HVAC/R

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Contents

Understand how to maximize efficiency and control with DOAS

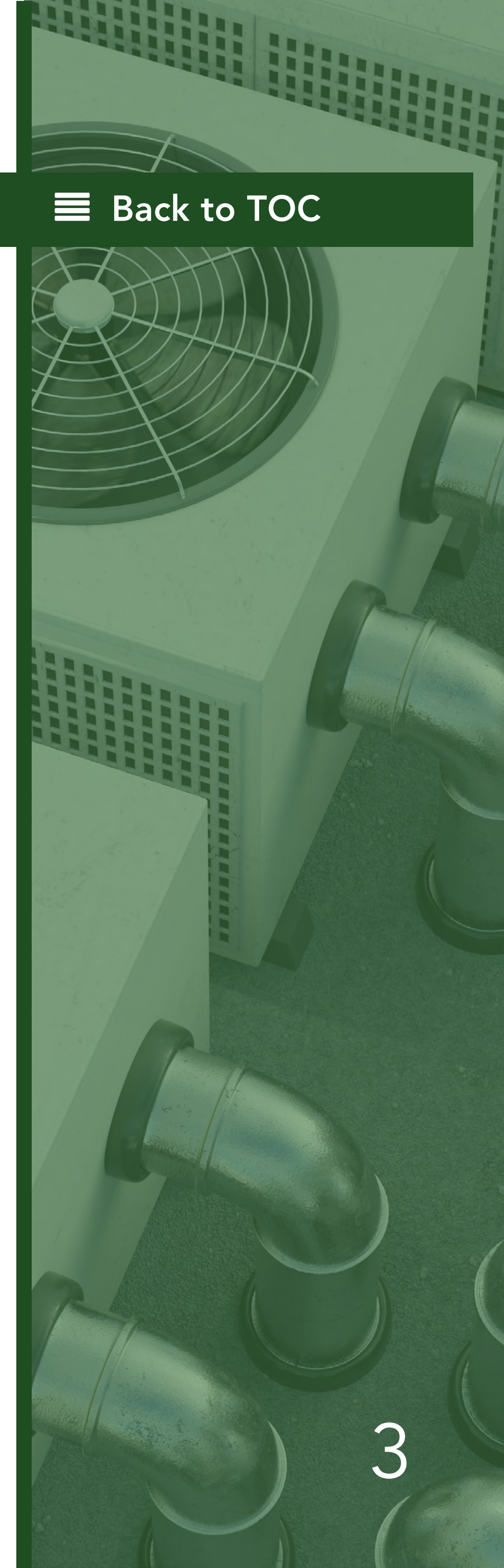
Dedicated outdoor air systems enhance humidity control, reduce energy use, simplify ventilation design and improve efficiency in building ventilation systems

Dedicated outdoor air systems (DOAS) have become common design considerations for the supply of ventilation, or outdoor air, to building spaces. As the name states, DOAS, provides dedicated outdoor ventilation air without real consideration of meeting the space cooling or heating loads. DOAS precondition the air, which relieves other space conditioning equipment of much of the latent load.

Why specify a DOAS?

The ASHRAE Design Guide for Dedicated Outdoor Air Systems states the following reasons for using DOAS:

- Improving humidity control.
- Reducing energy use.
- Desire to simplify ventilation design and control.
- Desire to use heating and cooling equipment that doesn't provide ventilation and/or dehumidification.
- Reducing installation cost.



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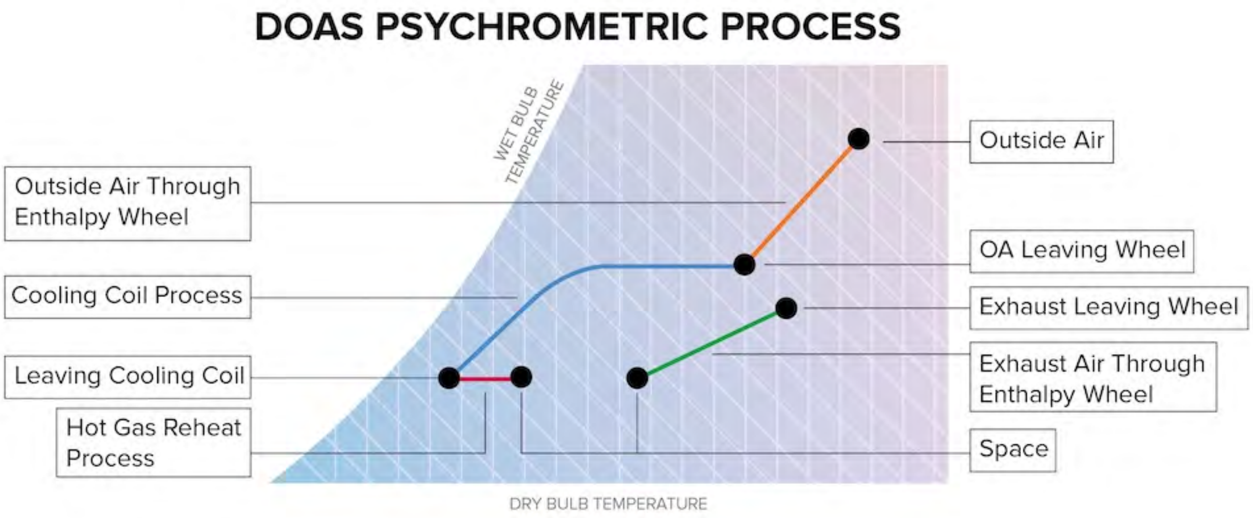
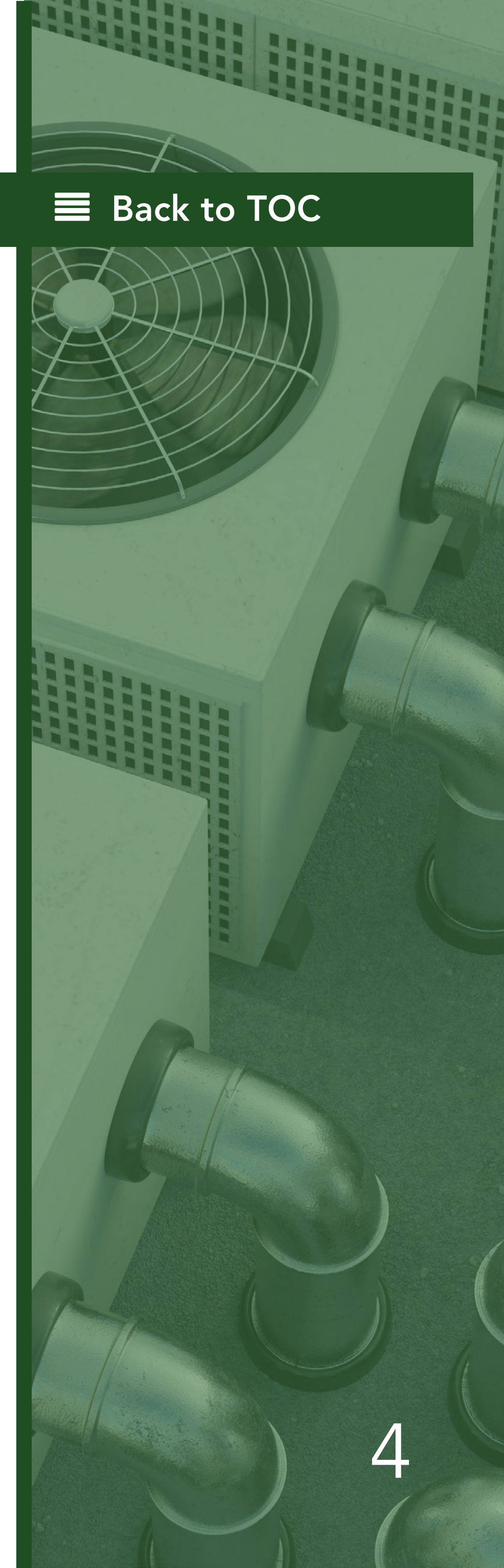


