequency drive), there may be two points on the pump curve that require the same power. An example is shown below in Figure 2.

Regardless, the use of both pressure sensors and power-based control results in some form of variable pressure control.

Common misconception: "If a pump-mounted sensor is used, the pump can only operate in constant pressure mode." This is incorrect, as current pump technology allows proportional and / or quadratic pressure control even in systems with pump mounted sensors.

There are four main types of pressure control for centrifugal pumps: constant pressure, proportional pressure, quadratic pressure, and constant pressure using a remote sensor. Figure 3 below shows the control curves for each of these pressure control types in blue.

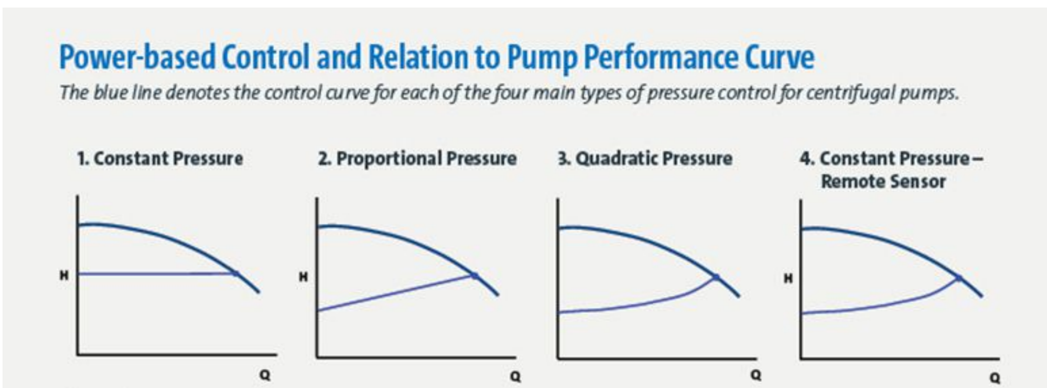

Figure 3

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1. Constant pressure mode

Constant pressure is technically not considered variable pressure control, but is a standard control mode for variable speed pumps. It is very widely used in service water boosting and is occasionally required for hydronic circulation systems, especially in those with higher-than normal pressures in low-flow conditions.

2. Proportional pressure mode

In this mode, the pump head is reduced linearly with flow.

3. Quadratic pressure mode

Quadratic (or squared) pressure best simulates the characteristics of a system resistance curve, because friction losses have a quadratic relationship with flow.

4. Constant pressure remote mode

This control mode uses a system-mounted sensor that is strategically placed in the piping system. Notice on the graphs in Figure 3 that the resulting control curve can essentially be the same for both quadratic control and constant pressure remote.

The first three control modes — constant pressure, proportional pressure and quadratic pressure — can be what are called "preprogrammed" control modes and can be used with pump- or system–mounted sensors and / or power-based pump control.

Some basic examples of pump and piping configurations with sensor placement are shown in Figures 4 and 5. Obviously, options for placement will vary significantly based on project requirements.

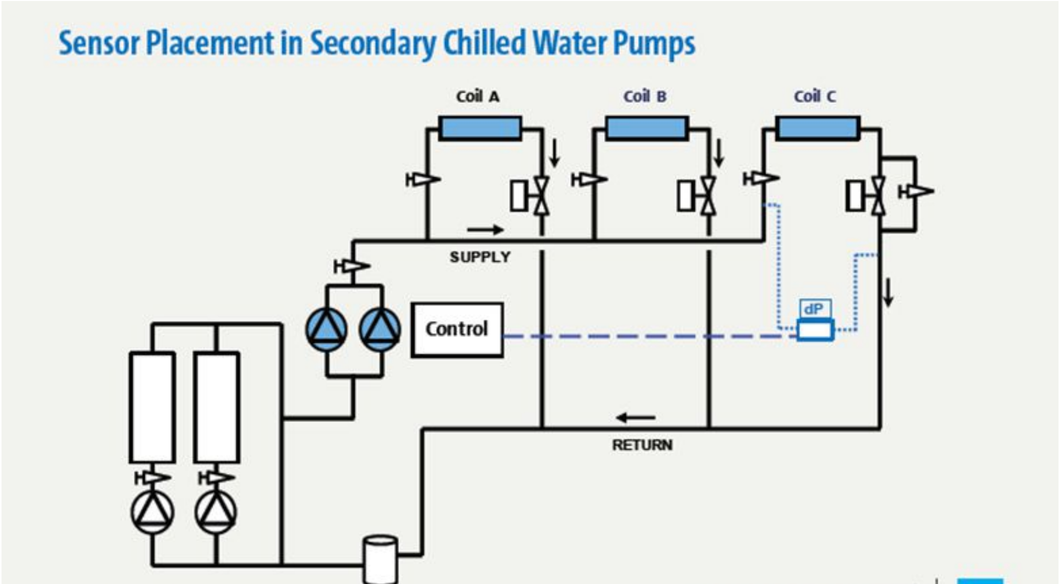

Figure 4

Pump-mounted vs. Remote Sensor

As previously mentioned, there are two ways to use sensors: either mounted on the pump or attached remotely. Following is a brief overview of how each configuration is used in both hydronic and pressure boosting applications.

Pump-mounted Sensor

When pump-mounted sensors or powerbased control are used (Figure 6), there must be two setpoints: head / pressure at design (or maximum) flow (A), and head / pressure at zero flow (B). These two settings define the control curve characteristics. To properly set these parameters during commissioning, the head at zero flow (i.e., fixed head) needs to be determined. This fixed head is also referred to as control head

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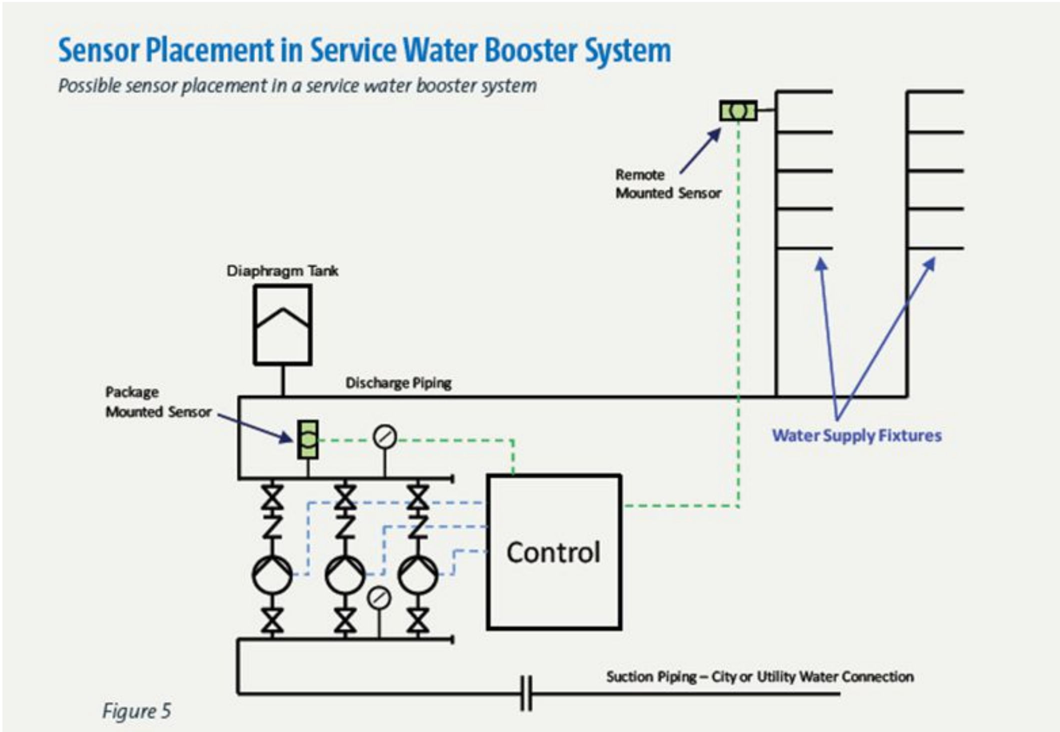

Figure 5

Hydronic application:

For a hydronic circulation system, similar to the example illustrated in Figure 4, the fixed head would also represent the control head required if a remote mounted differential pressure sensor were used.

Example:

Mode: Quadratic pressure control
Total head: 60 feet (26 psi)
Fixed head: 30 feet (13 psi)

Therefore, the head at zero flow would be programmed to 13 psi, and the total head

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would be programmed to 26 psi to represent the 50% reduction in head from design flow to zero flow.

Pressure boosting application:

Like the example illustrated in Figure 5, the head at zero flow will be the elevation head (i.e., static head), plus the residual pressure required at the fixture furthest from the pump system. An example of this might be a 10-story building with a setpoint pressure of 85 psi at maximum flow with an inlet pressure of 30 psi. This equates to a boost pressure of 55 psi or a total head of 127 feet.

Example:

Mode: Quadratic pressure control
Total head: 127 (55 psi)
Fixed head: 115 (50 psi)

Therefore, the head at zero flow might be 80 psi with 50 psi being the static head and 30 psi representing the residual pressure. The remaining five psi would be the only variable component of the pump head coming in the way of friction.

Variable Pressure Control With Pump-mounted Sensors

Maximum (design) flow is represented at point A, while head / pressure at zero flow is shown at point B.

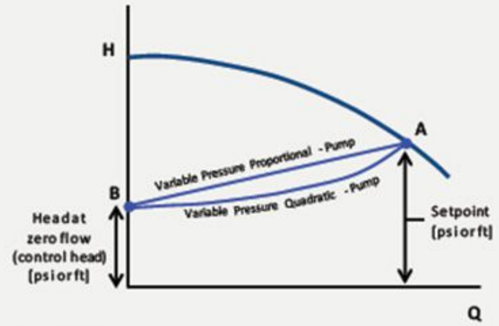

Figure 6

Constant Pressure Control with Remote Sensor

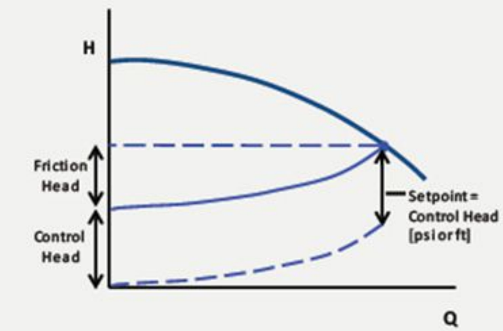

Figure 7

The frictional component of pump head in booster systems for multi-story buildings is typically less than 10% of the total head. The percentage of head reduction in hydronic circulation systems will be much greater than those in pressure boosting systems.

Remote Sensor

The last of the four pressure-based control modes involves the use of a remote sensor (Figure 7). When using remote sensors, only a remote system set-point is required for the pump system controller.

Hydronic application:

In a hydronic circulation system, a differential pressure sensor is typically installed at a strategic location in the piping. The secondary chilled water system example in Figure 4 shows a differential pressure (dP) sensor that measures the pressure loss through the coil, control valve and balancing valve. The design philosophy is that if the total pressure drop of these components is maintained at a fixed value, sufficient flow will be provided to all the other coils in the system. This sensor location is typically selected based on a worst-case pressure loss, involving long runs of the main distribution piping along with the pressure drops through the coil and valves. This sensor location is often at the end of a circulation loop but can also be 2/3 to 3/4 of the distance from the pumps to the furthest coil.

Pressure boosting application:

Instead of maintaining a constant pressure at the pump system discharge piping, a sensor is mounted at a location close to what is called the "critical fixture." The critical fixture might be located on the top floor of a multi-story building or at the furthest home from the pump system for municipal water supply.

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Which is better: pump-mounted or remote-mounted sensors?

The answer depends on your specific application. However, there is one distinct advantage of remote sensors. If the frictional (variable) component of the total pump head is less than what was calculated, pumps with remote-mounted sensors can potentially operate more efficiently than systems with pump-mounted sensors. Let's go back to one of our previous examples of a hydronic circulation system to show why.

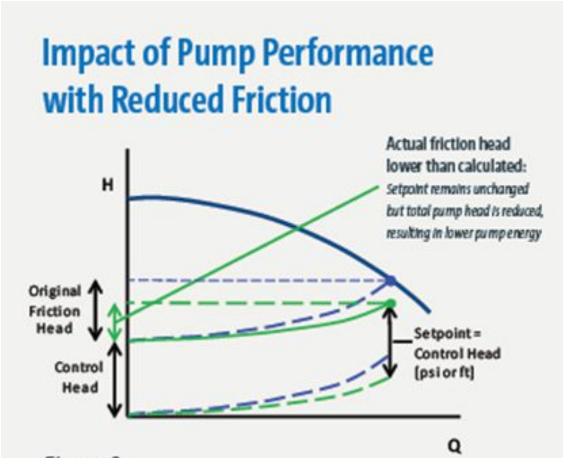

Figure 8

Example:
Mode: Quadratic pressure control
Total head: 60 feet (26 psi)
Fixed head: 30 feet (13 psi)

Therefore, the head at zero flow would be programmed to 13 psi, and the total head would be programmed to 26 psi to represent the 50% reduction in head from design flow to zero flow.

That would establish a predefined control curve resulting in pump head approaching 60 feet at peak flow rates. But what if the actual total friction loss in the system "as built" turned out to be only 10 psi instead of the calculated 13 psi? Because the only fixed head is the remote sensor setpoint of 13 psi, the total pump head as flow approaches design conditions only goes to 23 psi (10 psi + 13 psi) or 53 feet of head. In

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this way, energy is saved because in the reality of actual operating conditions, 60 feet of head is not necessary. The result of this new lower total head is shown in Figure 8. Note that the remote setpoint (control head) remains unchanged yet the total pump head is reduced resulting in lower pump speed and energy.

Because total pump head is often overestimated, the use of remote sensors acts as a failsafe, effectively right-sizing the system to ensure efficient pump operation despite the differing pressures. Systems with pump-mounted sensor controls can be adjusted to reflect the lower frictional losses, and achieve this same result. However, these systems require additional monitoring and setpoint adjustments to determine the optimum setpoint.

Impact of ASHRAE Energy Standard 90.1

There is a direct connection between the ASHRAE Energy Standard 90.1[3] and the control modes discussed here. The two sections that mention pumps are:

6.5.4.2 – Hydronic Variable Flow Systems
10.4.2 – Service Water Pressure-Booster Systems

The requirement for Hydronic Variable Flow Systems states that the system must have controls that will result in pump motor demand to be no greater than 30% of design wattage at 50% of the design water flow. A proportional or quadratic pressure control mode is required to meet this requirement.

For pressure boosters, there is no energy reduction requirement, but the use of pressure regulator valves to control system discharge pressure is not allowed. This re-

quires variable speed pump controls, and a remote-mounted sensor — or software that simulates remote sensing — must be used in conjunction with variable speed controls. In both cases, quadratic pressure control or remote sensing is the preferred method to meet the requirements of the code.

Rated Pump Curve

Pump selected for a design capacity of 500 gpm at 60 feet of head

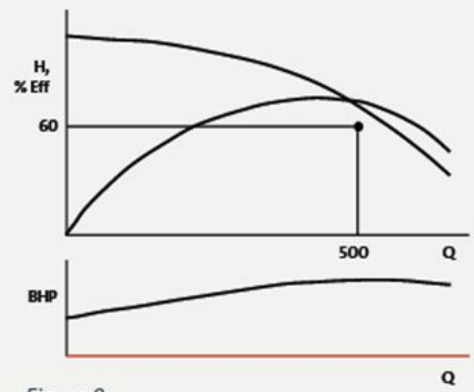

Figure 9

Rated Pump Curve with Control Curves

Control, efficiency and power curves illustrated

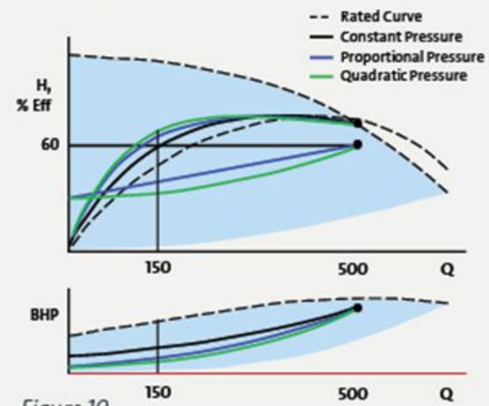

Figure 10

Difference in Energy Consumption

Since energy savings are the primary driving factor for the use of variable pressure control, let's look at an example of the power reduction of a typical hydronic circulation pump using the different control modes. Let's examine the performance curve for a pump selected for a design-day capacity of 500 gpm at 60 feet of head (Figure 9) and the impact different control modes have on efficiency and power (Figure 10). Notice pump efficiency at low flow is greatest when quadratic control is used (peak efficiency shifts to the left).