Figure 1: The psychrometric process of a dedicated outdoor air system is unique to other cooling systems. Courtesy: Smith Seckman Reid Inc.

Consider the first point. DOAS dehumidification is not just a byproduct of the cooling coil process, it is the primary function. The second point is accomplished by only conditioning the desired amount of ventilation air and using reclaimed condenser heat, in this case with direct expansion (DX) cooling, in lieu of other heating means that have an associated cost. The third reason considers that the DOAS is a separate system from the space cooling and heating systems, which simplifies calculations for multizone systems that can be controlled separately from the space conditioning system equipment.

Therefore, the ventilation is "decoupled" from the heating and cooling systems, and operation of one does not affect operation of the other. The fourth point is that, typically, DOAS systems use low-pressure ductwork and are only sized for outdoor air requirements. This, along with other cost benefits, explains the fifth reason.



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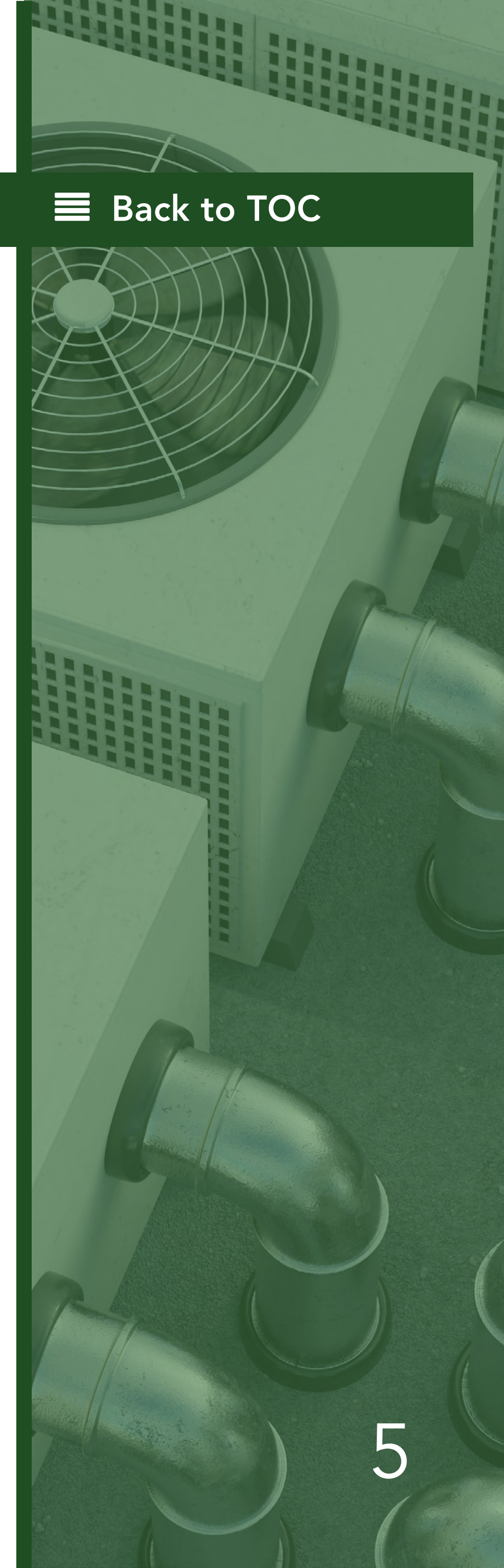
Ventilation air distribution in DOAS

An important consideration in DOAS design is how to distribute the ventilation air in the space. Two methods are commonly used. In the first method, the DOAS preconditioned air ventilation air can be mixed with return air from the zone-level heating, ventilation and air conditioning (HVAC) system. The supply air ductwork and diffusers are then utilized to distribute both the ventilation air and air for conditioning the spaces. This eliminates the need for extra diffusers and ductwork in the space, may be less costly and may make it easier to design on a drawing. Codes do require the ventilation air to be supplied continuously, so this method needs the supply fan(s) to operate continuously while the space is occupied. Zone air distribution effectiveness (Ez) must be accounted for when utilizing this method and is discussed in more detail below.

Figure 2: The status of an enthalpy wheel is key for energy efficiency considerations and temperature measurement. Courtesy: Smith Seckman Reid Inc.

A second method to distribute the ventilation air is to deliver the DOAS air directly to the space utilizing traditional diffusers and grilles. Both methods are common, but this method is used especially with ductless system types, such as variable refrigerant flow (VRF) cassettes and chilled beams. An advantage of the second method is that if there is an op-



erational problem with either the DOAS or space conditioning system, it can be identified without being masked or compensated for by the other system. Another benefit comes from the possible reduced amount of required air to a space.

Most ventilation codes include an Ez for the required outside air calculations. In many traditional systems, which are responsible for providing both ventilation and space conditioning, the outside air is mixed with the return air and conditioned before being supplied to the space. When this air is designed to be supplied from a ceiling diffuser that is 15 °F warmer than the space temperature, and the return air is via the ceiling, the Ez value is 0.8. This results in a 20% increase in the required outdoor airflow provided to the space. This must also be applied to DOAS if the air from the DOAS is mixed with return air from the space and then conditioned (heated) to satisfy the heating load in the space. When ducted in this manner, the required ventilation air from the DOAS to the return air stream is effectively increased 20%.