The most significant reduction in pump power, as seen in Table 1 is accomplished by using a constant pressure control over a fixed speed (unregulated) pump, for a 53.3% decrease in power. When moving from constant pressure to proportional pressure,

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another big drop in power is achieved, reducing power by another 42%. Lastly, when moving from proportional pressure control to quadratic control, an additional power reduction of 19.5% can be achieved. When looking at just the three variable speed-controlled pumps, the largest reduction in power occurs when moving from constant pressure to proportional pressure. It may not always be possible to utilize quadratic control or even proportional pressure control, so it's important to understand that there still can be significant energy savings when using constant pressure control over fixed speed pumps. This is most important when looking at replacing existing fixed speed pumps.

Parallel Pump Control

The use of parallel pumping can help to achieve even greater efficiencies, as smaller pumps can be used, and duty can be distributed in a much more efficient manner. When using parallel connected pumps, especially with pump-mounted or powerbased sensing, make sure that the control curve is set to incorporate all connected duty pumps as shown in Figure 11 . Individual pumps often come with integrated controls that can be field-connected to work in parallel. This can result in pumps operating on single pump control curves that can produce more head than necessary and can consume more energy than is required.

Performance Comparison at 150 gpm

Impact of control mode on pump with a performance at 150 gpm, or 30% of design flow.

Control Mode	Speed [rpm]	H [ft]	Eff [%]	bhp	Savings
Unregulated	3500	108.3	48.1	8.53	–
Constant Pressure	2657	60	57.2	3.98	53.30%
Proportional Pressure	2165	39	63.9	2.31	42.00%
Quadratic Pressure	1994	32.7	66.5	1.86	19.50%

Table 1

The use of packaged systems built to incorporate parallel pumps helps reduce the extra work of configuring individual pumps with individual controls into a multi-pump parallel system.

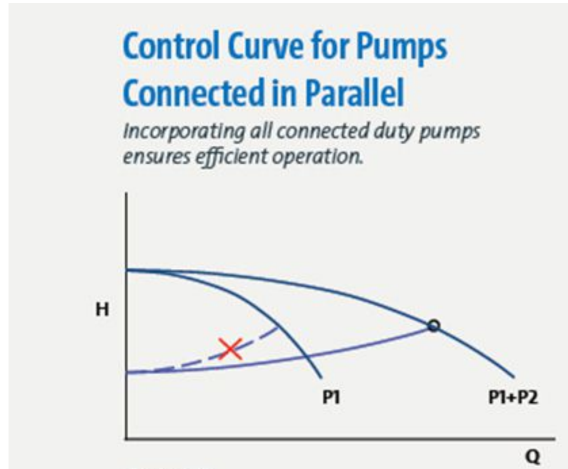

Figure 11

Conclusion

By now you've gathered that for most systems, the quadratic control curve will result in the greatest energy savings, provided the controls are programmed to match the system characteristics. But it's not always easy to achieve the desired results with field-built pump systems where pumps, drives and controls come from different manufacturers. Connecting two or more pumps in parallel, which is often required, adds another level of difficulty, as the controls need to be set up for redundancy and / or cascade operation.

One way to eliminate many of these challenges is by choosing a packaged pumping system. Packaged systems can come with sensors on the inlet and outlet manifolds (or differential pressure sensors), and can be programmed to provide either proportional or quadratic pressure control. Any set-point changes can be made on a single pump controller either at the control panel or through the building management system (BMS).

When remote sensors are used, many packaged systems can be programmed to provide pressure control in the event of a remote sensor failure.

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When the remote sensor signal is lost, the packaged system can revert to the package mounted sensors while the remote sensor problem is being resolved. In some cases, the remote sensor location can turn out to be suboptimal. While a new remote sensor location is being tested, package-mounted sensors can provide the needed backup control.

Another benefit that comes with the packaged system is ease of integration to the BMS. All information regarding pumps, drives, controls and sensors can be transmitted through a single pump controller.

While energy efficiency continues to grow in importance, it seems project completion time and budgets continue to shrink proportionally. Faced with these challenges, engineers must begin to think about new ways to accomplish old tasks. The use of variable pressure control modes, a sensor system that best fits your application, and the consideration of packaged pumping systems can all be combined to achieve better results in less time, while saving money.

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Designing hydraulic systems on high-rise, large buildings

Know how making correct decisions in the initial hydraulic plan helps the facility operate more efficiently and effectively.

Hydraulic system components should be determined early in the design of a heating, ventilation or air conditioning system, regardless of capacity range or type of occupancy:

- Heating or cooling central utility plant.
- System type.
- System distribution.
- Design standardization.

While the components are similar, the integration of each into large projects can present special challenges. For any complex facility, a central utility plant acts as the cooling and heating generation source while the system distribution plan serves as the skeleton of the building.

Water distribution systems type

There are typically two major pumping configurations applied heating and chilled water distribution systems: primary-only and conventional primary-secondary. Over the past 20 years, there have been numerous industry publications examining constant

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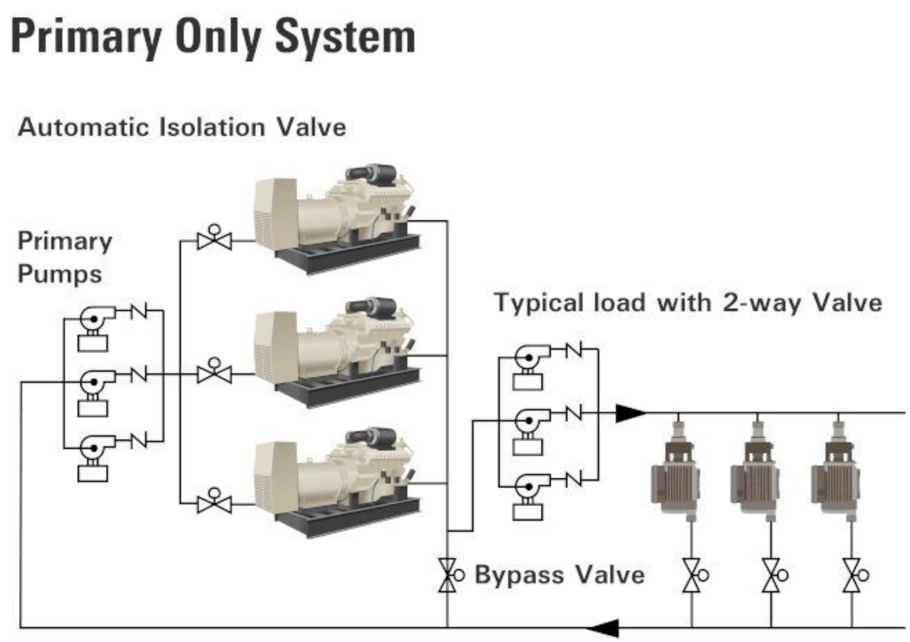

Figure 1: This illustration shows a typical variable-primary system with bypass control valve. Courtesy: ESD

primary flow and variable-secondary systems versus variable-primary systems.

ASHRAE and several manufacturers all provide extensive guides and case studies on those systems. The pros and cons of primary variable and primary (constant) and secondary (variable) are well documented. Modern chilled water distribution systems in large CUP applications have two main systems: variable-primary systems and primary (constant) secondary (variable) systems.

Modern CUPs are usually designed with centrifugal chillers with variable frequency drives. This allows the chillers to vary their load more easily from 10% to 100%. However, chillers need to maintain a minimum of 1.5 to 2 feet per second velocity to avoid laminar flow conditions in evaporator coils to maintain proper heat transfer factor.

In the case of centrifugal chillers with VFDs, a load can continue to drop to between 10% to 15% of design load. Flow needs to be maintained between 40% to 50% of the

design flow to maintain a proper heat transfer rate. Comparing the load and flow values reveals the range gap where load and flow will not fully follow a linear relationship. Proper control of the distribution flow during the partial load condition between 10% and 40% should be carefully analyzed.

The industry has not yet widely recognized the practice of variable-primary and variable-secondary systems. A central plant with 7,000 to 10,000 refrigeration tons in commercial applications usually has complicated occupancy schedules and a large geometry complex. Based on design and operation trends in the commercial sector over the past 10

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years, variable-primary and variable-secondary systems (as well as tertiary systems for some applications) are recommended to simplify operations and adjust for future system variations. Independent secondary systems can fully use the CUP's built-in thermal mass before initiating the chillers from the primary loop. The fluctuated flow range in primary loop helps the facility avoids the low-return water syndrome.

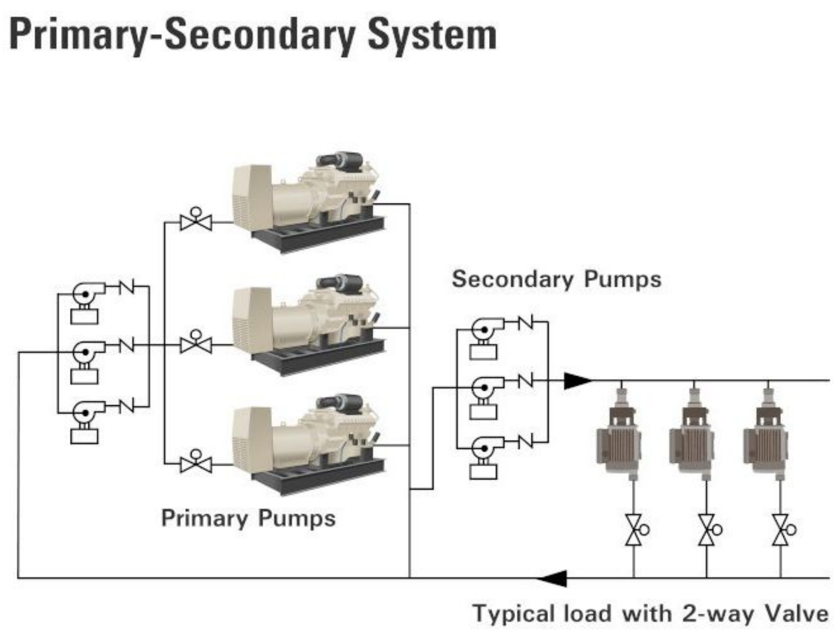

Figure 2: Shown is a convential constant primary and variable-secondary system. Courtesy: ESD

As previously noted, variable-primary flow helps chillers fill in the gap between 10% to 30% load conditions. Variable-primary and variable-secondary systems can:

- Be fully independent.
- Enhance the partial load condition.
- Reduce the overall hours of chiller operation.

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- Cut the amount of horsepower needed to operate the pump.

As illustrated in the Figure 1, the bypass valve in the variable-primary system is necessary to maintain minimum flow for either the chiller or the pump. The location of the pressure independent bypass valve should be either in the CUP or one of the remote distribution branches. After comparing the chiller and pump minimum flow in the case of the above plant capacity range, the pressure independent bypass valve size is likely to fall between the minimum flow of the chiller.

This critical component requires reliable performance with robust construction. During partial load conditions, it must constantly monitor CUP operation and track selected flow pressure at the distribution branch. While many reputable manufacturers are developing new and improved pressure independent valves, for an 8-inch valve size and above, the options are more limited.

In a real-world example running at the above-mentioned capacity (and where the CUP space and construction budget are met), a variable-primary and variable-secondary distribution system should increase the longevity of the chilled water distribution system (see Figure 2). For a CUP with half of the cited capacity range or smaller, variable-primary distribution with good perdition of load profile may be a better option. With no need for secondary distribution pumps, installation costs would be reduced and energy savings on chiller and pump operations could be realized.

Typical heating hot water system in large commercial plants has similar system design approach as above mentioned chilled water systems.

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Central utility plant design

In commercial buildings, the initial design of the CUP includes not only chiller and boiler capacity but the total quantity of the source equipment as well. Planning for standardized systems, components and equipment is one of the most important design steps. It is especially key to designing large capacity CUP in complex commercial buildings. Identical major equipment will help the maintenance crew streamline routine upkeep, reduce spare parts storage and more easily troubleshoot problems.

Figure 3: A 20-inch chilled water supply and return header is in a 7,000-ton central utility plant. Courtesy: ESD

ASHRAE 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings Appendix G provides a baseline for building compliance with the performance rating method (G.3.1.2.2 lists coil and plant sizing factor and capacity). For a CUP with a cooling capacity between 7,000 to 10,000 refrigeration tons, the total quantity of chillers is determined based on plant coincident load and a full study of various partial load conditions for the facility. One chiller is recommended to handle a maximum of 25% of the calculated peak coincident load.

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As previously noted, modern CUPs generally opt for centrifugal chillers with VFDs. Chiller load varies from 10% to 100% capacity while chilled water minimum flow varies from 40% to 45% (value slightly varies by different manufacturer). In straight math, the single chiller can be operated at 10% to 12.5% of total facility coincident design flow and a minimum of 2.5% of plant coincident load. Verifying the two parameters is determined during the total quantity of plant machines analysis.

Project budget also plays an important role for most commercial buildings. After a load profile is completed, it's typical that the same capacity of chillers and boilers in modern CUPs can be designed in parallel. With this approach, the CUP does not need to be oversized.

Mechanical system analysis

It is worth analyzing the total numbers of chillers, boilers, heat exchangers (if district cooling or heating source is being used) and primary distribution pumps when designing for a large-capacity CUP. The best option is to integrate uniformly sized equipment with built-in resilience. The only exception could be free cooling if the 24/7 load is too small to have identical cooling tower partial load capacity. In a practice with automatic bypass valve and cooling tower cold water basin heaters found in most commercial facilities, it is possible to use identical cooling towers that match the heat exchanger/building 24/7 cooling load's performance on a one-to-one basis.

To offer the most flexible combination of operation patterns, chillers, cooling towers, boilers and primary distribution pumps are recommended to be one-to-one. When CUP is set up with a modular operation and control type, plant equipment will have equal operation time and ultimately result in no limitation of interchange among the

same type of equipment. Under this configuration, chillers and boilers typically connect into a common-sized header instead of a telescope-type header arrangement. Plant equipment piped into a common size header acts to divert or mix temperatures with low local pressure drop. A common header sized for the designed peak flow of a plant results in little or no increase in the cost of the pipe header. It creates a scenario for the plant to operate with much less friction loss for most days of operation.

Figure 4: This is an example of a heating hot water header at primary system. Courtesy: ESD

The common pipe, also called a decoupler, maintains low pressure drop by keeping the same pipe size as the main pipe header. The same common pipe header concept is recommended for distribution pumps. A prefabricated header applied in the central plant is possible if grooved pipe connections are an option.

Chillers and pumps can be paired to work with any equipment within the same group (see Figure 7). Without oversized equipment, the CUP has built-in redundancy. Uniformed arrangement of valves, check valves, motorized valves, flow switches and

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similar components with interchangeable features help CUPs operate more flexibly and limit the amount of necessary parts storage. With a common size header, the application will further simplify to CUP maintenance routine.

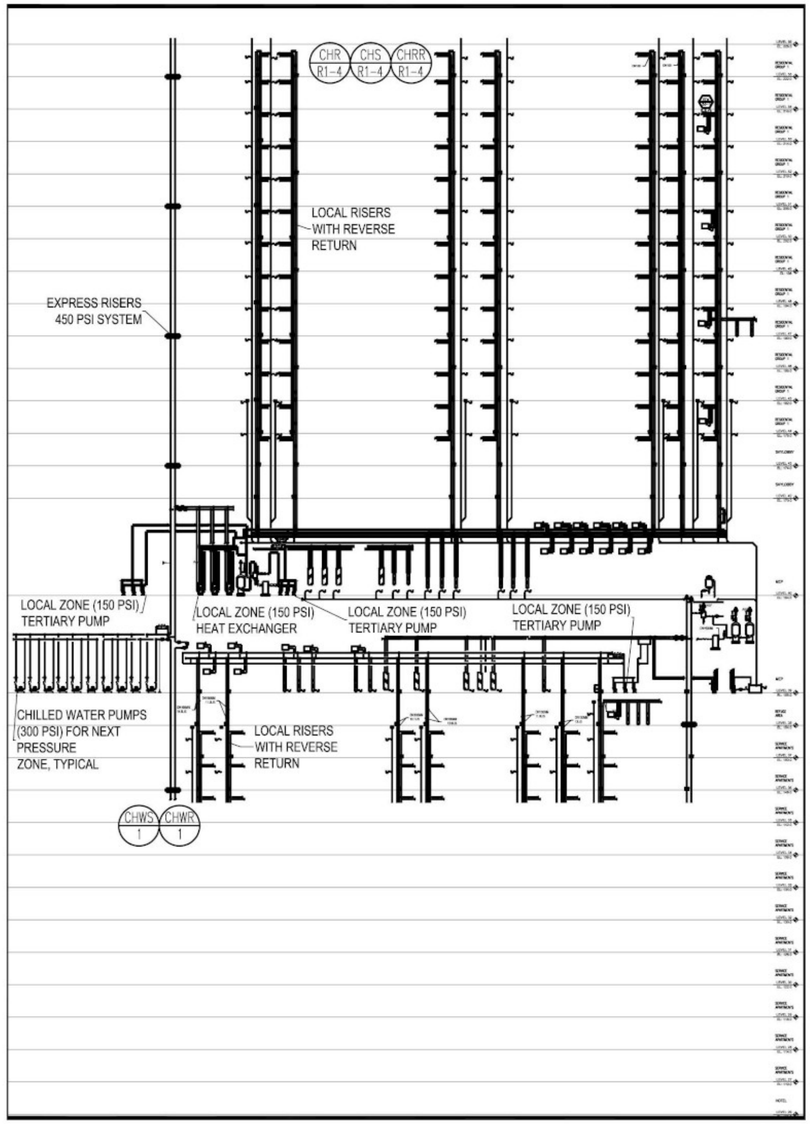

Figure 5: An example of a high-rise building chilled water diagram shows hotel zone low section with express risers. Courtesy: ESD

Tall and specialty buildings

Large, complex facilities typically fall into two categories to describe their physical grandness: vertical and horizontal. These are either supertall buildings or structures such as convention centers that occupy a large footprint. A distribution system in a large-footprint complex requires multiple areas of differential pressure monitoring sensors. These sensors are either located at remote branches or critical zones. Secondary pump VFDs will constantly adjust the frequency in response to those values. This overview, however,

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focuses on the distribution system of supertall buildings.

The Council on Tall Buildings and Urban Habitat defines a supertall building as being more than 984 feet in height. Buildings fitting this widely accepted definition depend on a system of vertical zone level occupancy functions.

Multiple levels of building service system floors are needed to maintain delivery of HVAC to typical floors. These mechanical, electrical and plumbing equipment floors provide hydrostatic pressurebreak, house central air handling or makeup air units or provide a tertiary pumping system to distribute hydraulic systems to each local floor.

One common feature found in high-rise buildings, especially supertall buildings, is the core that contains many vertical transportation routes to building occupancy and building service systems. Because of the central location of the core, it also defined the unique construction process of high-rise buildings. Standardized design in high-rise buildings magnifies its benefits.

For supertall buildings, a strategically located pressure break heat exchanger is essential. Depending on the type of manufacture, heat exchangers and pumps have pressure limitations of 400 and 300 pounds per square inch, respectively.

For Air-Conditioning, Heating and Refrigeration Institute certified heat exchangers, a 2°F approach benefits both pressure drop and its footprints and maintains desired chilled water temperature at the upper zone.

Supertall buildings with multiple system levels require the use of “express risers.” An example of MEP floors chilled water distribution system is illustrated in Figures 5

and 6. It illustrates the express riser with higher value of pressure break heat exchanger. It represents a local zone riser with a local pressure break heat exchanger. Without a significant footprint for equipment, identical heating exchangers and distribution pumps offer built-in redundancy. The identical capacity of heat exchangers and pumps in express risers is even more important as the upper zone's operation relies on more resilient and robust capabilities.

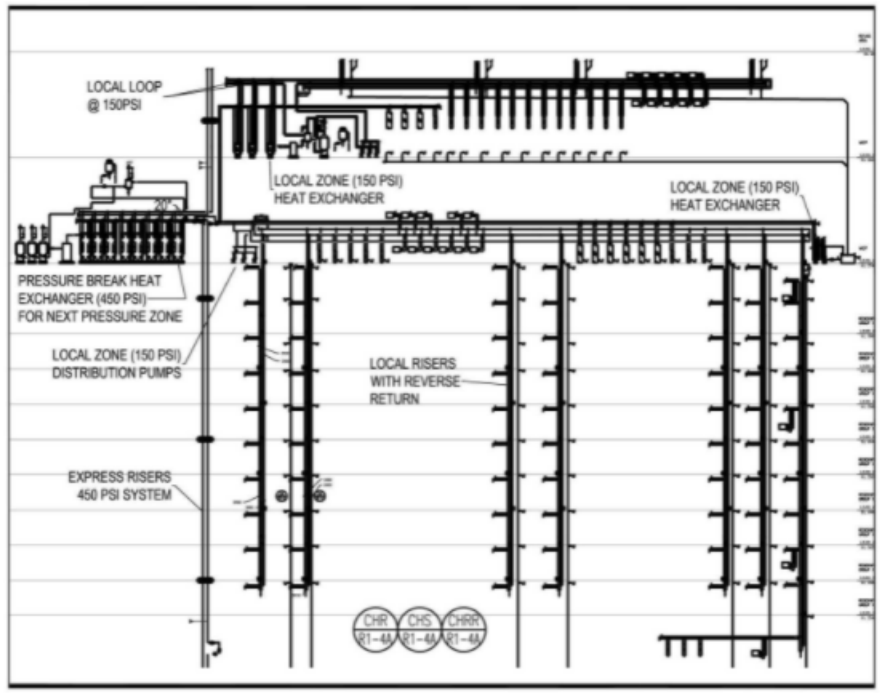

Figure 6: A sample high-rise building chilled water diagram shows hotel zone high section with express risers. Courtesy: ESD

This example shows local risers designed with a 150 psi system. Although coils in terminal units and control valves have 300 psi ratings, this setup saves construction time, reduces product storage, contractor training time and avoids human error. All terminal units, like fan coil units, control valves, strainers, and shut valves are each 150 psi rated. Maintaining local risers serving typical floor units with a uniform 150 psi system helps optimize operation maintenance and spare parts inventory.

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The same pressure rating concept can be applied to hydraulic accessories. In Figures 5 and 6, each pump is maintained with a 300 psi rating while pre-filled diaphragmed expansion tanks have a rating of 125 psi. Common diaphragmed expansion tanks have two pressure rating options: 125 psi or 250 psi. Locating expansion tanks at the top of each pressure zone avoids struggling with the proper location, especially when applied to express risers.

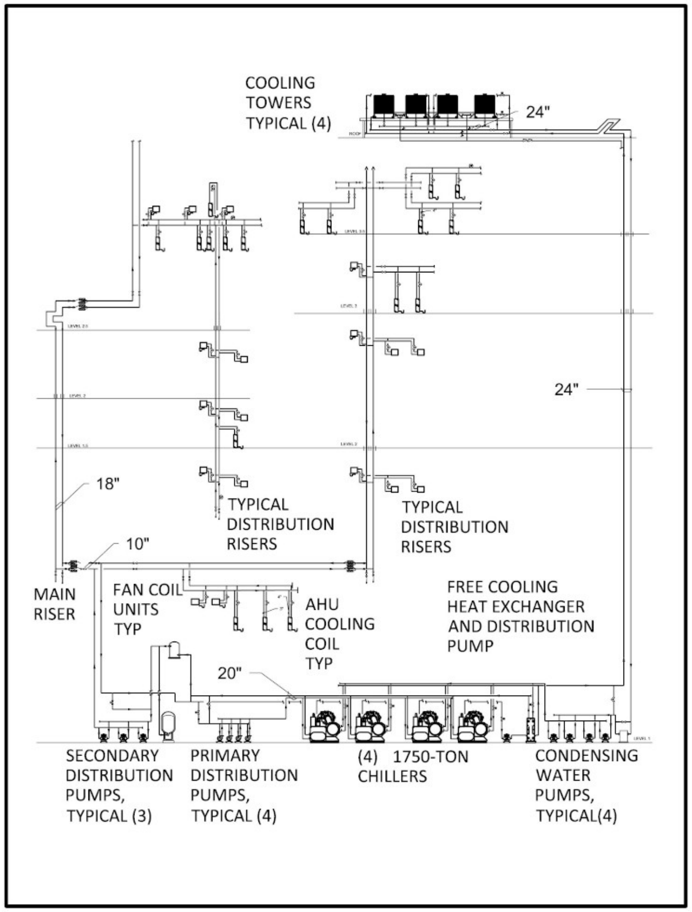

Figure 7: An illustration of a 7,000-ton chilled water central plant diagram is shown. Courtesy: ESD

Pump seals are often the most easily broken parts during high-pressure operation. Although there are 400 psi pump options, position pumps maintaining 300 psi extends the unit's operation life and offers more manufacturer choices. Air separators are typically located at high temperature and low-pressure locations within the hydraulic loop where dissolved air has a higher chance of escaping from liquid media. The pump suction side is a good location for air separators and protecting the pump's impellor.

There are also common types of air separators American Society of Mechanical Engi-

neers rated at 125 or 300 psi. Installing the same type of pressure rating of air separator at the suction side of the pump while maintaining a 300 psi rating simplifies the supertall building system. Standardized design concepts dissolve the conflicted system into several standard system solutions. Due to generic structural requirements, horizontal pipe distribution on typical floors is always a challenge. To accommodate service, risers distributed from building system floors are often the solution. ASHRAE Standard 111: Testing, Adjusting and Balancing of Building HVAC Systems indicates the hydraulic system balance and verification. For a large building, especially when applied to a supertall building, post-construction testing and balancing can be time-consuming. To balance each individual local riser in every pressure zone in a supertall building could be troublesome, especially if it relies on dynamic balance. Any change after a prebalanced system requires a rebalance.

Figure 8: This shows a 20-inch chilled water pump header on secondary distribution system. Courtesy: ESD

Per ASHRAE terminology, a reverse return is a two-pipe system in which the heat transfer medium supplied to the first load is the last returned to the heat transfer equipment. This system includes water return piping from terminal units sized to provide

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equal lengths for balanced flow rates. Compared to the direct return system, the reverse return design has a generic self-balanced feature.

For large-footprint complex buildings, the reverse return is difficult to accomplish. However, it could be more feasible to establish in high-rise applications because the typical distribution is closer to the core area. This potentially solves the testing and balance issue and should not need to be rebalanced after system alteration.

In Figures 5 and 6, vertical risers are used for the reverse return in the hotel occupancy section of a mixed-use supertall building. This vertical application of reverse return solves the challenge of limited horizontal piping in limited ceiling cavity below structural beam. The vertical riser size is small and is located within 150 psi local zones, which leads to a small increase in piping cost.

Avoiding engineering conflict

Complex facilities with large capacity central plants present a complicated set of variables that could easily evolve into a set of conflicting systems. Engineers can apply a standardized concept to translate a difficult system into a simplified, uniform solution. To accomplish this, however, extensive engineering work is required early in the design stage.

Ideally, design and planning include a comprehensive review of all complex factors, providing the output with the following characteristics:

- A simple system designed with reduced construction team size.

- A robust system with built-in redundancies.

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- A resilient system with interchangeable ways to operate.
- A standardized system that reduces building storage area and spare parts requirements.
- A user-friendly system that streamlines troubleshooting and reduces maintenance time.

Applying a standardized design practice can be key to developing better engineering practices and better facilities.

Suzan Sun-Yuan

Suzan *is a technical authority|mechnical with ESD. Sun-Yuan has extensive experience in the design of commercial, institutional and educational facilities. ESD is a CFE Media and Technology content partner.*


The new iVECTOR S2
Heating and cooling with
low temperature systems
Optimum room climate

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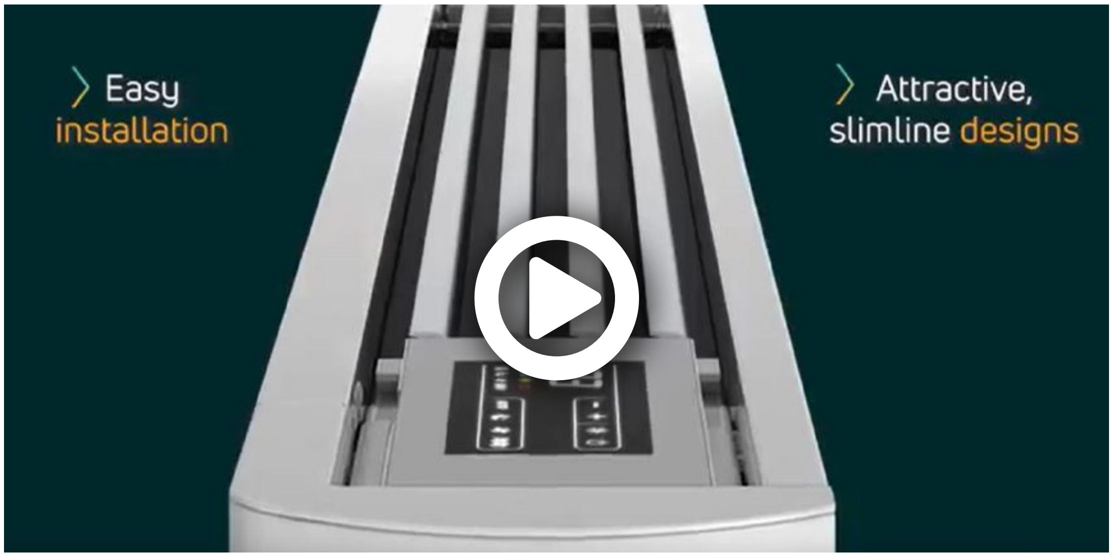

iVECTOR S2

A new generation of hydronic fan convectors for heating & cooling

iVector S2 Series: a hydronic fan convector unit with intelligent cooling & heating capability

A smart way to improve indoor climate

Today, both renovation and new building projects have strict standards that raise the bar for overall efficiencies. At the same time, there is a demand to reduce dependence on finite energy sources, cut emissions and lower overall costs. Modern hydronic heating systems are designed to work at significantly lower temperatures to help improve system efficiency, achieve meaningful energy savings and improve indoor climate comfort.

Meet the newest generation of fan convectors

Advanced European technology adapted for the North American market. The iVECTOR S2 is the newest energy efficient fan convector from MYSON, designed specifically to address emerging demands for comfort and energy efficiency. Boasting an attractive, compact design the iVECTOR S2 can provide high heating performance even when operating at low temperatures and with low water content. This provides efficient energy use without sacrificing outputs. When combined with a reversible heat pump or a separate cooling source, the iVECTOR S2 can offer both heating and cooling functions, making it a perfect solution for both commercial, multifamily and single family residential use.

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Built with flexibility in mind

With iVector S2 it's all about design flexibility. Installation options include both surface mounting as well as built-in options (walls or ceiling). Controls are available in either onboard or remote options, along with solutions for fully autonomous control, 0-10V control for BMS systems or fixed fan speed control. With a choice of either 2-pipe or 4-pipe heat exchangers, iVector S2 is available in 5 different sizes so specifiers won't have a problem finding an iVector S2 model to meet their project's needs.

Combining iVector S2 with other low temperature systems, for example hydronic panel radiators or a radiant system, provides an ideal combination for optimum indoor climate comfort all year long. The iVECTOR S2 is also the perfect solution for rooms not in regular use such as guest rooms or hobby rooms thanks to rapid heat-up and cool-down times.

Modern/Slimline Design

With inspiration from leading Italian designers, the aesthetically pleasing iVector S2's slimline design allows for discreet positioning without compromising performance. Whether it be wall or ceiling mounted, or a recessed/built-in installation, iVector S2 will blend into its environment seamlessly. For maximum design flexibility, all casings and grilles can be produced in virtually any RAL color (standard is RAL 9003).

Controls with a high IQ for smart buildings

The heart of the iVector S2 is its ingenious and highly accurate controls with PID logic and specially designed algorithms that intelligently drive optimal performance all year long. Combined with a high efficiency DC fan motor, the result is ideal comfort and energy efficiency.

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User interface flexibility

Whether selecting the intuitive onboard SmartTouch user interface or the remote wall mounted SmartTouch user interface, specifiers have choices when specifying iVector S2. The onboard control is capable of controlling a single unit while the remote SmartTouch can control up to 30 similarly equipped iVector S2 units. If these solutions aren't optimal, then iVector S2 can be fitted (field or factory) with the available 0-10V control board for use with suitable 3-party thermostats or BMS systems.

Performance versatility

iVector S2 is available in either a 2-pipe or 4-pipe version with standard connections on the left side of the unit (field or factory changeable to right side). Depending upon unit size, heating outputs range from 7,541 btuh to 32,552 btuh at 176/167/68oF (2.21 kW – 9.54 kW at 80/75/20oC). Total sensible cooling ranges from 3,106 btuh to 12,659 btuh at 45/54/81oF (0.91kW – 3.71kW at 7/12/27oC). All values at high fan speed.

Consider iVector S2 for your next project and enjoy all of these benefits;

- **High heat outputs at low system temperatures**
  The iVECTOR S2 provides high outputs in low-temperature heating systems. Ideal in combination with heat pumps!

- **Fast, responsive heat-up times**
  The iVECTOR S2 has considerably less water content than conventional panel radiators. Its low thermal mass ensures fast heat-up times and efficient operation.

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- **Cooling**
  Cooling is possible with the iVECTOR S2 when connected to a reversible heat pump or a separate chilled water source.

- **Intelligent control**
  The iVECTOR S2 is equipped with an intelligent control system. It allows easy operation and integration with other building management systems

- **Whisper quiet operation**
  The latest in modulating fan technology offers the best heat output with the lowest imaginable noise level.

- **Space-saving installation**
  Thanks to its compact dimensions the iVECTOR S2 provides high heating and cooling performance with minimal size.