However, if the DOAS air is supplied directly to the space at the ceiling at a temperature just cooler than space temperature, the Ez effectiveness is 1.0 and no increase in required ventilation air is needed. The extra 20% can add up across a building, and can lead to increased DOAS equipment and energy costs. Usually, the DOAS air that ducts to grilles in the spaces are easier to balance. An additional benefit of DOAS ducted directly to spaces is that the supply fans used for space conditioning do not have to operate continuously to maintain code required ventilation. They can cycle off in a deadband condition when not required for space cooling or heating. On the other hand, supplying DOAS air directly to the space does require the costs of grilles, their installation and any additional ductwork.

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Figure 3: Exhaust and ventilation airflow should provide overall positive building pressure and meet the code-required minimum energy recovery enthalpy recovery ratio. Courtesy: Smith Seckman Reid Inc.

Note the nominal capacity of a DX cooling coil, such as what you'd find in a zone-level packaged or split system, is listed in product catalogs at Air Conditioning Heating and Refrigeration Institute (AHRI) Standard Rating Conditions. The engineer is advised to account for different entering air conditions when DOAS are used in conjunction with the space cooling and heating equipment. Capacities of the space conditioning equipment and other parameters differ from the nominal AHRI published conditions for the space equipment based on entering air condition. Nominal capacity values, or capacities listed at AHRI conditions, do not apply and a manufacturer's selection is recommended to ensure space loads are met. The HVAC engineer should consider these strategies and determine which is best for the project before detailed design begins.

DOAS energy recovery considerations

Exhaust air energy recovery is often considered when designing a DOAS to potentially reduce equipment sizing and energy usage. Energy codes require energy recovery for systems with high percentages of outside air. The percentage where energy recovery is required has steadily decreased with new code updates. The applicability of this re-

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quirement varies based on climate zone, supply fan airflow rate, percentage of outside air and ventilation system operating hours per year. When required by codes, energy recovery devices, such as enthalpy wheels and fixed membrane heat exchangers, must have a minimum enthalpy recovery ratio of 50%.

Additionally, a bypass damper or some other control must be included to disable the device when outside air conditions are not conducive for energy recovery, such as when air economizers would normally be active.

There are exceptions to the energy recovery requirements, so verify specific code requirements enforced for each project. It is considered best practice to utilize energy recovery where possible, even if there is an exception that applies. At times, the exhaust flow from the spaces may need to be increased from minimum requirements to meet the efficiency standard for the energy recovery device. The engineer should design the DOAS ventilation airflow and the exhaust airflow to provide overall positive building pressure and meet the code required minimum energy recovery enthalpy recovery ratio.

Figure 4: Delivering dedicated outdoor air directly to a space using traditional diffusers and grilles is common in chilled beam applications. Courtesy: Smith Seckman Reid Inc.

When including energy recovery in a DOAS, engineers must decide whether to account for the capacity of the

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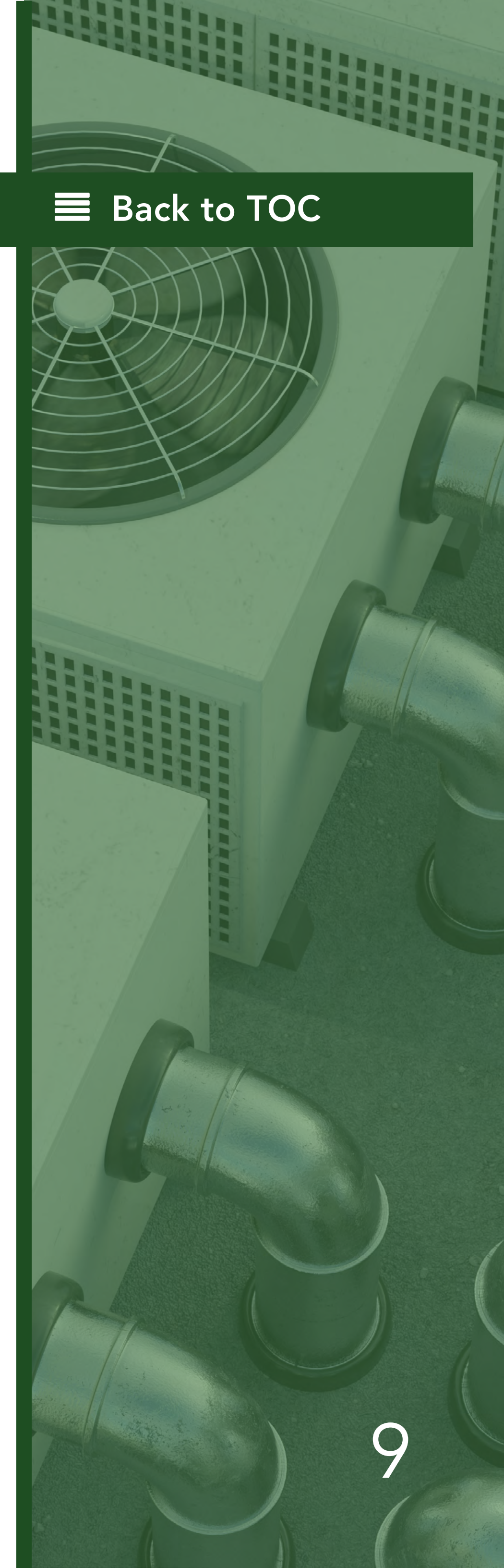

energy recovery device when sizing cooling and heating coils. If cooling and heating capacities are reduced, energy recovery can appear more cost-effective, but risk increases. However, if capacities are not reduced, the ventilation load is met even if the energy recovery device fails or is later removed. Either way, maintenance of the energy recovery device is just as critical as any other portion of the DOAS.

Supply temperatures for DOAS

To dehumidify the raw outdoor air in summer, the DOAS cools the supply air down below saturation or dewpoint, and moisture is removed from the air as condensate. Many engineers will use the ASHRAE dehumidification design condition and heat recovery temperatures to assure they have accounted for the full dehumidification load. A leaving coil temperature of 52 °F or lower is typically used for the design. In cooling season, the air can be sent to the spaces at this temperature, but there is a risk of overcooling some spaces. At times, the saturated air is reheated to avoid over cooling.

However, energy codes limit the reheat in cooling season to no more than 60 °F if the majority of zone-level HVAC systems served by the DOAS require cooling. In this way, not only is no ventilation load added for the space conditioning systems, but the DOAS helps to reduce the load on the space cooling system.