MYSON is a brand of Purmo Group (www.purmogroup.com) and is one of the oldest and most respected names in the HVAC industry. We have been manufacturing fan convectors for over 50 years. With a reputation for maximizing the role of innovation and technology in our operations, we are committed to helping reduce CO_2 emissions by developing energy efficient heating and cooling products that are capable of operating effectively at low flow temperatures.

Contact us today to for complete information about iVector S2 including model specifications, submittals, iVector S2 performance metrics and more.

Raypak® A Rheem® Company

XVERS™ POWERED BY KŌR

SCAN HERE

Powered by Raypak's new high-efficiency stainless steel KŌR fire tube heat exchanger, XVers + KŌR packs more heat into a smaller footprint.

Efficiency
XVers + KŌR is ENERGY STAR listed and low NOx certified.

Dynamic Protection
Built-in self-protection technology allows XVers + KŌR to continuously monitor flow conditions and optimize performance.

Small Footprint
XVers + KŌR is one of the most compact condensing fire tube boilers on the market and easily fits through a standard doorway.

Serviceability
Easy-to-handle removable jacket panels provide convenient access to key components, while XVers + KŌR's short height provides the best top access in compact boiler rooms.

VERSA IC Controls
Modulating temperature control, safety limits, and ignition programming combined into one user-friendly integrated control platform.

Raymote Connectivity
Remotely monitor, troubleshoot, diagnose, and control XVers + KŌR with instant access to vital information.

RayMoTe™

LEARN MORE AT
Raypak.com

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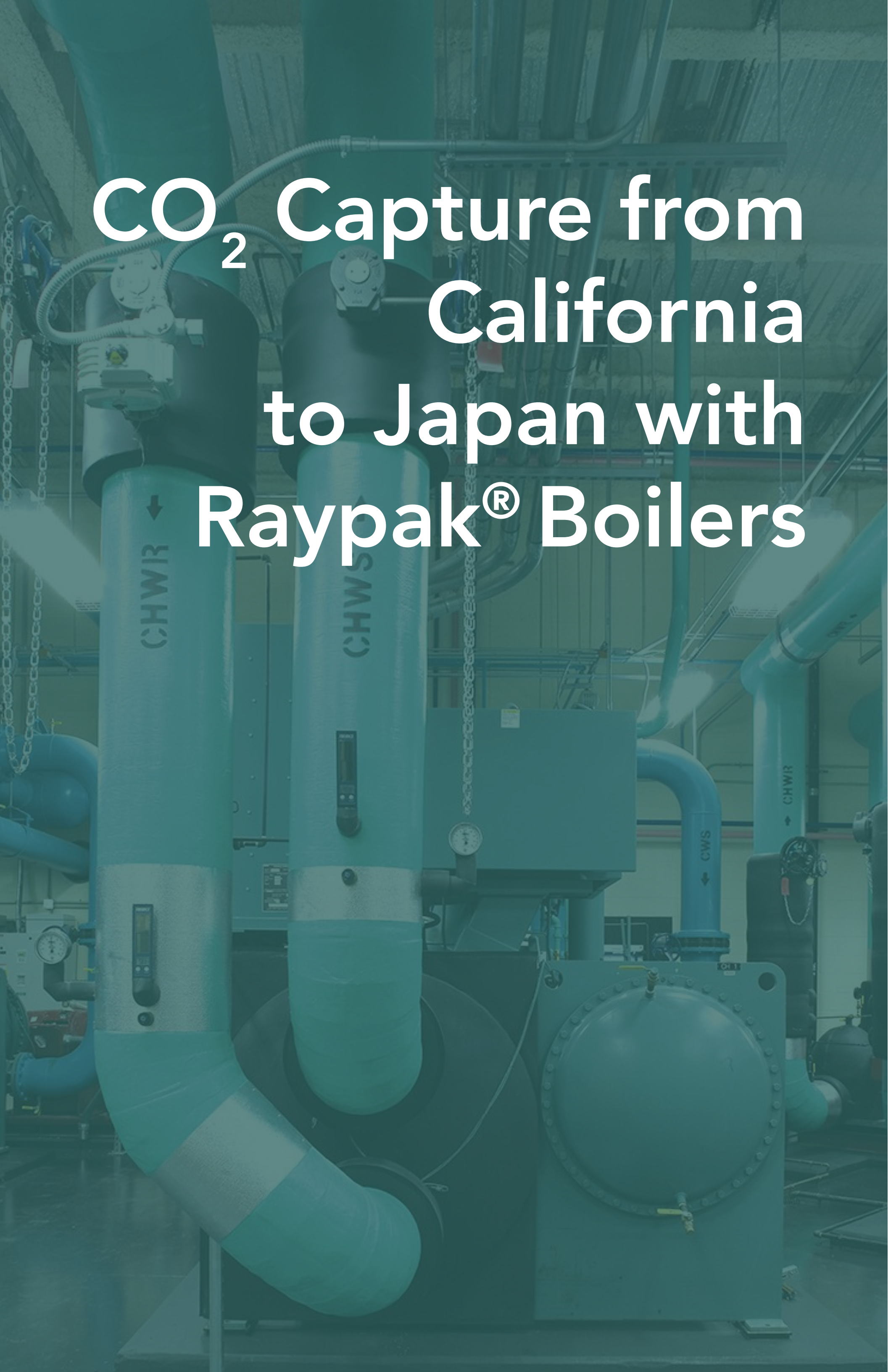
Raypak® XVers™ Powered by KŌR™ Condensing Fire Tube Boiler

More heat less space. Advanced Self-Protection Technology. VERSA IC Intelligence with Raymote Access

CO_2 Capture from California to Japan with Raypak® Boilers



BioTherm® makes CO_2 conditions right for their customers' indoor growing with help from Raypak XVers® Condensing Boilers

The Customer

Jim Rearden and Mike Muchow

BioTherm

California-based BioTherm is the exclusive dealer for Raypak boilers to the Controlled Environment Agriculture (CEA) industry. BioTherm has been at the forefront of developing highly efficient greenhouse solutions since 1980. They specialize in providing climate control solutions for indoor and greenhouse operations from heat and hydro sciences to optimized air.

The Challenge

Indoor and greenhouse farming are growing industries and will continue on this path as consumers look for produce grown closer to where it is sold. But no matter where they are, all plants need just the right levels of light, temperature, moisture and air composition. Greenhouse and indoor farming mean these factors can be dialed in for the best result possible. Many plants require a dose of Carbon Dioxide (CO_2) to increase the efficiency of photosynthesis and maximize growth, and in Fukushima, Japan, it is no different. So, when vegetable facilities there, as part of the regrowth of the Fukushima fallout, sought out BioTherm to find a CO_2 recapture solution, the team at BioTherm got to work. Until this point, the only real solutions for introducing CO_2 into an indoor farm or greenhouse were large bulk tanks or individual CO_2 burners.

The Solution

After experimenting with other Raypak solutions, the introduction of Raypak's XVers® and XVers L Condensing Boiler lines was a game-changer! BioTherm knew that with the right condensing boiler system in place, BioTherm CO_2 Systems can easily be integrated for more customers to achieve the perfect CO_2 levels in indoor and greenhouse operations with clean, safe and dry CO_2.

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BioTherm systems harvest CO_2 directly from the boiler's exhaust gases and distribute them uniformly into the growing environment while ensuring other harmful gases are kept at a safe level. With a BioTherm CO_2 System, there is no need for large bulk tanks or individual CO_2 burners.

Raypak's XVers Family efficiently serves two functions in one for BioTherm's customers. First, the boiler provides the hot water needed for successful farming. And secondly, it helps optimize the CO_2 levels in the air. By adding the simple process of collecting the

Benefits

High Efficiency & Clean Burning:
Up to 99% Thermal Efficiency

Air Optimization Friendly:
Burns clean and is easy to get the right amount of CO2 from the exhaust

Wide Range:
From 399 to 3000 MBTUH

Small Footprint:
Well suited for small to large facilities

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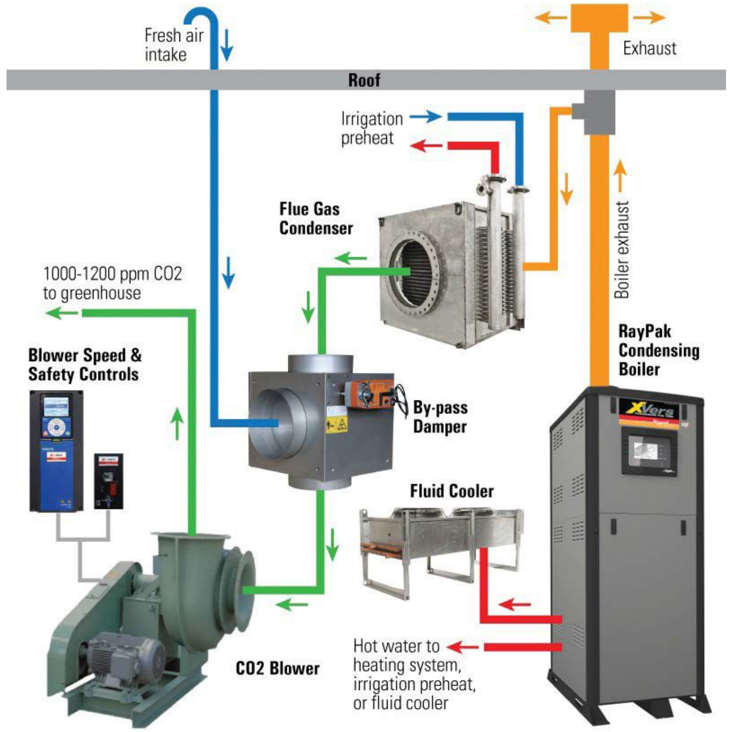
boiler's exhaust, the controllability of the XVers Family allows for a precise level of CO_2 to be introduced into the space for further improved growing efficiency.

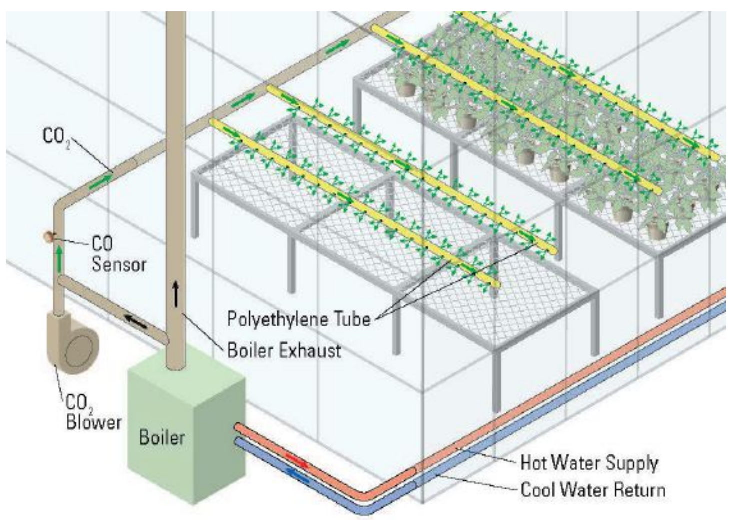
The Installation

The BioTherm CO_2 System features a Raypak XVers Condensing Boiler and secondary heat exchanger paired with BioTherm's Control System and Inline Fan.

The Final Result

"The other options they (cultivators) have are to have a gas provider bring out a giant tank they keep filled to emit the CO_2. Others use CO_2 generator products with an open burner that generates CO_2 but makes it hard to reach the desired parts per million. With our system, they make it on-site and it burns clean. It doesn't take much to get them to the desired set point.





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It's a much more economical way to do it and easier logistically without having to get it delivered. It's dry and clean and gives them a big benefit for their buck.

"If they have an existing BioTherm system, this is a simple add on."
— Jim Rearden, President of BioTherm

"BioTherm is impacting this industry and using Raypak boilers to do it!"
— James Kastigar, Regional Sales Manager for Raypak

Here are results from some users of BioTherm's CO_2 System with Raypak XVers Family Condensing Boilers:

- 50% savings on supplemental lighting hours through increased efficiency of photosynthesis with CO_2 (Lef Farms New Hampshire)
- $90k annual savings for a single site using CO_2 from the Raypak Boiler System (Large, multi-state horticulture operation)

Note: Stated savings are self-reported from BioTherm customers.

To learn more about our High-Efficiency Condensing Boiler Solutions,
visit **Raypak.com**

Design parameters for boilers and hot water heating systems

Understand the design and application of condensing boilers and heating water systems

Boilers can be thought of as encased heat exchangers with a primary goal to increase the temperature of the fluid in question a given delta above design setpoint. These robust pieces of equipment are built and constructed to The American Society of Mechanical Engineers Boiler and Pressure Vessel Code, which takes into consideration both exterior and interior construction material, size of the equipment, temperature and pressure.

This code includes several sections; in particular, section IV provides guidelines for heating water boilers and section VI focuses on care an operation of heating boilers. Inside the boiler, heat exchange occurs through combustion which is a reaction between the fuel and oxygen; a simplified stochiometric equation for combustion would look like:

$\text{Fuel} + O_2 \rightarrow CO_2 + H_2O$

Below are a few common fuel sources for boilers, as well as their heating values, per ASHRAE Handbook Fundamentals: Chapter 28 Combustion and Fuels:

- Natural gas HV (23,900 Btu/pound)
- Diesel HV (19,300 Btu/pound)

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- Propane HV (21,669 Btu/pound)

Boiler code and design

Figure 1: These are 6,000 MBH natural gas and oil dual fuel condensing boilers at the central plant for Texas Scottish Rite in Frisco, Texas. Courtesy: TDIndustries

Some boilers are specified as dual fuel, with natural gas as the primary fuel source and either diesel or propane as the secondary fuel source. Engineers specify boilers to serve various systems and/or processes, depending on the goal. Boilers specified in central plants deliver hot water for heating, ventilation and air conditioning, or domestic or process use.

Boilers are most often specified when designing new buildings such as a greenfield site, which is undeveloped land, or when retrofitting an existing central energy plant.

To begin with, the design engineer needs to know the building location and the weather design day criteria as indicated under the ASHRAE Handbook: Fundamentals, Chapter 14 Climatic Design Information. Second, the building occupancy type, which is dictated by the International Building Code and adopted by the state where the proj-

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ect is being designed, the central plant location with respect to the building it serves and the boiler room within the central plant.

All of the above, in addition to the floor plan layout, provides the design engineer parameters to perform the building load calculation including building envelope heat loss, building occupancy, system distribution losses and equipment load.

For example, a building of occupancy type I2 is a hospital as indicated in IBC; therefore, code requirements regarding air changes per hour for specific room types as well as room temperature and relative humidity boundaries need to be satisfied. The total load calculation is expressed in either British thermal unit per hour (Btu/hour) or 1,000 British thermal units per hour (MBH). Once calculated, the number of boiler's are selected along with the system temperatures to meet the building demand.

Third, the central plant location affects how engineers design the optimal pumping arrangement. This may either be variable-primary where the flow varies as the differential pressure in the loop remains constant, or primary-secondary where there are two piping loops. The primary pumps serve the major equipment within the central plant and the secondary pumps serve the distribution to the building air handlers, fan coil units and variable air boxes.

To optimize the design, the engineer must weigh the benefits between pump energy consumption and a design set temperature difference; since the total building load (Q Btu/hour) = 500 (constant) * gallons/minute * temperature difference (°F).

Note that the constant considers the fluid weight, in this case water (specific gravity ~1.0), 8.34 pounds/gallon and unit conversion, 60 minutes/hour.

The International Code Council and NFPA provide codes and standards for engineers to design buildings with safety in mind.

International Building Code focuses effort on providing minimum criteria for building design and construction depending on the occupancy type.

- Section 509.1: Provides guidelines for boiler room boundaries and/or wall requirements regarding the separation to other rooms under Section 509.1 Table 509 Incidental Uses; room shall be 1-hour fire rated or provide automatic sprinkler.