Additionally, engineers need to be mindful of the supply location of the DOAS airflow in the space, and that the air needs to be cooler than the space temperature to utilize the zone effectiveness ratio of one for the required airflow calculations mentioned above. Therefore, many engineers specify duct insulation on the DOAS air even when the duct is exposed in a conditioned space.

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Demand control ventilation

Demand control ventilation (DCV) can be accomplished with a DOAS design. Typically, variable air volume (VAV) cooling only terminals are used to provide DOAS supply air to a space requiring DCV. In this scenario, the DOAS maintains a duct static pressure setpoint in the supply duct and the supply fan speed varies to maintain the static pressure. The VAV terminal can be set to a minimum unoccupied flow. As carbon dioxide (CO_2) levels rise when spaces become occupied, the VAV terminal opens and supplies more ventilation air – requiring the DOAS supply fan to increase until the CO_2 setpoint level is obtained.

Figure 5: Measuring the temperature, humidity and other status points allows engineers to see the benefits and required maintenance on dedicated outdoor air systems. Courtesy: Smith Seckman Reid Inc.

Constant volume VAV terminals are also needed to maintain the proper ventilation air for other spaces that do not need DCV. Without constant volume VAV control, the required ventilation airflow can fluctuate and become too little or too much. Likewise, there needs to be control for the exhaust amounts and supply, while maintaining overall building pressure. Energy codes are less likely to require DCV

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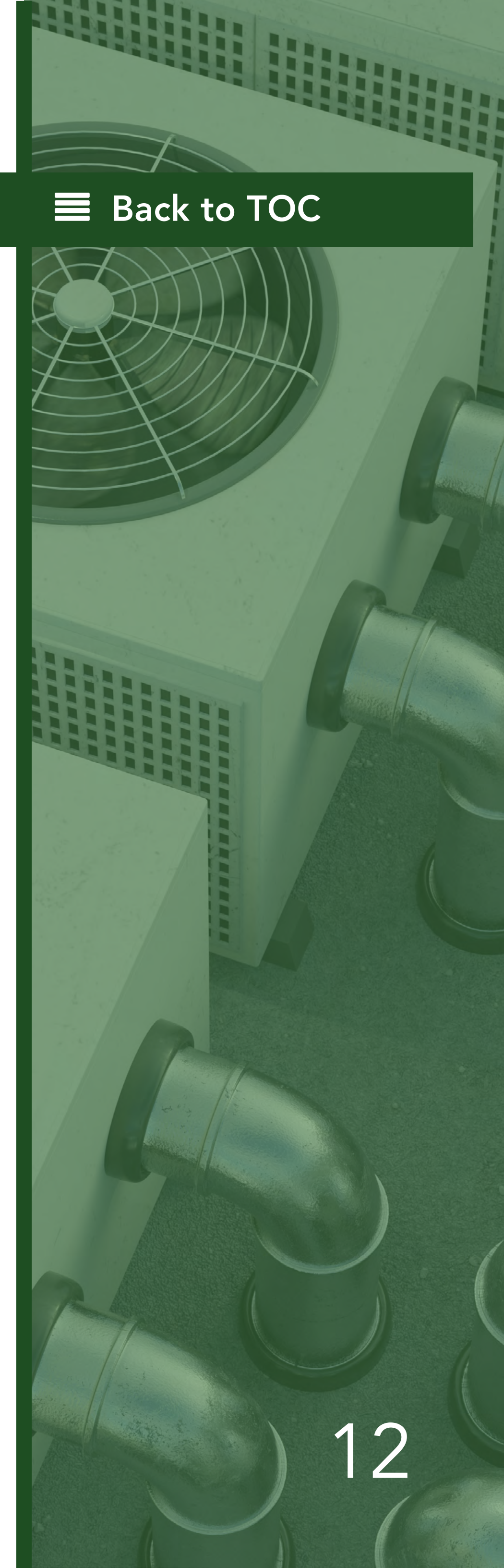
if energy recovery requirements are met. The requirement depends on which code or standard is used, and which year version is enforced. To minimize complications, the engineer is advised to check the DCV code section that applies to the project early in the design process.

Manufacturer provided versus designed controls

Packaged equipment manufacturers provide almost all components necessary for the operation of a DOAS, but there are a few others the engineer may want to consider.

Outside air measuring stations: DOAS units do not necessarily include an outdoor air measuring station. Information from the station can be valuable in trouble shooting, and can be used to vary the supply speed based on filter loading so that the airflow rate through the unit remains constant. The outside air measurement provides one of the most crucial pieces of information available for why a DOAS was chosen in the first place. You can't control what you don't measure, so the outside air measurement should be considered for each DOAS. There are multiple ways to accomplish reading the airflow values, including piezo rings and thermal dispersion instru-

Figure 6: This 11-ton, roof-mounted, packaged dedicated outdoor air system is a heat pump that uses a separate variable refrigerant flow system to heat and cool individual spaces. Courtesy: Smith Seckman Reid Inc.



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ments. For similar reasons, exhaust airflow measurement is desired and the engineer can choose what might be the best method for their project.

Condensate overflow sensors: While these are not required for most applications, many DOAS units are roof mounted and ducted through to the spaces below. Eventually, condensate drains get clogged and need to be cleaned out. Even though the condensate is at the roof level and may not pose an immediate nuisance threat to occupants below, chances are high that the overflow will get into the duct and leak into the ceiling space. An overflow alarm sensor prevents this from becoming a problem. It can de-activate the unit and keep it from becoming a larger issue. The building automation system (BAS) or local alarm should be signaled. The DOAS is the main way ventilation air is supplied, so its continued operation is crucial to the indoor air quality.

Filter gauges: These should be provided, and control alarms signaled, when the filter pressure drop indicates it requires changing. It is not uncommon for the filters to need changing more often than most facility operators may be expecting. DOAS, with 100% outside air, have the capability of introducing much more air particulates than other air systems, making monthly filter changes common. The particulate quantity depends on the local environment and what might be circulating in the air at the project site. There are many variables, so a good filter alarm is crucial. It is also best practice to filter the exhaust before it flows through the enthalpy wheel, and place a filter gauge and alarm there as well.

With packaged DOAS equipment, most temperature and humidity sensor status indicators are included. The usual monitoring points include:

- Temperature points include exhaust, outside air, mixed air (outside air downstream of enthalpy wheel), cooling coil leaving air, hot gas reheat leaving air and supply air to spaces.

- Humidity points include exhaust before the enthalpy wheel (or space humidity), outside air and supply air to spaces.