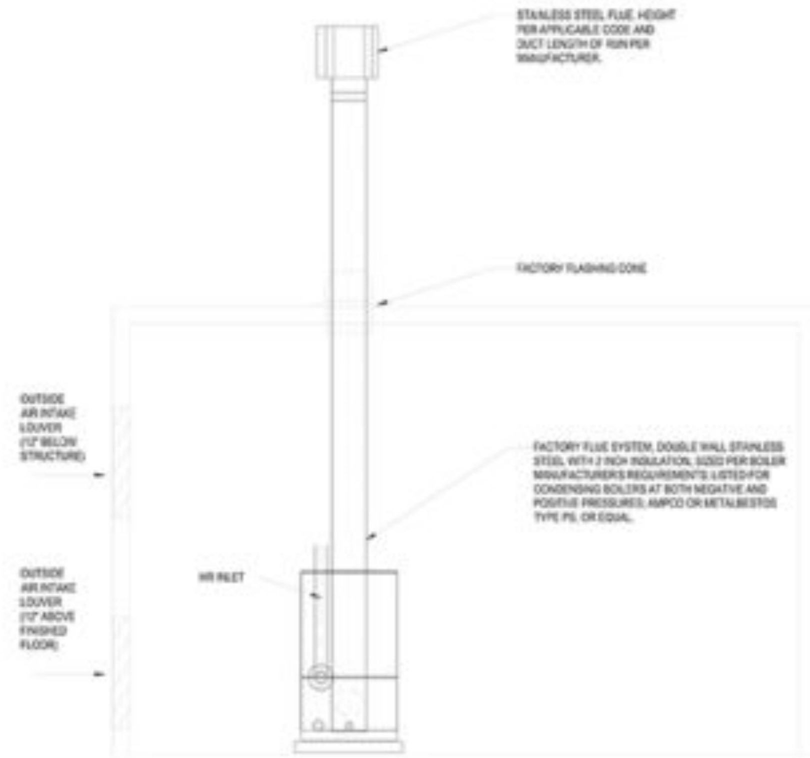

Figure 2: This schematic represents an example of natural combustion through a high and low louver. Louver size must meet the International Fuel Gas Code rates, this includes all input rating appliances in the mechanical room. Courtesy: WSP USA Buildings

- Section 1006.2.2: Regarding boilers, this code provides guidelines for means of egress based on the room usage.

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NFPA 101: Life Safety Code is all about building and occupant safety.

- Chapter 7, Means of Egress: Section 7.13 Mechanical Equipment rooms, boiler rooms and furnace rooms.

- Chapter 8.7, Special Hazard Protection: Provides guidelines on room boundaries and wall type construction, either 1-hour fire barrier or fully sprinklered room.

- Chapter 18, new health care occupancy section:

- Section 18.3.2: Protection from hazards.

- Section 18.3.2.1: Provide guidelines on identifying which are hazard room. Boilers, due to their combustion characteristic, follow in this path.

International Mechanical Code: Chapter 10, Boilers, Water Heaters and Pressure Vessels provides guidelines, which are required for boiler construction under ASME Boiler and Pressure Vessel Code as well as controls and safety devices depending on boiler rated MBH. The break line is < 12.5 million Btu/hour. If the boiler is larger than the value indicated above it must comply with NFPA 85: Boiler and Combustion Systems Hazards Code.

- Maintenance must be kept in mind and the manufacturer recommendations must be verified before installation.

- Provide safety relief valves, refer to detail.

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- Provide a low water cutoff.

- Heating water systems must be provided with an expansion tank either open or closed type.

- Boiler shall be provided with a temperature and pressure gauges.

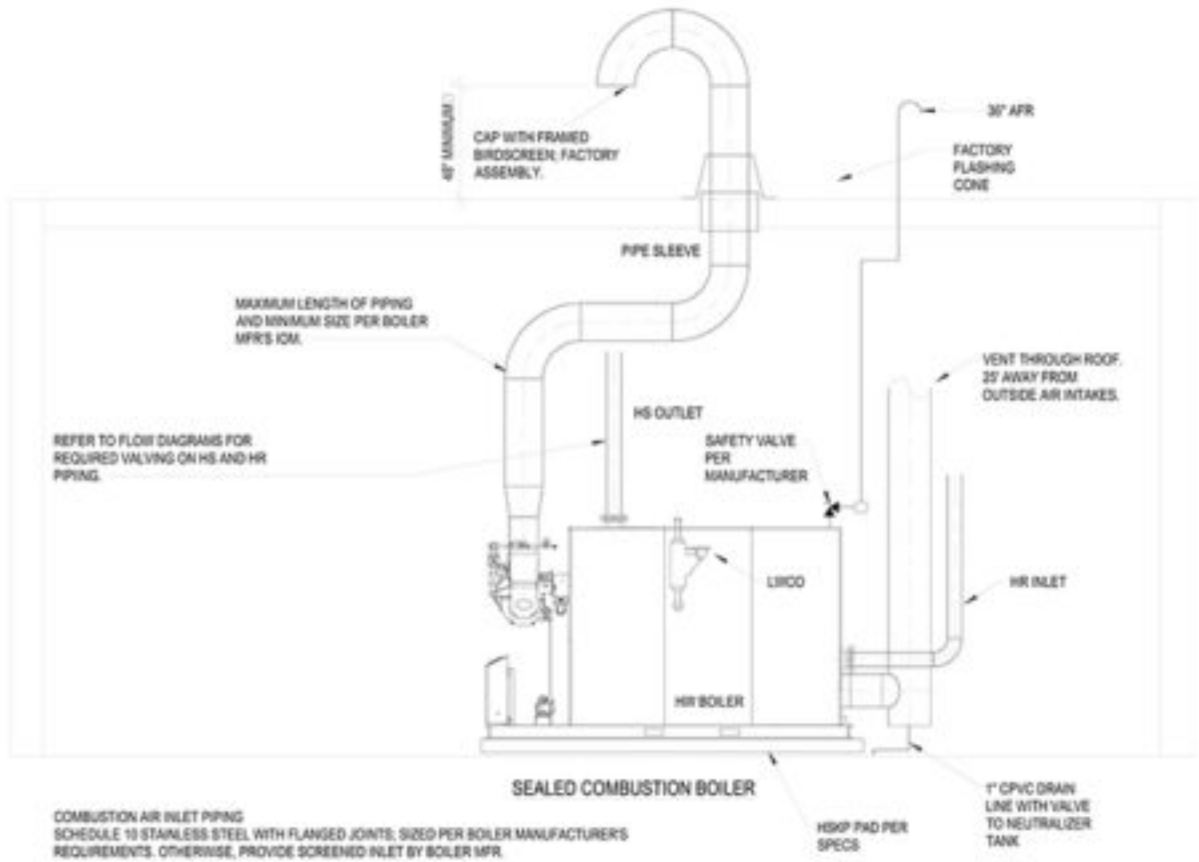
- Condensing boiler flue or stack is typically specified of noncorrosive material such as stainless steel, due to the acidity of the water.

- The design engineer must consider boiler location within the room to ensure compliance with IMC for required distances to outside air intakes.

- For safety and equipment functionality boilers come with lower water cut off and are provided with safety valves.

NFPA 85: Boiler and Combustion Systems Hazards Code provides guidelines for gas and oil fuel startup. This code is also applicable to boilers exceeding 12.5 million Btu/hour as referenced above.

State boiler code: The design engineer should verify if the state of the project in question provides any additional guidelines that may exceed the current International Code Council adopted. The Texas Boiler Code has included requirements for carbon monoxide monitor and controls for boiler room design.



Boiler ventilation

IFG 2018: International Fuel Gas Code is probably the most important code for the design engineer because it involves combustion air. The boiler produces heat due to a reaction therefore, the need to introduce outside by either natural or mechanical means is necessary to complete the process of combustion. One focus of this code is to provide

Figure 3: This represents an example of sealed combustion via a duct penetrating through the roof. Typically, the boiler has an internal fan. The design engineer must coordinate with the basis of design manufacturer for the required approved length of run from the boiler to the combustion air intake because an external exhaust fan may be required. Courtesy: WSP USA Buildings

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guidance for preventing either flue gases or fuel leakage into the building.

There are various ways to design a boiler room:

Natural ventilation

Figure 4: An exhaust fan serves a combined flue for dual fuel condensing boilers in a mechanical room. Courtesy: TDIndustries

Indoor air: May be achieved provided the cubic feet of air as indicated in Section 304 of the International Fuel Gas Code is met. This option allows to introduce the air either from the same level adjacent spaces or from higher levels provided there is a duct that introduces the volume of air to the space.

Outdoor air: May be brought either through horizontal or vertical openings or vertical opening under Section 304 from the International Fuel Gas Code.

Combination: May be brought portion from outdoor and portion room indoor.

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Mechanical (force draft)

Rates are indicated under the same section, and the engineer must consider all equipment inside the room to calculate the volume of air required. Makeup air should also be considered as well as interlock of the equipment and the fan. See Figures 2 and 3 for each option for schematic purposes.

Condensing type boilers

Condensing type boilers have become more popular in the past 15 years. The combustion reaction within the boiler has a byproduct, $CO_2 + H_2O$. This means that water must develop somewhere and water condenses in the boiler stack or flue due to the dew point temperature in the stack. This is latent heat of vaporization.

This water is very corrosive in nature with a pH of 3 to 4, therefore, condensing boilers are typically stainless steel or another noncorrosive material. In addition, a condensing boiler is always specified with a "neutralization kit." The neutralization kit includes limestone media, which raises the pH level of the condensate. The kit is installed inline to the drainpipe from the boiler and before the discharge to the floor drain. Discharging condensate directly to the floor drain will deteriorate and corrode the floor drain in a short time and it is not compliant with code in most jurisdictions.

Condensing boilers are designed with lower return water temperatures to the boilers. Typically, with return water temperature below (<130°F). Condensation will start developing in the exhaust stack. This condensate contributes to the systems higher efficiency by recovering the latent heat of vaporization and reducing waste heat. The lower the return water temperature, the more efficiency will be obtained from the boiler

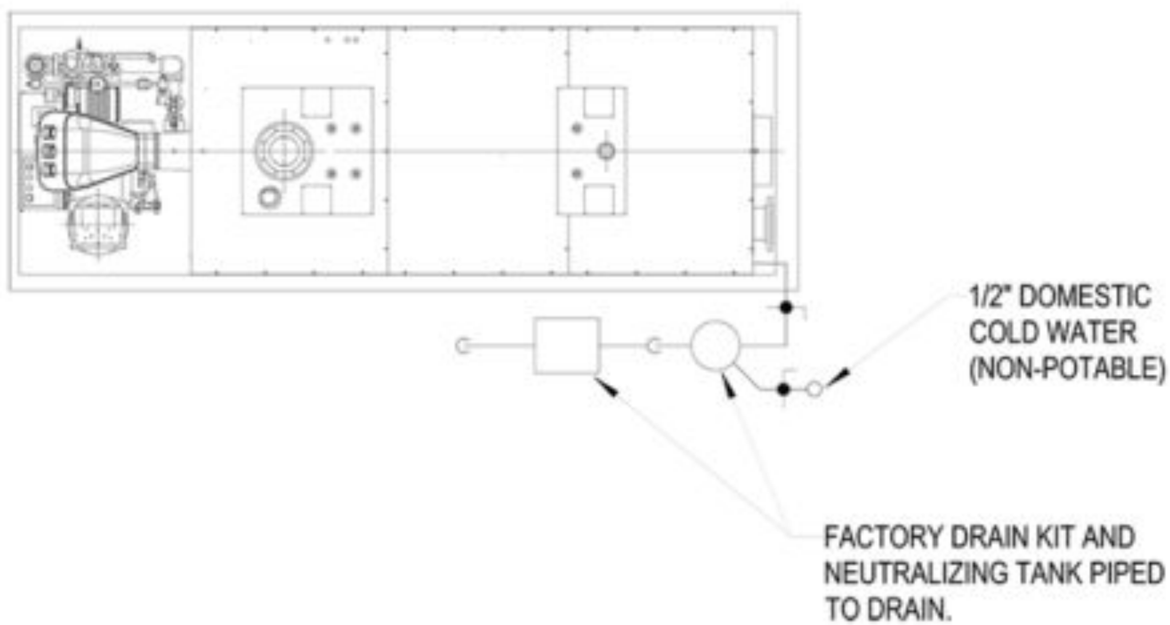

Figure 5: In this boiler plan view, the neutralization kit is tied to the condensate drain line from the boiler and before the sanitary drain. The neutralization kit consists of a vessel, which is filled with limestone or other material that stabilizes the condensate pH before reaching the drain. The main goal of the neutralization kit is to protect the drain from acid condensate, which corrodes the drain. Courtesy: WSP USA Buildings

system because more heat is extracted from the flue gases.

Condensing boilers provide other advantages such as smaller compact footprints when compared to the noncondensing larger steel boilers. In addition, new technology includes smaller and more efficient heat exchangers within the boiler that make the heat transfer optimal. Another benefit is the turn-down ratio. Some boilers may provide a 25:5 turn-down ratio. The points mentioned above may vary per manufacturer; therefore, always consult with the basis of design manufacturer.

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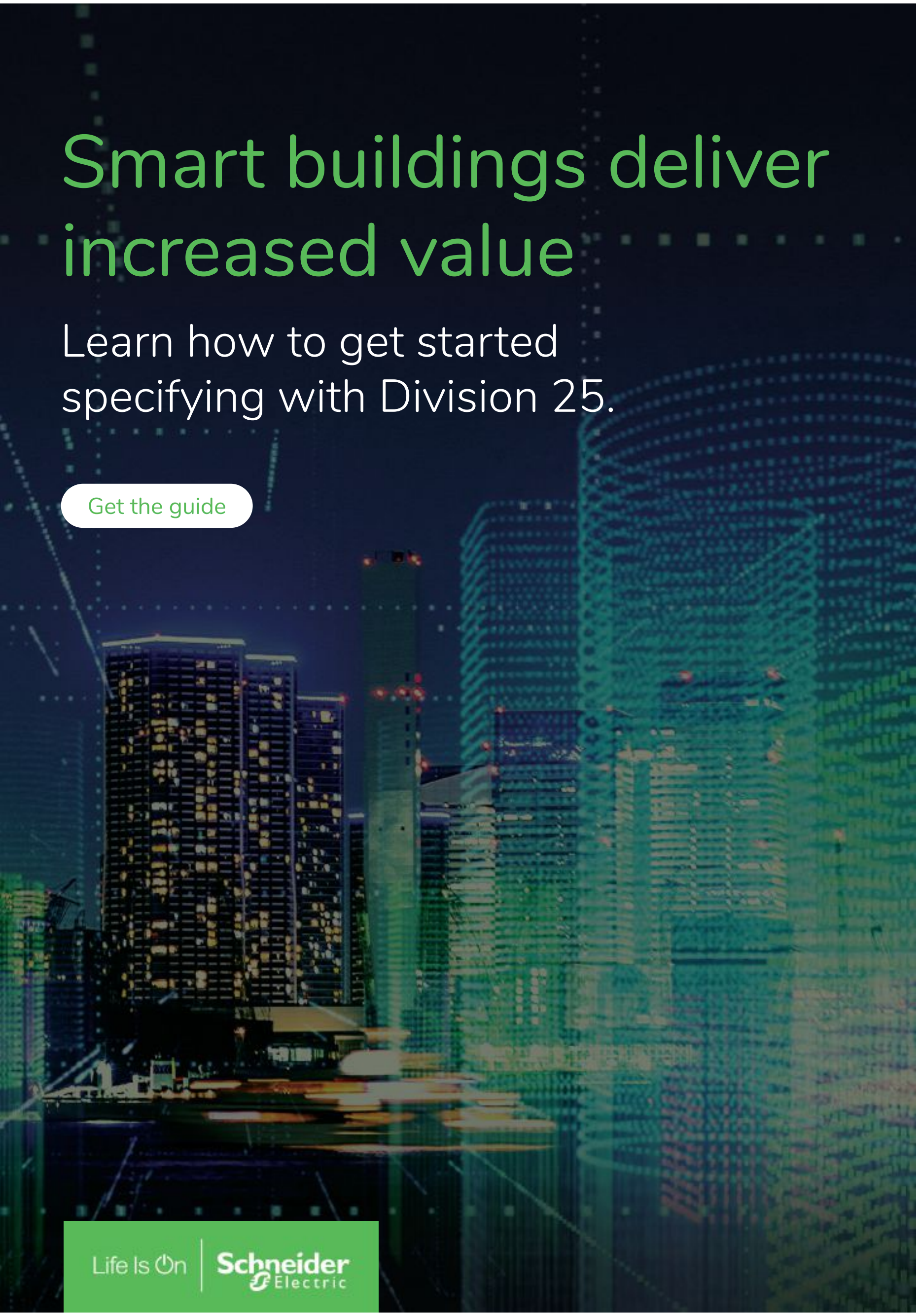

Design parameters

Design parameters for heating water systems vary per project. For example, a system design with 130°F,maximum leaving system hot water design, and 100°F,minimum return water system design, most often includes a heat pump chiller. In summary, these lower water design temperatures take advantage of free heat from the condenser side on the heat pump chiller; with the lower heating water return temperatures.

Other systems focus mostly on a design of 150°F/120°F; in addition, these systems can take advantage of the return water temperature to preheat the domestic incoming water with a heat exchanger to the domestic side. Consequently, the lower return water temperature to the boiler assists with boiler efficiency operation.

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When designing new hospitals or data centers, it is important for the engineer to discuss with the owner about equipment redundancy, which is typically provided for these types of facilities. This is often referred to as N+1. Redundancy may be specified at the equipment level for both water and air side.

The peak building load that must be satisfied on design day is the load if the building were to peak at the same time. However, in reality, load varies during the day therefore, the design engineer takes into account the building load profile throughout the entire year to optimize the equipment size and selection.

Boiler controls

Most boiler manufacturers include integrated controls and a master panel that can set boiler sequencing and designate a lead boiler. The lead boiler may rotate every month, for example, or at a preset time frame. This evens out wear and tear of the equipment. There are several strategies for boiler operation when the central energy plant includes more than one boiler. For example, one boiler may fire and carry a larger percent of the building load or two boilers may run at a lower firing rate to meet the building demand.

In summary, when designing and specifying boilers for heating water systems it is very important to research and study the codes and standards. In the United Sates, each county, municipality and state have authorities having jurisdiction that implement building codes. Some states may have amendments to current codes adopted that may exceed the minimum requirements.

Paulina Diaz

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Buildings of the Future depend on an all-digital, all-electric world — a world that Schneider Electric is helping to create. Together, we can harness the power of digitization to create more sustainable, resilient, hyper-efficient, and people-centric buildings for all.

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Increase building value with Division 25

Building value is in the eye of the stakeholder. A landlord may seek building analytics to help achieve WELL Building Standard® for potential tenants' comfort. To impress employers, a building owner may want a voice-enabled, smart device to turn down the lights and lower the blinds in a conference room. A building manager may request motorized meter relays, so each breaker can automatically turn on or off, and send alerts about how much power is being used at any given interval.

In essence, building stakeholders increasingly realize the full value of smart building technologies. Providing this value begins with a **Division 25 specification.** Division 25 is the integration platform for consulting engineers to connect mechanical, electrical, IT/OT, and other key systems to deliver value-add smart building technologies.

In this post, I will explain how this building connectivity increases value, and why Division 25 is the first step to delivering that value to stakeholders.

Bridge technologies for more value

Division 25 specified buildings are powered by intelligent building management systems — known as iBMS. This "intelligence" goes beyond traditional BMS to take systems out of their disciplinary silos, so they communicate with each other for increased efficiency and reduced costs.

For example, to automatically adjust lighting and HVAC systems according to building occupancy levels, mechanical and electrical systems all must be able to “talk” with each other, along with IT and OT. This system-wide communication cannot take place without iBMS.

This connectivity can also help building owners and employers better safeguard employees and occupants in a pandemic-conscious environment. These safety-driven smart building capabilities include:

- Setting capacity thresholds for room, floor, or building levels

- Providing contactless doors, coffee machines, bathrooms, and climate controls to prevent the spread of illness

- Increasing control over humidity, air circulation, and overall indoor air quality (IAQ) to increase safety and occupant well-being

Data produced by these connected systems can also help stakeholders automatically adjust lighting, HVAC, and other building climate controls to return to pre-pandemic levels when occupants return to the building.

Share data to save costs

Division 25 enables smart building devices and systems to share data through an **IoT platform.** This data integration can help building managers determine where to run HVAC systems at a reduced load to prevent the electrical system from overheating. Or, they can also use the data to locate hotspots between the HVAC and electrical systems.

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With electrical fires being a common cause of building damage, this connectivity provides the electrical intelligence to predict costly problems before they occur. This way, building managers can transition from reactive maintenance to proactive cost-saving measures.

The generated analytics from this connectivity can help stakeholders:

- Reduce unscheduled maintenance
- Minimize energy costs
- Decrease building occupant complaints

Share data to add value

To deliver value to key stakeholders, consulting engineers must be able to take electrical power management systems (EPMS) to high-performance, smart-building levels. One way to deliver this value is plug load (lighting load) management, which can dramatically reduce energy costs and increase overall building value. This requires data sharing between the EPMS and the iBMS for on/off and scheduling plug load control.

Specifying with Division 25 provides the connectivity to integrate motorized breakers into the IP communication and remote iBMS, which automatically turns the power on and off, based on ceiling and wall motion sensors.

This integrated plug load solution delivers:

- Premium space optimization — as the entire system can fit into existing enclosures

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- Reduced labor investment — because the new smart system does not require rewiring and rerouting

- Significant materials savings — with less disruption to existing conduits and wiring

This, in turn, dramatically increases upstream and downstream energy efficiency with a shorter value payback from the new motorized breakers. Energy savings are realized when the plug loads turn off automatically after hours and when space is unoccupied. The new solution also gives stakeholders peace-of-mind compliance with ASHRAE 90.1-2016 standards that require 50 percent of plug loads to be off at any given time.

Deliver more value to stakeholders with Division 25

The above plug load example is just one-way consulting engineers can use Division 25 to provide more value for key stakeholders and help them choose smart building capabilities — from voice-activated climate controls and lighting systems to fire detection and efficiency controls.

Specifying with Division 25 empowers engineers to offer more value with:

- The connectivity to increase energy savings and lower costs

- The infrastructure to reduce risks, such as electrical overloads

- The analytics to increase oversight and value assessment

Take the first step to delivering more value to your stakeholders by downloading our new e-book, **Improving Building Design With Division 25 Specifications.**

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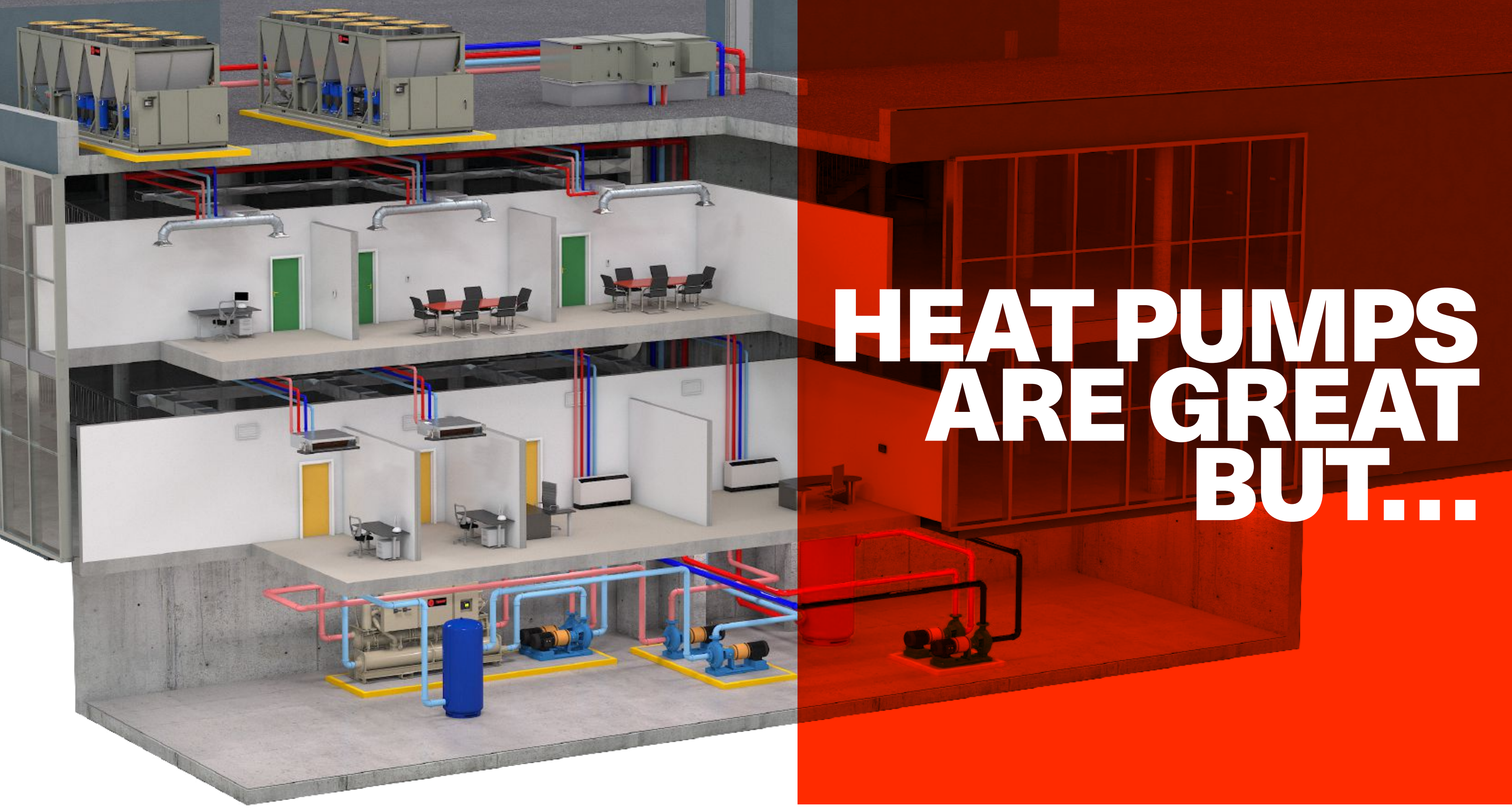

WHAT SOLUTIONS ARE AVAILABLE? | HOW DO I HANDLE DEFROST? | WHAT ABOUT SIMULTANEOUS HEATING & COOLING?

Decarbonization through efficiency and electrification are achieved when system controls and equipment work together. Trane collaborates with you to create reliable, cost-effective, and efficient electrified systems: properly size equipment, effectively include options to the layouts, implement control sequences and connect to many (and mixed) styles of air-handling systems for meeting IAQ objectives (filtration, increased/variable ventilation, air cleaning).

Get guidance on packaging the controls, equipment, and knowledge necessary for system success.

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TRANE TECHNOLOGIES

TRANE®

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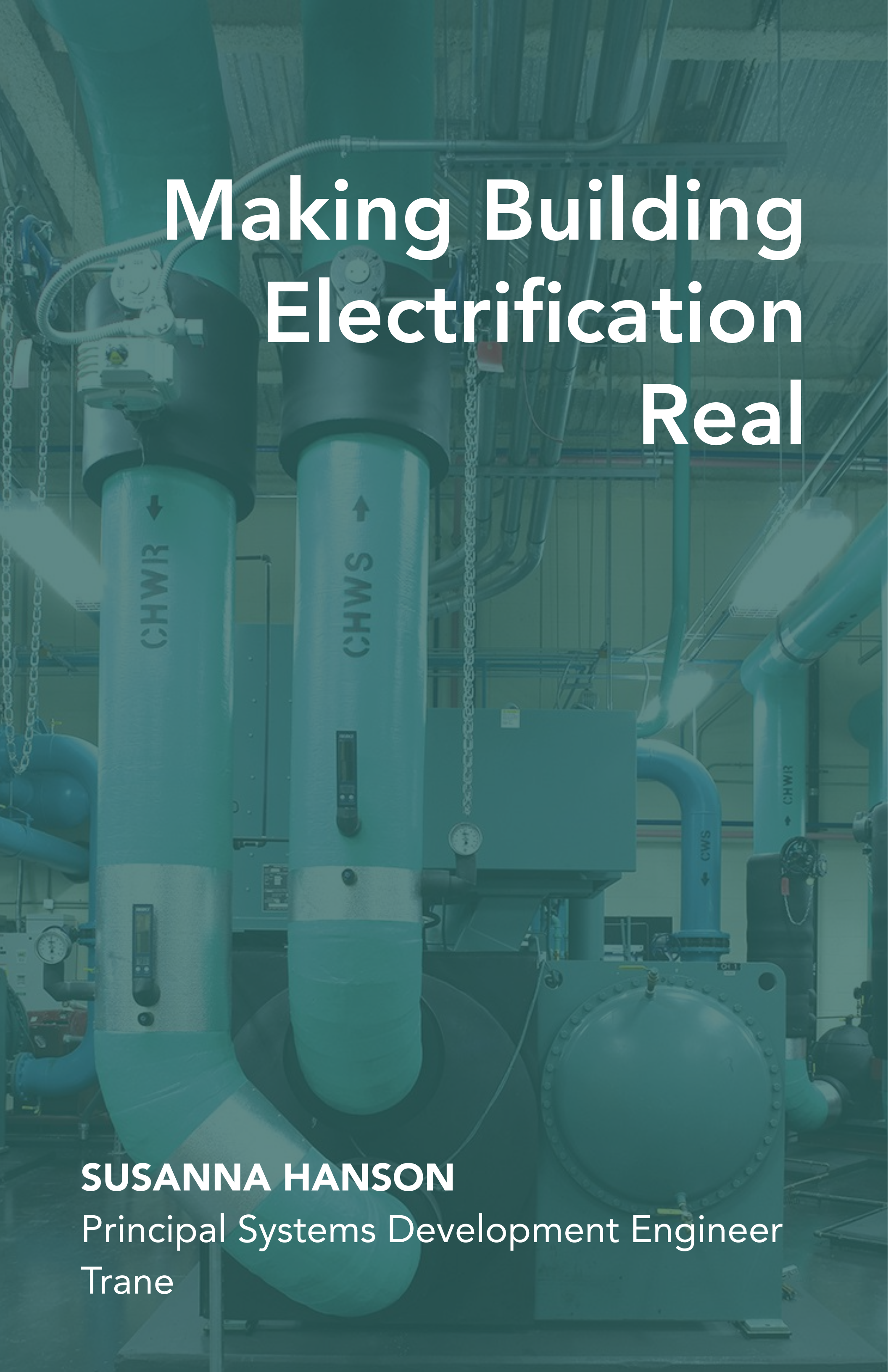
TRANE®

Electrify your building’s heating and cooling with Trane

Achieve your decarbonization goals by electrifying both heating and cooling systems with the new Ascend® air-to-water heat pump, model ACX. It’s energy efficient, ASHRAE 90.1 compliant with AHRI-certified cooling performance with heating tested in accordance with AHRI.



Making Building Electrification Real

SUSANNA HANSON
Principal Systems Development Engineer
Trane

Using Trane's new Ascend® Air-to-Water Heat Pump and Comprehensive Chiller-Heater Solution to Deliver Flexibility, High Performance and Reliability for a Broad Spectrum of Buildings.

Introduction

The decarb movement is coming soon to a building near you. Are you ready to participate?

Along with energy efficiency, next generation refrigerants, safer refrigerant management practices and various efficiency-focused building upgrades, the electrification of heating and cooling is essential for reducing the environmental impact of buildings. As the nation's energy grid transitions to greener, carbon-free and less emissive energy sources, policymakers and decision makers at all levels are now looking to concurrently reduce fossil fuel consumption in buildings while amplifying and accelerating the effect of cleaner power to reduce greenhouse gas emissions. We are on the cusp of a major transformation in building HVAC systems across the country. Trane's Comprehensive Chiller-Heater System is ideally suited to provide commercial buildings with reliable, cost-effective, energy efficient building comfort – without or with very little fossil fuel.

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Electrification is the (near) future

Across the country, building electrification is gaining increased momentum as a practical strategy to decarbonize buildings. It's effective and logical in places where the electric grid is transitioning to clean renewable energy sources. Most electricity generation today still draws from fossil fuels; however, the rapid growth of utility-scale and onsite renewables in the energy mix around the world is making decarbonization through electrification possible.

It's a noteworthy accomplishment that, nationally, the electric power sector has reduced emissions more than 25%. On the other hand, there has been no real change in carbon emissions from direct fossil fuel use in homes and businesses in decades. Cooling (air conditioning) is already electric. The majority of emissions that come directly from buildings is traceable to the use of fossil fuels for heating systems.

Change is in the air. A burgeoning effort to remove direct fossil fuel use inside buildings is in full swing across the world and will soon impact main street building owners and influence companies' ESG reporting. Many states and cities have instigated policies that incentivize electrification in North America: New York's Climate Mobilization Act mandates buildings above 25,000 square feet to cut emissions by 40% by 2030. The state mandates an 80% reduction by 2050. Massachusetts' 3-year energy efficiency plan includes incentives for strategic electrification, including incentive programs for fuel switching—targeting oil and propane customers for fuel conversion to air source heat pumps and other technologies. Minneapolis, MN, targets a 30% reduction in GHG emissions by 2025 and an 80% reduction by 2050. Its planned pathways to achieving GHG reductions from buildings include electrification.

The pressure is on building owners, and it gets financial

More than 20 states have already set mandatory decarbonization targets to reduce their reliance on fossil fuels. To help drive reductions, many more entities are also establishing financial incentives for building electrification – in essence replacing fossil-fuel driven HVAC systems with electric alternatives such as heat pumps. They have to. Reducing CO_2 emissions from buildings is necessary to meet these goals, as buildings account for 38% of global energy-related CO_2 emissions and HVAC accounts for 40% of building energy use.

So far 48 states have incentives in place for the use of heat pumps by buildings, and 13 have incentives for all-electric heating systems. Furthermore, many companies' own sustainability goals – which 92% of S&P 500 companies have – include net-zero commitments that will likely necessitate carbon reduction measures and accelerate a transition to hybrid or all-electric HVAC systems. Forty-two percent of Fortune 500 companies have either an absolute or intensity-based emissions reduction target. Legislated change takes time. Social and financial pressures will likely motivate action sooner. Whether out of conviction on the merits or compliance with changing regulations and financial incentives, building electrification will cause many building owners to look for guidance from consulting and specifying engineers.