- Other status points: supply fan on/off status and speed, exhaust fan on/off status and speed, enthalpy wheel on/off status, filter differential pressures, supply and exhaust airflows and heating percentage.

- Any sensors not provided by the DOAS manufacturer can be added to the BAS as separate control points.

Package units usually come programmed for five modes of operation.

- **Cooling:** In cooling mode, supply air temperature set point can be 60 F and the compressors modulate to maintain the supply air setpoint.

- **Heating:** In heating mode, the supply air setpoint can be 68 F, or 2 degrees lower than the space temperature, and the heat input is modulated to maintain the supply air setpoint.

- **Vent:** Vent mode is when neither cooling nor heating is required. The enthalpy wheel can be turned off or bypassed.

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- **Dehumidification:** Dehumidification is a special case of the cooling mode, and is initiated when the exhaust or space humidity level reaches a setpoint of 60% relative humidity. The compressors only modulate to maintain a low suction temperature and the hot gas reheat is modulated to maintain the supply air temperature.

- **Off:** Off is for when no ventilation air is required or unoccupied periods.

It is best practice to use the packaged unit manufacturer's programmed algorithms for these functions and only monitor the sensors and devices mentioned above. Actual control points for user input are usually unit start/stop, supply air temperature setpoint, cooling season setpoint and heating season setpoint. This keeps the controls simple for operating personnel.

Daniel Rucker
R. Daniel Rucker, PE, *Smith Seckman Reid Inc., Nashville, Tenn.*

How Low-mass Boiler Systems Best Meet Efficiency, Environmental Requirements of Today's Facilities

Nery Hernandez
Sr. Product Manager
Hydronic Solutions

Introduction

For decades, there was one boiler design for commercial heating systems – high-mass. There is a growing trend, however, towards utilizing low-mass boilers because they provide multiple benefits. A low-mass heating system occupies a smaller footprint, better addresses environmental initiatives and regulations, and generally lowers operational costs, making it a wise alternative for modern facilities.

Not all low-mass boiler systems are created equal, however. To truly optimize system design and operation, and reap the maximum benefits associated with a low-mass system, engineers and facility owners need to thoroughly evaluate how they operate and what equipment is best suited for specific designs.

What Are High-mass and Low-mass Systems?

There is no ASME classification that specifically defines high-mass or low-mass boilers. They have become common industry terms used by engineers, contractors, and manufacturers to classify boiler types. Typically, non-condensing units with cast-iron or scotch marine designs are considered high-mass systems. Low-mass systems are usually condensing units built with either stainless steel (figure

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1) or aluminum heat exchangers or non-condensing units with a copper construction.

A traditional high-mass system utilizes older technology, which can lead to less efficient performance. The boilers typically have basic controls and greater water volume content, which prevents the unit from short cycling. In some environments, the extra water serves to protect the heat exchanger. By contrast, low-mass boilers require much less water, resulting in a significantly smaller footprint. Typically, they address short cycling considerations using advanced technology and controls, most notably modulation and data analytics.

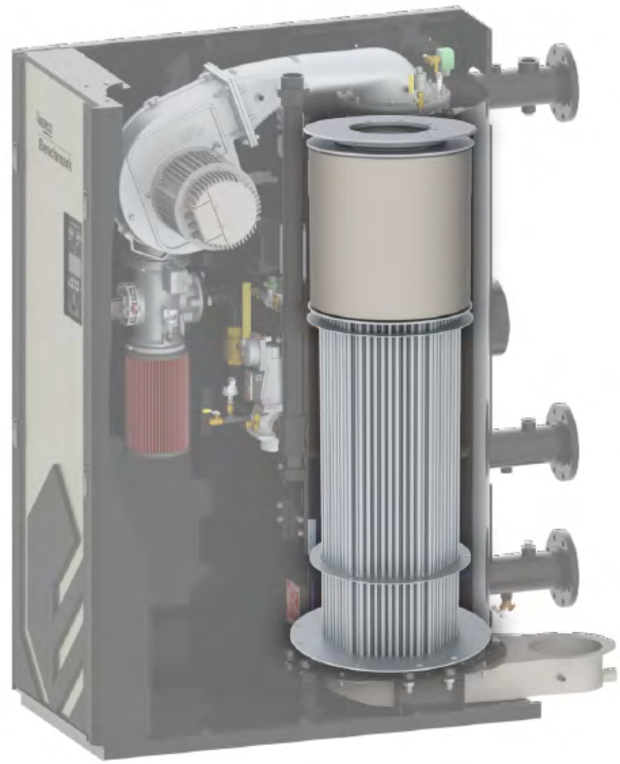

Figure 1: Stainless steel heat exchangers are used in low-mass boilers.

Determining 'True' System Costs

There has been a belief in the market that equipment costs are commonly less expensive for a high-mass heating system. That is really a misconception, as there are ancillary costs that can often make high-mass systems more expensive. For example, cranes and additional building frame support may be necessary with larger, heavier high-mass systems. Actual installation costs may ultimately be higher due to these factors.

Further, engineers and facility owners need to look beyond the initial price tag and

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conduct a thorough side-by-side comparison between a high-mass and low-mass system. Taking this more in-depth analysis will reveal that the latter design provides lifetime savings and a greater return on investment (ROI).