Heat Pumps have a key role to play

So, why focus on heat pumps? Other forms of electric heating exist—such as resistance heating, which includes electric furnaces and baseboard heaters. Heat pump technology has bubbled up as the industry leader due to its lower energy consumption and, subsequently, lower operating cost and reduced impact on peak load demand. Furthermore, hydronic heat pump systems, the focus of this article, are proven performers

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that are readily available in North America. This is a rare example of how meaningful industry transformation can be based on a proven solution that already exists.

Some of your clients may be familiar with heat pump technology, if not in their commercial buildings, then in residential use. Most will need an explanation of its advantages, and you can keep it as simple as this: Heat pump solutions do not generate heat; they move heat from areas with excess heat to areas that need more heat. Due to the laws of thermodynamics, it takes less energy to transfer heat than to generate it, which results in significant energy and cost savings. Think of it as the "recycle & reuse" of a building's heat energy.

Trane's solution: A new Comprehensive Chiller-Heater System featuring the Ascend® Air-to-Water Heat Pump

Traditionally, heat pumps were seen as a residential heating and cooling solution, and rarely scaled to the sizes needed for larger buildings. And their use was limited to climates with outdoor temperatures greater than, say, 20°F. Below that temperature, second stage heat from either fossil fuel or electric resistance is activated. And even in temperate climates, heat pumps must periodically defrost. The same constraints that limit heat pumps in residential use in colder climates require the same considerations for commercial buildings—on a much bigger scale.

Trane's new system provides commercial users with reliable, cost-effective, energy efficient options to cool and heat their facilities while reducing carbon emissions – without sacrificing occupant comfort. Our pre-engineered solutions make electrified HVAC easier to specify and implement while delivering the benefits building owners expect:

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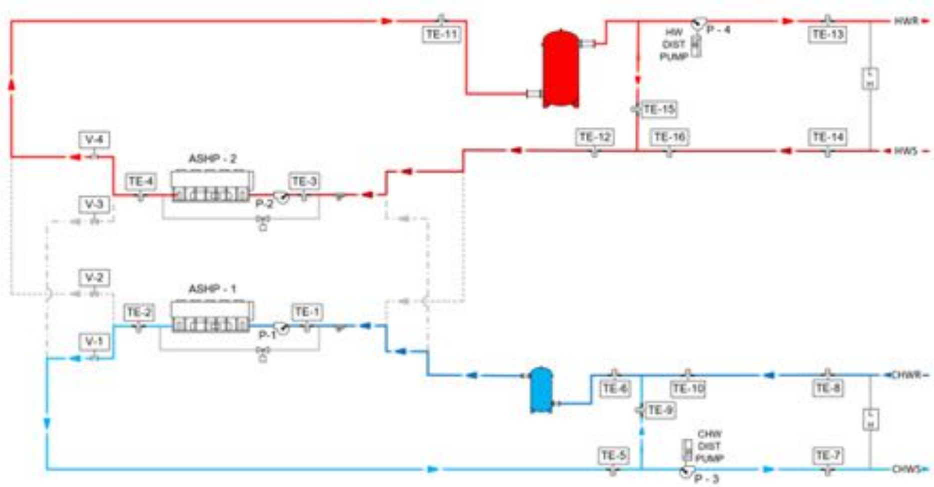
- **Flexibility—**to satisfy diverse heating and cooling loads and complying with electrification regulations and sustainability objectives.
- **High performance—**by exploiting significant improvements in heat pump heating to enable buildings to function better and reduce carbon emissions.
- **Reliability—**by managing equipment capabilities to reduce the impact of defrost on system performance and enabling cold climate operation.
- **Lower cost of ownership—**by reducing equipment and energy costs while increasing efficiency and reliability for building owners.



Comprehensive Chiller-Heater System

At the center of the system is Trane's new **Ascend® Air-to-Water Heat Pump model ACX.** The Ascend® ACX is available in six sizes ranging from 140 to 230 Tons of nominal cooling and 1500 to 2500 MBh heating capacity and complies with ANSI/ASHRAE/IES 90.1-2019. As we mentioned earlier, heat pumps move and increase the grade of heat rather than generate it, which means Ascend® model ACX can be up to three times more efficient

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than electric resistance heating. And, it brings Trane's economical heat pump technology up to a scale that provides an energy-code-compliant electrification solution that can serve the needs of a broad spectrum of commercial buildings, including government facilities, commercial real estate, K-12 schools, hospitality and out-patient healthcare facilities.

Features include:

Ascend® Air-to-Water Heat Pump Model ACX

- Heating efficiency meets ASHRAE® 90.1-2019; 2.77 COP
- Cooling efficiency meets ASHRAE 90.1-2019; 9.215 EER
- Dual expansion valves – one for heating and one for cooling – for better system control and efficiency
- Cooling and heating efficiency meets building energy codes
- Variable-speed fans, intermediate discharge valves on the compressor to optimize efficiency at all operating conditions
- Electronically commutated fan motors and brazed-plate evaporator for enhanced efficiency

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- Common platform to the Ascend air-cooled chiller for simplicity of maintenance and availability of supplies

Flexible solution with options to meet your requirements

The **Comprehensive Chiller-Heater Systems** can also support a building's IAQ objectives because it can be installed to fit with many existing hydronic air-side systems, including fan coils, air handlers and radiant systems. And these systems are supported by Trane with tools that make an electrified HVAC system easier to specify and implement.

Ascend® heat pumps come with many standard features and a wide range of options. Trane will provide the heat pump that meets your requirements for efficiency, cost and acoustics:

- Scroll compressor technology is affordable and practical, without compromising efficiency or sound

- Wide operating map meets load in extreme conditions

- Multiple sound packages to choose the level of acoustic performance desired

- Fin and tube coil reduces footprint

System design considerations

Some system design and control principles from chilled-water systems transfer well when applied to chiller-heater systems. But, there also are some important considerations that designers must factor regarding equipment sizing, buffer tank location,

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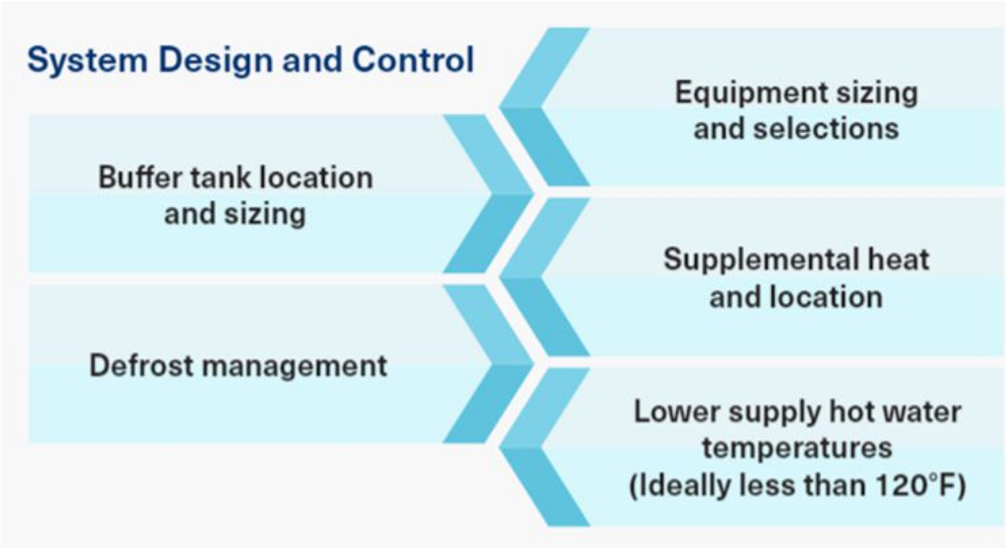
the need for supplemental heat in some climates and defrost management.



System design considerations

Reliability – The consequences of poor heating system performance are potentially more significant than a cooling system failure. Engineers need to factor into system design the potential for a 50-year weather event. Ascend® air-to-water heat pumps can deliver 140°F fluid temperature at 55°F outdoor air temperature (OAT) and are capable of heating down to 0oF while delivering 100°F fluid temperature.

Because air-to-water heat pumps have operating limits that become more restrictive as temperatures drop, engineers need to ensure they factor into their plans a redundant and reliable backup heating strategy to accommodate the potential for extremely low OAT. Comprehensive chiller-heater solutions can be optionally configured to allow for supplemental or dual-fuel heating when necessary, with more system configuration options such as dedicated heat recovery, free cooling and diurnal energy storage.

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Flexibility – Heat pumps are designed to serve two systems with different expectations: cooling and heating. A cooling system for example may be designed for 10°F-12°F degree delta T while a traditional heating system might have been designed for a 20°F-30°F degree delta T. The system must be able to accommodate both needs. The Trane Comprehensive Chiller-Heater System can be configured with two (or more) heat pumps – one for heating and one for cooling – with the proper system volume to match heating and cooling loads in real time.

Outdoor air temperature – Heat pump capacity and maximum supply fluid temperature are reduced as the OAT drops, and the system has outdoor air temperature operating limits. Equipment sizing is affected by these temperature conditions, the dual heating-cooling role and the availability of supplemental heat sources. It's important to determine equipment sizing that fits temperature, flows and redundancy requirements to meet your year-round cooling and heating needs.

Defrost mode – An air-to-water heat pump will occasionally operate in defrost mode to ensure reliable heat exchange with ambient air. While the system is in defrost mode, heating from the hydronic system is interrupted. This interruption can be mitigated through equipment sizing, the use of a buffer tank and/or the use of a supplemental boiler. A proper mitigation strategy can minimize these disruptions.

Cold climates – The Trane Comprehensive Chiller-Heater System featuring air-to-water heat pumps can also be configured for colder climates through the use of phase change energy storage and water-to-water heat pumps. The concept is to allow the air-to-water heat pump to only bring in supplemental energy into the building when the outdoor air conditions are suitable for operation, for better efficiency, and for better heating capac-

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ity. The energy brought in is stored in the phase change of water. Later, either when outdoor air conditions are unsuitable, energy prices are high, or when loads are higher, the water-to-water heat pump removes the stored energy and pumps it to a higher grade of heat for distribution. This system can be paired with other sources of low-grade heat such as solar thermal, wastewater systems, and airside energy recovery.

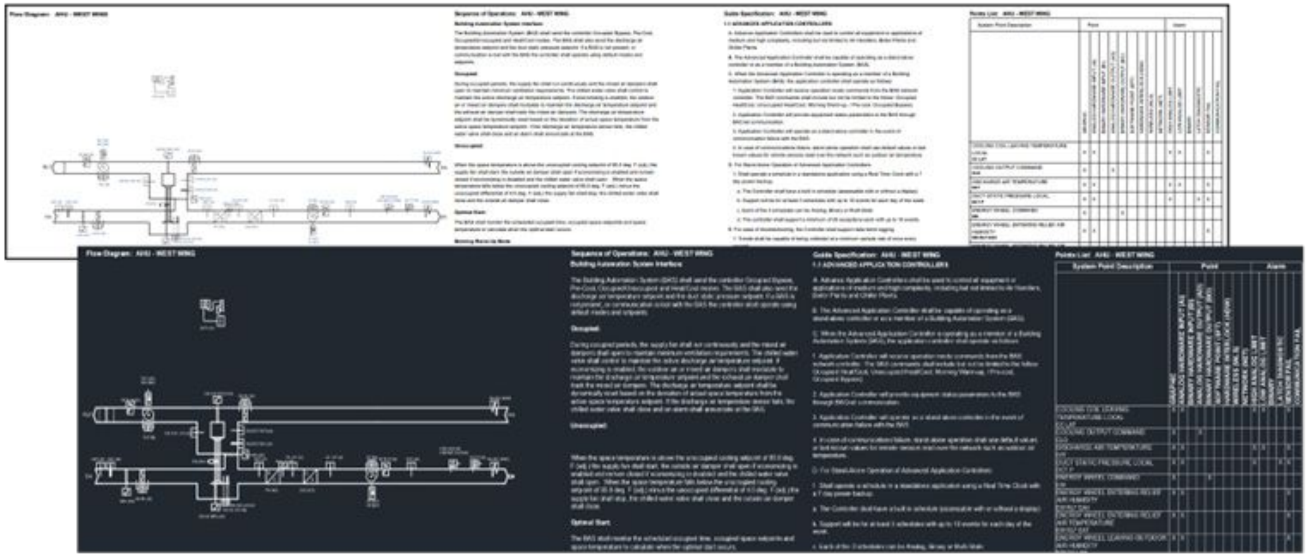
Another solution for cold climates is to use supplemental heat. This can take the form of fossil fuel-based boilers to be used only in extreme temperatures, auxiliary electric-hydronic heating in the form of an electric boiler, electric resistance heat in air-handling elements or electric radiant panels in the space.

Design support and expertise to simplify the task

Electrification brings new kinds of system components and system design requirements into the mix for consulting and specifying engineers. Trane has a full complement of resources to support design, equipment specification and selection to ensure a Comprehensive Chiller-Heater System featuring the Ascend® heat pump meets your application needs. Contact Trane for more information.

Our **Application Guide** provides extensive information about system codes and standards, system and unit sizing, configuration and optional system components. We also offer system layouts and control sequences, and water-volume and carbon calculator tools.

There are also many system **design and analysis tools** from Trane to select the equipment you need on PC, tablet or smartphone, plus system design resources, system analysis tools and various calculators, including LEED compliance.



Trane Design Assist

Trane Services organization and system support

Commitment beyond the decision.

Any decision to decarbonize using a heat pump requires an ongoing commitment to maintain its benefits. Beyond the consultation and installation, professional providers must be available to optimize the system's performance year after year. The consequences of heating system failure can be more significant than for cooling systems. Beyond the typical maintenance that's required from a gas-heating system, heat pump systems must be prepared for extreme weather events. Not every service company has familiarity with heat pump technology and its unique requirements. Trane can provide all the expert services building owners will need to maintain the system's ability to deliver consistent, reliable comfort and peak energy efficiency over time.

Contact Trane to get started at **trane.com**

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Understanding WELL v2 certification

As WELL v2 certification becomes more prevalent, project managers, engineers and designers need to understand which preconditions and optimization features are impacted by the systems they design

The International Well Building Institute WELL program considers occupant health concerns including both the perception of health as well as physical condition. This thought process follows the idea that the subjective attitude of building occupants can be correlated with the physical environment.

WELL v2 has 10 concept areas with 23 mandatory preconditions and an additional 97 possible optimizations. The 120 optimizations are labeled as "features" and are individually numbered by category. The 10 concepts are air, water, nourishment, light, movement, thermal comfort, sound, materials, mind and community. Certification requires either letters of assurance or performance verification in the form of testing on-site.

There are unique testing requirements for air quality, water quality, lighting, temperature and acoustics and the testing and sampling methods are defined in the WELL Performance Verification Guidebook. Verification may be a detailed performance test, a visual inspection or a spot check, as defined in the guidebook.

For some feature points, testing will be ongoing during occupancy through active monitoring and data logging. One of the aspects that sets WELL certification apart from other types of building design guidelines is the use of active monitoring and annual data submission.

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How engineers can use WELL

As WELL certification becomes more prevalent, engineers should know how their systems are impacted. The International Well Building Institute was launched in 2014 with the first version of certification standards called WELL v1; the second version was issued in 2018 called WELL v2.

This article will focus on the impacts that each of the WELL v2 concept areas and associated features has on mechanical, electrical and plumbing systems in commercial (nonresidential) buildings. MEP engineers will have the greatest responsibilities in the concepts of air, water, light, thermal comfort and sound. It is important for MEP engineers and project managers to understand how the entire scorecard is structured; the goal of this article is to serve as a holistic primer for each concept.

The driving force behind the standard is promoting a healthy building environment that looks at the human experience with a holistic approach. The process has multiple steps and a substantial amount of documentation to help guide the design teams and develop the appropriate building scorecard. The scorecard can be thought of as a nutrition label for the building, providing a quick glance at how the building promotes health and wellness.

The scorecard results in certification at three levels: silver, gold and platinum. The design team will ensure all preconditions can be met within the project scope and budget, then choose optimizations based on the desired certification level with a secondary goal of providing a diverse scorecard.

There is an additional approach for shell and core buildings with multiple tenants.

WELL core has four scorecard levels and is adapted to account for the spaces the building owner can and cannot control during design and construction.

Projects should know if they are going for WELL certification at the onset of the programming phase. Project registration is the first step in the process and basic building information is needed at this time. Additionally, the project will need to choose between WELL v1 and WELL v2 and the precertification process should identify the target compliance level.

Figure 1: Creating an environment that promotes healthy nourishment and movement can integrate these necessary activities into office culture. Courtesy: The Unfound Door, IMEG Corp.

Once registered, the project team will include certified professionals and a dedicated WELL reviewer, coaching support and a performance testing agent. WELL certification documentation is updated quarterly and designers should check regularly for updated information. For detailed information designers can reference "WELLographies," which are white papers that are available on the IWBI website.

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Air

Improvements of air quality are believed to be linked to improved focus and alertness. Concerns of indoor air quality include adequate ventilation air (air that is from outside the building), interior contaminants, exterior contaminants, interior material off-gassing and microbial sources. There are four precondition categories. Feature A03, ventilation effectiveness, is the one that heating, ventilation and air conditioning engineers and designers will need to address.

The other preconditions are related to tobacco use on the property, the management of construction pollution and measurements of particulate matter organic gasses and inorganic gasses. Ventilation effectiveness compliance method depends on the system being either mechanically ventilated or naturally ventilated.

The mechanical ventilation system will be expected to meet one of four standards. Buildings pursuing natural ventilation methods have performative requirements based on the desired certification level. That is to say, a gold certification has more stringent requirements than a silver certification as it relates to parts-per-million.

In the United States, the applicable standard for either mechanical ventilation or natural ventilation is ASHRAE 62.1: Ventilation for Acceptable Indoor Air Quality for commercial buildings or ASHRAE 62.2: Ventilation and Acceptable Indoor Air Quality in Residential Buildings for occupancies classified as dwelling units. Within this standard, engineers will reference tables for minimum ventilation rates, minimum exhaust air rates, acceptable indoor air quality and requirements for various types of ventilation systems.

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Figure 2: Automated operable windows at the WELL certified Aspen (Colo.) Police Department not only reduce energy consumption by providing free cooling they also significantly increase the supply of outdoor air directly to the occupants, further promoting a connection to the outdoors. Courtesy: Dallas & Harris Photography, IMEG Corp.

Feature A06, enhanced ventilation, can be pursued by providing enhancements to the ventilation requirements, which is to go above and beyond the minimum requirements in the precondition feature. Feature A07, operable windows, uses a design practice that the industry has moved away from. This feature includes points for managing the using of operable windows by using hourly monitoring of exterior air quality and temperature.

Active monitoring is a common theme throughout the air concept category and is focused upon in feature A08, air quality monitoring and awareness, which requires a system that logs data for reporting for annual submissions to maintain certification.

MEP engineers will also be engaged in the combustion management feature A10, combustion minimization, which either bans or limits the amount of emissions from

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combustion sources including water heaters and hot water boilers.

The requirements of particle filtration for ventilation systems are defined in feature A12, air filtration, which correlates outdoor air particulate thresholds with MERV ratings for filters and requires the pressure drop across the filter be monitored to alert staff when replacement is needed.

HVAC designers will be involved in feature A13, active volatile organic compound control, which can include activated carbon filtration to mitigate indoor levels of VOCs. Both A12 and A13 include ongoing reporting to ensure filter media are being maintained.

The last feature in the air concept category is microbe and mold control, for which ultraviolet emission can be used to control microbial growth on cooling coils in forced-air cooling systems. Additionally, interior humidity levels are managed to control interior condensation. Ongoing reporting is also required for this feature.

Water

Drinking water quality is the primary focus of the water concept category. Plumbing system designers will need to coordinate with the local water utility for historical water quality at the site as well as design filtration systems to ensure drinking water properties are maintained. The need for adequate, daily water intake is well documented.

There are a variety of factors that affect the quality of drinking water and system designers will be faced with the challenge of quantifying water quality that enters the project site and then ensuring the water meets the prescribed standards.

Within this concept there are three precondition features and six optional features. Six of these features focus on controlling and mitigating harmful contaminants. Most of the aspects of these features require on-site testing as well as ongoing testing and reporting to ensure water quality thresholds are being maintained. All of the parts in feature W01, fundamental water quality; W02, water contaminants; W04, enhanced water quality; and W05, water quality consistency, require performance testing or ongoing data reporting.

Feature W08, hand-washing, affects the size of the sink and faucet selection to ensure the water column is of sufficient size and positioned to keep hands away from surfaces.

Light

Historically, lighting was used for wayfinding and task illumination. Electric lighting or lighting-on-demand, has resulted in longer days and shorter evenings, which influences human health and stress. It has only been 100 years since half of the U.S. homes had electric light. Since the widespread adoption of electric lighting, our afternoons indoors do not have enough light and our evenings have too much light, compared to being outside.

It is difficult to ignore effects that artificial light has on the human body. We now know that the spectral density of lighting affects the circadian clock and its production of melatonin. Melatonin is made by our body but is naturally suppressed when our body interprets our surroundings as "daytime."

The light concept has two preconditions features and six optimization features. Feature L01, light exposure and education, requires daylighting design meet a series of crite-

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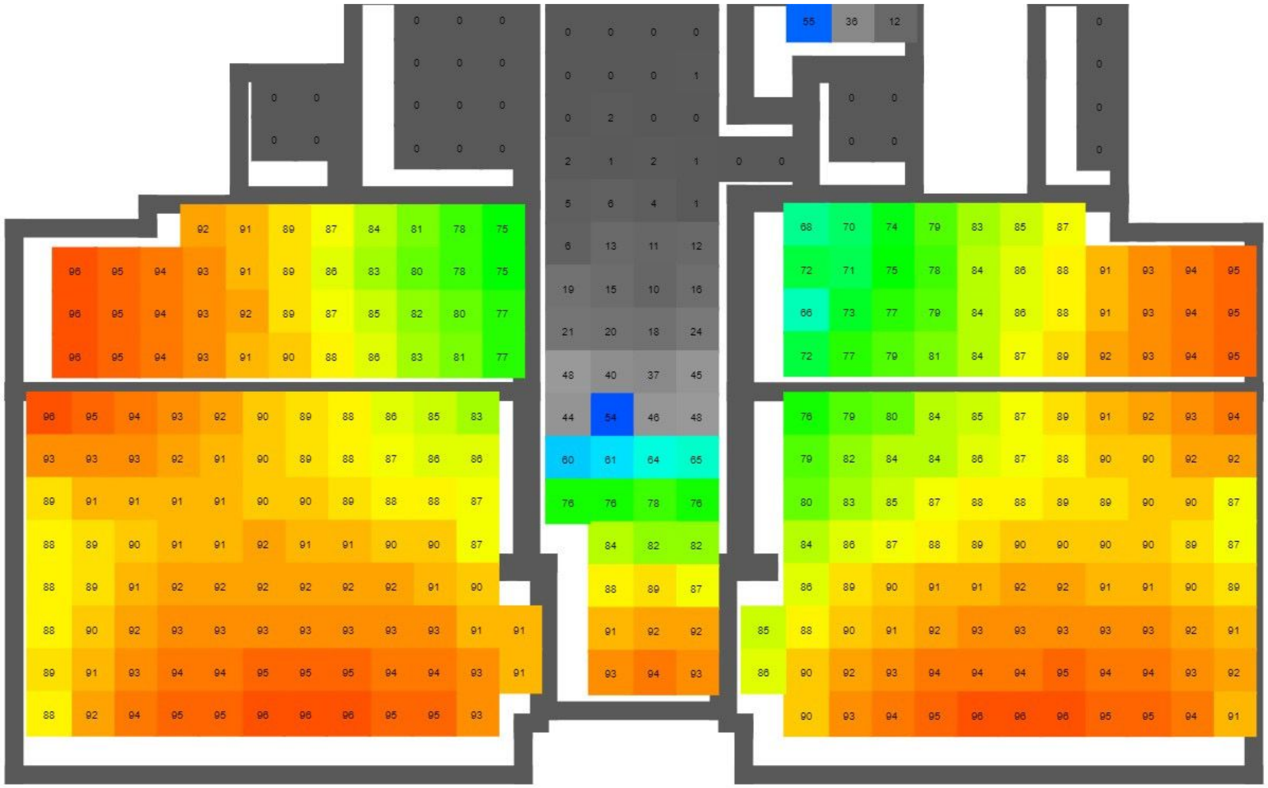

ria that the lighting designer will need to coordinate with the architect. Two primary options are provided: either daylighting in common spaces only or daylighting in all spaces.

Figure 3: Shown is the output from a spatial daylight autonomy analysis. Courtesy: IMEG Corp.

There are two main metrics used in this feature: spatial daylight autonomy and visible light transmittance. The spatial daylight autonomy metric is used to quantify the amount of daylighting that is present in a space relative to the total size of the space. It answers the question "Am I getting enough usable daylight in my space to promote well-being?"

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Figure 3 provides output from a spatial daylight autonomy analysis. Visible light transmittance is a value that is associated with the optical property of exterior glazing and it indicates the amount of light that passes through the window. A higher value indicates an increased amount of light transmission. It is important to note that visible light transmittance is affected by the window frame. An enhancement to the precondition requirements is identified in feature L05, enhanced daylight access.

Feature L02, visual lighting design, is a precondition that relies on the Illuminating Engineering Society 10th Edition Handbook for indoor and outdoor lighting illuminance level recommendations. To verify compliance, the project verification includes annotated design documents and on-site performance testing. Lighting design used to be a process of calculating the foot-candles (or lux) at the task height and then choosing fixture locations that minimized shadows at the task location.

As color temperature options increased, designers started to consider how colors would be rendered. Color rendering may be architectural, based on surface finishes, or it could be for medical applications where the hue skin tone is important. More recently, the spectrum of color — not just the overall color temperature — is of interest.

One application of lighting color and spectrum is in feature L03, circadian lighting design. This feature requires that the lighting designer use the spectral data file for the lighting fixtures chosen to perform calculations at the vertical plane of the occupant's eye location(s). Both melanoptic and photopic levels need to be quantified, as this feature sets a minimum equivalent melanoptic lux for regularly occupied spaces.

Another circadian metric is circadian stimulus, which looks at spectrum and also mela-

tonin suppression levels. A CS of 0.7 means that 70% of melatonin is being suppressed (max measured). When CS is less than 0.1, amber lighting, there isn't a measurable effect on melatonin suppression. With CS greater than 0.3, blue light, suppression is effective.

Feature L04 is glare control, which incorporates both interior and exterior lighting source glare control. The lighting designer and electrical designer will coordinate shade control that allows for either automatic control or occupant controls. There are additional requirements for manual controls to ensure daylighting is provided. Glare for interior luminaires requires luminance data and photometric information, and the designer needs to coordinate both the fixture selection, mounting height and the fixture orientation.

The concept of visual balance, identified in feature L06, visual balance, requires photometric study of uniformity between spaces and within the space. Glare from reflections is included in this feature, requiring surface finish coordination with the architectural design team.

Feature L07, electric light quality, continues the visual comfort approach of this concept. Luminaire selections will include specifications for color rendering index or may comply with IES TM-30 fidelity, gamut and color rendering index ranges listed in the feature.

Rounding out the light concept category is feature L08, occupant control of lighting environments, which defines requirements for lighting controls and relates to circadian tuning and occupant adjustment of lighting color in addition to levels.

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Thermal comfort

The thermal comfort concept uses the same building systems (i.e., air handling units) as the air quality concepts, but uses a different series of metrics. Like the air concept, requirements are split between mechanically ventilated and naturally ventilated spaces. The mechanical system metric in prerequisite T01, thermal performance, and feature T02, enhanced thermal performance, are the predicted mean vote that uses heat balance concepts to describe thermal conditions and relate multiple comfort factors that an average person would agree with.

ASHRAE Standard 55: Thermal Environmental Conditions for Human Occupancy is a standard for thermal comfort that applies to projects in the United States. Features T03, thermal zoning, and T04, individual thermal control, relate to zoning and individual control, respectively. Building HVAC designs commonly combine multiple offices on a single zone to mitigate cost and feature T03 allows for multiple occupants.

While private offices are a fairly straightforward application of shared thermostats, an open office concept may be more complicated to implement. The heating systems in feature T05, radiant thermal comfort, are limited to hydronic or electric systems for at least 50% of the occupied areas. Radiant heating systems provide a substantial improvement to thermal comfort.

A computational fluid dynamics analysis was done for three different perimeter heating options along perimeter glass in a cold climate. Comfort is best achieved with consistent temperatures from head to ankles. This feature also includes a dedicated outdoor air system to achieve ventilation requirements. These systems offer energy savings by allowing for a variety of thermal control systems such as hydronic fan coil systems,

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chilled beams, variable refrigerant flow or even forced air systems that can be solely recirculation.

Feature T07, humidity control, is achieved by controlling relative humidity for at least 98% of operating hours during the year. The systems required to achieve this goal will vary based on physical location and will be affected by the arrangement of building entrances and locations used for taking humidity measurements. Control of humidity can be accomplished in a number of ways and will likely be accompanied by feature A14, microbe and mold control for ultraviolet treatment of cooling coils that will remove moisture from the air during the summer months.

Figure 4: Integrating biophilia into the design brings natural materials into the space, as shown in this photo of IMEG Corp.'s WELL Gold Denver office. Using specialty plants and planters can further optimize indoor air quality and create an environment for positive mental health. Courtesy: The Unfound Door, IMEG Corp.

There are two beta features within the concept that enhance the physical comfort of the site: T08, enhanced operable windows and T09, outdoor thermal comfort. Feature A07 is a precondition of feature T08 because both apply to operable windows. This en-

hanced point further refines operable window requirements and associates opening characteristics with seasonal temperatures. An interlock is required between window position and mechanical cooling operation, resulting in a likely need for sensors at each window to monitor the status. This enhancement feature further requires low openings during summer months and high openings during winter months, which needs to be coordinated with the architectural team for sensor positions and function.

Feature T09 rounds out this concept by awarding points for providing adequate shading by area or via temperature modeling of shading elements. This feature also requires a computational fluid dynamic study of wind speeds in areas designated as exterior seating to ensure wind speeds are not sustained at levels that would discourage use of exterior seating areas.

Sound

The aspects of a typical acoustical study will seem familiar to designers performing the calculations and preparing the necessary documents for the sound concept features. The only precondition is S01, sound mapping. Background noise level metrics can be either dBA (A-weighted overall sound pressure level) or noise criterion, known as NC. The acoustical designer will need to take all noise sources into consideration, both interior and exterior, to develop the necessary metrics.

Interior noise commonly includes HVAC systems, for which modeling is required. Exterior noise includes traffic, which can be modeled using software from the Federal Highway Administration. These calculations will provide overall dBA at the building façade, which the designer can use to correlate glazing transmission loss with interior noise contribution.

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The second part of precondition S01 requires acoustical privacy be identified by listing the transmission loss metrics for demising walls and doors.

The third part of this feature includes identifying spaces as being either loud, quiet or mixed. This classification impacts decisions made to achieve optional features. The first optimization feature S02, maximum noise levels, identifies the maximum permissible noise levels for several pre-defined interior spaces. Higher points are available for quieter results during performance testing on-site. Feature S03, sound barriers, is related to S02 in that it quantifies transmission loss of demising partitions and doors, which contributes to a reduction in overall noise levels.

Feature S04, sound absorption, sets maximum permissible levels of reverberation time, labeled as RT60. This is the amount of time, in seconds, it takes a sound impulse to decay by 60 decibels. This metric is used to characterize a space as being "lively" or "dry," and most occupants will relate "lively" to a room with noticeable echoes. To control reverberation time, sound absorption elements are typically added to the ceiling and walls and the second and third parts of this feature set quantities for surface treatments with a minimum noise reduction coefficient of 0.70.

The spaces identified as "quiet" in S01 are referenced in feature S05, sound masking, for scope of sound masking, with a maximum defined sound masking level. Other areas known for congregating — such as dining, corridors and open offices — have a higher sound masking level requirement. Impact insulation class is a measurement of noise transfer through floor-ceiling elements as a result of physical impact, i.e., footfall.

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Feature S06, impact noise management, specifies minimum insulation ratings, all of which will require a resilient flooring solution to achieve.

Active speech amplification systems are identified in feature S07, enhanced audio devices, which focuses on speech intelligibility and accessibility though the use of audio equipment. Requirements are based on location and can be audio/video systems, public address systems or speech reinforcement systems, with separate requirements for each. The second aspect of this feature allows for individuals to have access to or away from the systems listed in this feature.

Hearing conservation is an important aspect for all employers and building owners to consider and feature S08, hearing health conservation, focuses on how noises can adversely affect occupants. Compliance with this feature requires access to hearing protection, compliance with applicable regulations and no-cost audiogram testing. This feature also requires the designation of a qualified supervisor that is responsible for the execution and maintenance of the conservation program.

This article focused on the concepts and associated features that heavily rely on MEP support, and designers can expect coordination with the entire design team as other features are pursued. Achieving compliance with nourishment, movement, materials, mind and community will require participation by all project designers.

Educational resources for building occupants occur in several concepts and features and MEP designers can assist the team for applicable information. Educational resources can include active monitoring results for air quality using the building automation system or information on healthy options for water, nourishment, light and movement.

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There are additional points available for innovation aspects that provide designers with additional freedoms to exceed requirements with a focus on the goals and mission of WELL. As designers become more familiar with the concepts and features within the WELL certification system, a similar holistic approach to building design is likely to become prevalent in noncertified building designs.

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