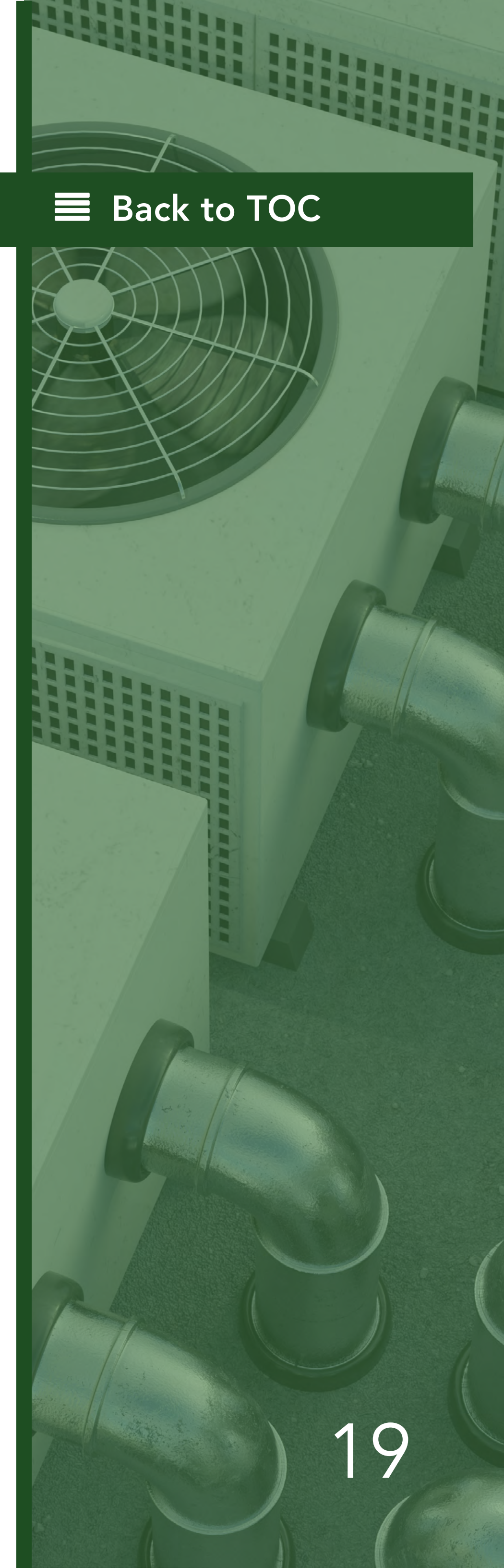
Evaluating Overall Installation Costs

Because high-mass boilers require more water, they are usually larger and weigh more. Therefore, if the system is designed on a higher floor, reinforcement framing must be made, adding construction costs.

Bigger, heavier equipment increases costs in other ways. Rigging crews and equipment, such as wire ropes, jacks, bolts, and turnbuckles used with cranes and other hoisting systems, are often required when installing high-mass systems. Economics isn't the only associated factor. Installations requiring rigging are more complex and come with safety risks.

Figure 2: The Benchmark® Platinum is an example of a modulating boiler.

Low-mass equipment typically does not come with those additional concerns, as it has a much smaller footprint compared to their high-mass counterparts. In fact, most low-mass boilers can fit through a standard door and in a freight elevator and are easier to manage around tight corners. These factors make installation much more efficient in terms of time and cost. There are exceptions to this rule, of course. For example, some old buildings often found in major cities have staircases,



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elevators, and doorways that may be too narrow to accommodate low-mass equipment. In those – and similar cases – low mass systems may be disassembled so the equipment can be installed.

Optimizing Building Real Estate

Given the substantial investment in commercial real estate development, maximizing each square foot is a premium consideration. As noted above, high-mass systems require more water to operate, making them heavier than their low-mass counterparts. A gallon of water adds an estimated eight pounds to the system weight.

If you have a 5,000 MBTU high-mass system, the total weight can be between 10,000-12,000 pounds. Roof installation may be more expensive, as reinforcement beams will have to be added. This makes the option impractical, and usually limits the location of the mechanical room to the basement or ground floor. The lower weight of a low-mass system provides building designers with more options to choose the optimal location for the mechanical room.

The greater water volume also results in a larger boiler size. A low-mass system occupies a smaller footprint (figure 2). In certain instances, a low-mass boiler can be half the size of a high-mass unit with an equivalent BTU. This means that more space is available for revenue-generating operations. For example, additional rooms can be added to a hospital, hotel, or apartment complex.

Lowering Operational Costs

Turndown and operating efficiency are key specifications and critical elements as to why low-mass systems have smaller on-going costs. While turndown helps improve

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efficiency, it is not the only reason low-mass boilers have lower lifetime system costs.

Turndown is the ratio between the highest and lowest fire rates of the boiler, and it helps make system operation more efficient. For example, many high-mass boilers will have a maximum turndown of 10:1. That translates to the boiler operating at 10% of its full capacity when firing at its lowest rate. Compare this to a low-mass boiler with a 20:1 turndown, which operates at 5% of full capacity at the lowest firing rate. Therefore, it is more efficient when operating at lower firing rates.

Utilizing modulation technology and advanced controls optimize turndown to achieve improved system operation. Modulating low-mass boilers with advanced controls and high turndown can operate between 0.5-2.0% more efficiently than high-mass systems. Given these parameters, an ROI can be realized as quickly as three years in certain scenarios due to the higher efficiency, making a low-mass system a sounder financial investment.

High-mass boilers are also more susceptible to heat loss, which leads to higher utility bills. Due to the lower shell surface area and smaller water volume to be heated, a low-mass system has less radiant losses for more efficient operation.

Importance of Modulation

A technology common in certain low-mass boilers is modulation. Working hand-in-hand with turndown, modulation technology is the ability to adjust a boiler's firing rate to precisely meet system heating demand. For example, a 2,000 MBH capacity modu-

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lating boiler (figure 3) can run with as little as 100,000 BTU/hr., or 5%, input. In a multi-unit system (which are in most commercial buildings), each boiler gradually increases in precise 1% increments up to 100% capacity to meet actual load requirements.

When modulating units operate at "part load," less fuel is burned and heat transfer is enhanced. Constant operation maintains temperatures within the heat exchanger, yet the reduced input increases the time the combustion gases are in contact with the heat exchanger surface. Greater energy transfer and cooler exhaust gases are achieved to create an inverse efficiency curve, as the boiler performs best at lowest loads (figure 4).

Figure 3: The Benchmark® Platinum is an example of a modulating boiler.

Another factor that aids heat transfer is materials of construction. High performing, low-mass boilers use 439 stainless steel, which is a superior material than traditional 316 stainless steel used by most boilers. The result is 439 stainless steel can transfer 30% more heat, allowing a smaller heat exchanger to be used. So, 439 stainless steel does more than increase efficiency, it helps reduce boiler footprint.

Some older boiler designs do not utilize modulation while other legacy boilers have very low modulation rates of 5:1 or less. As a result, they are either on or off. This creates cycling losses each time the unit shuts down because the heat exchanger cools and must be fully "reheated" before heat transfer can begin. An additional problem is that the hiring firing rate may be far more than what is required to meet the building's load, creating inefficien-

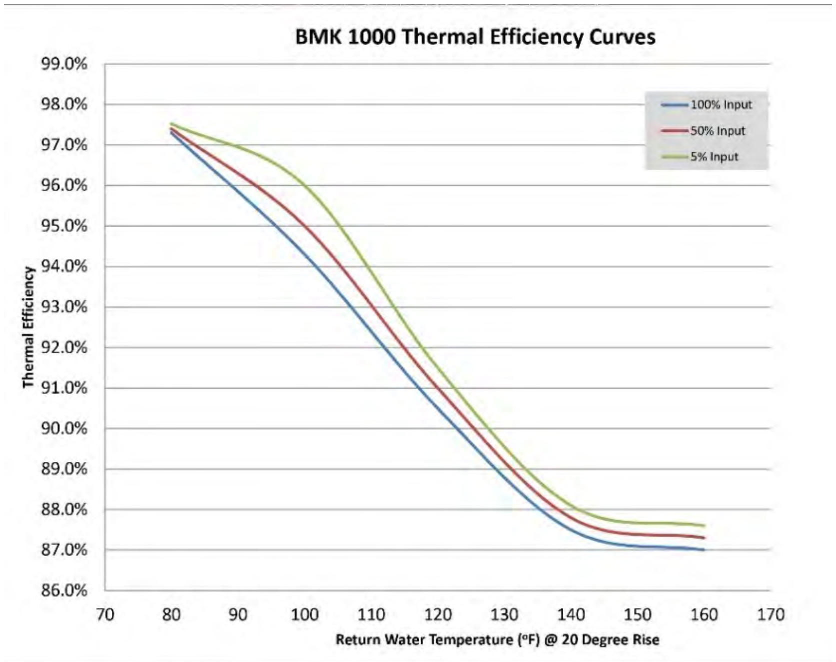

Figure 4: The chart shows how a modulating boiler performs best at lower loads.

cies and wasting energy.

Modulation technology is particularly beneficial during the shoulder months, which account for 80% of the heating season. Engineers design heating plants based on the maximum capacity to fully heat a building on the coldest day or night. Typically, only a few winter days come close to the "design conditions." Non-modulating boilers fire non-stop at high capacity during warmer days during the spring and fall, even though far less demand is necessary to maintain building heat.

Boilers with a modulating design increase efficiency under part-load conditions. Greater overall savings are possible compared to conventional equipment whose performance is maximized only at full fire and whose efficiency suffers from cycling losses in part-load conditions.

Right-sizing your Boiler Plant

Based on well-established parameters used to properly size the boiler plant to prevent excessive cycling, low-mass units are often the better choice. This is due to their higher

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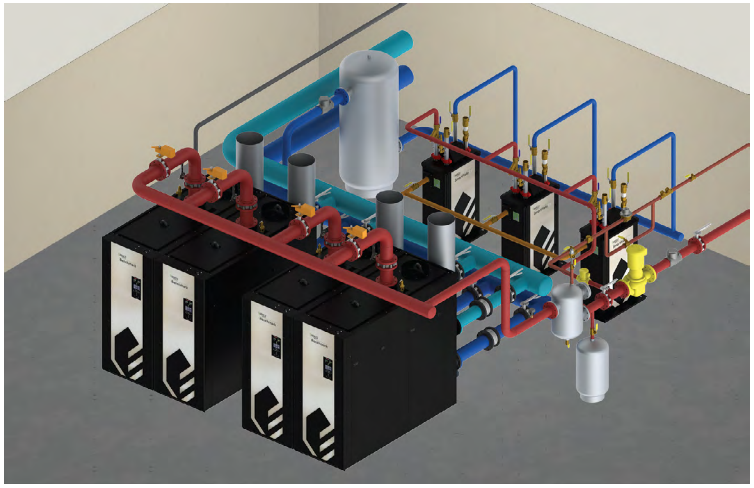
efficiency and smaller footprint, so the necessary number of boilers can be designed without wasting space.



There are a range of key factors to consider when designing a boiler plant. The physical layout of the plant must fit in the space allotted yet provide sufficient room for maintenance technicians to effectively do their work. The piping, controls, and support equipment should be focused around efficient operation for reduced fuel and maintenance costs. It is critical to correctly size all equipment to prevent excessive cycling for a long operational lifespan.

The following equation is typically used to determine the minimum system volume in a heating plant:

$$\text{Min. Volume [gal]} = \frac{\text{Min. Cycle Time [mins]} * (\text{Min. Boiler Input [MBH]} - \text{Min. System Load [MBH]})}{\text{Temperature Rise [°F]} * 500}$$

The other factor to consider is how many boilers will be needed to meet load demands. An ideal boiler plant will have a minimum of two units for the heating load, and a third for N+1 redundancy. To reduce the size of the "redundant" boiler, a 3+1 or 4+1 plant can also be installed.

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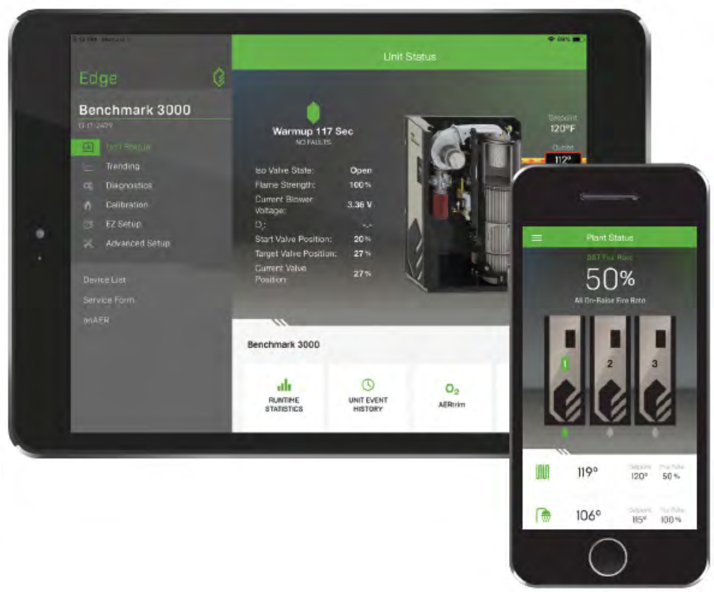
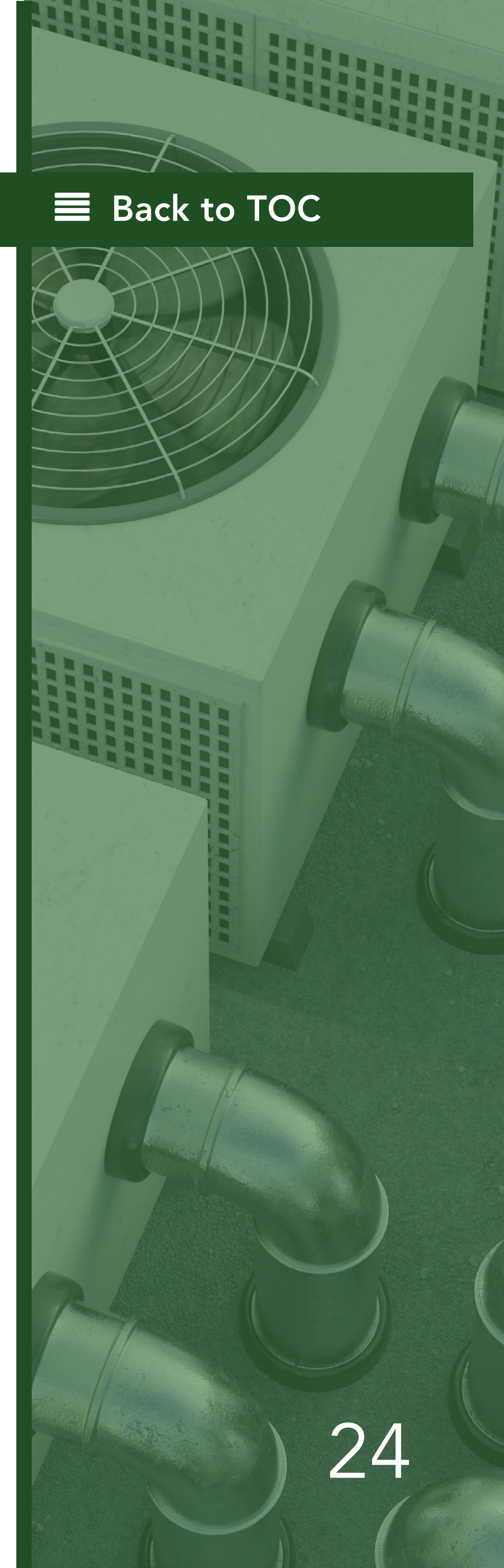
Benefits of Intelligent Controls

Many low-mass boilers incorporate advanced analytics and technology to complement the inherent performance benefits of the design. For example, intelligent controls are available on some low-mass units, allowing them to communicate with related equipment. Advanced controls optimize the overall system and increase efficiency to lower operating and maintenance costs.



Certain controls have predictive maintenance tools that open access to real-time system performance for 24/7/365 monitoring. The most effective tools add a level of intelligence in that they do more than merely address faults after the fact – they predict when to perform maintenance to prevent them. Engineers and facility managers can see exact unit and plant efficiency, how many cycles per hour are occurring, O2 levels, and more with the proper controls.



Users can pro-actively review data and trends to ensure units are operating optimally. Instant alerts are received if a boiler is down and those that need maintenance or repair. Possible causes and suggested actions are also conveyed through certain controls. Facility managers can use these features to help maintain optimum efficiency of a low-mass system.

Conclusion

The trend in boiler system designs is to optimize operating efficiency to control costs, offer enhanced "green" features to reduce carbon footprint, and reduce the size of the mechanical room. A low-mass boiler system best addresses these essential factors and is the optimal choice for new facilities and retrofit projects.

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Important things to know when designing and applying AWHP

Air-to-water heat pumps offer a straightforward solution for heating, electrification and facility decarbonization; however, their selection and application require expertise to specific and unique criteria

Various technologies are available to provide heating in facilities without using on-site fossil fuels, which can help meet the decarbonization agenda. Air-to-water heat pumps (AWHPs) are an approach growing in popularity and this technology does not have the limitations associated with other nonfossil fuel burning technologies such as solar, geothermal or electric heating.

Coefficient of performance (COP) for AWHPs exceed the 1.0 COP associated with electric heating. AWHPs do not have the associated cost and land area needed for geothermal bore fields and unlike solar heating, AWHPs may not need backup heating equipment.

However, owners of facilities with AWHPs commonly experience startup and operational issues due to misapplication of equipment. While AWHPs have been increasingly used in Europe over the past decade, the technology being applied in North America is a new practice leading to misinformation and limited application knowledge.

Proper application of AWHPs starts with the expected building load. Figure 1 shows a typical building load profile where the blue line represents the cooling load over the course of a year and the red line represents the heating load over the same period. Once the load profile has been determined, equipment can be selected that meets the peak heating and cooling load. Oversizing the equipment is not recommended.

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The next step in the design process is when AWHP operating modes should be considered. In addition to providing heat for a building, AWHPs can also provide cooling. There are two distinctly different technologies available to achieve this. Sometimes referred to as a simultaneous or multipurpose unit, these AWHPs can provide cooling, heating or both cooling and heating simultaneously.

Alternatively, a more simplistic unit is available that can produce either heating or cooling, but not both at the same time. It is important to evaluate the building load profiles to determine how many units should be simultaneous versus a more traditional AWHP for the equipment to operate effectively and efficiently while also being cost conscious at the time of installation.

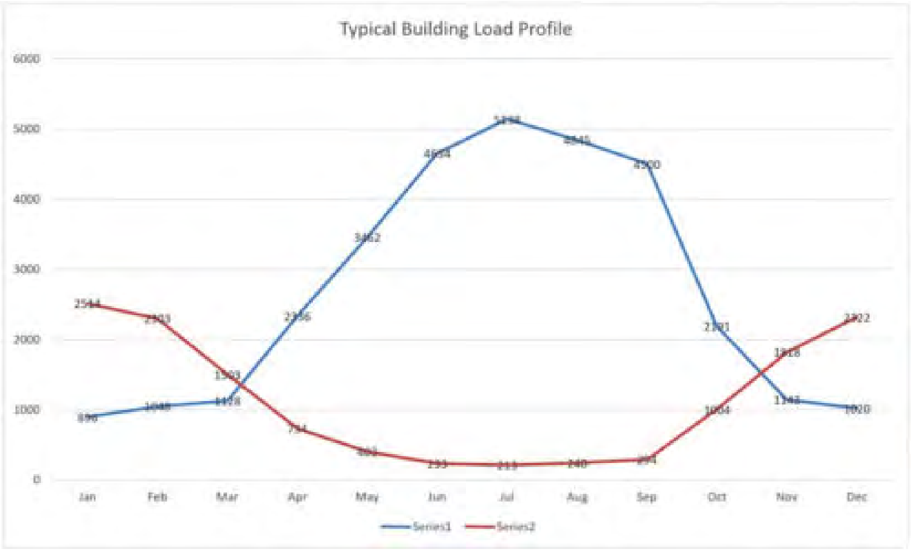

Figure 1: In this sample building load profile, the blue line represents cooling load, and the red line represents heating load. Courtesy: Metropolitan Equipment Group

AWHPs are available as a packaged type and a modular type. From an output perspective, packaged and modular type AWHPs can be used interchangeably (i.e., a packaged type could be installed in place of a modular type and vice versa), however building constraints will have an impact on which type of AWHP is best suited for the application.

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AWHP building constraints

If the AWHP will be installed in an existing building, a review of the building's structural capacity is necessary. A structural engineer should identify the load-bearing capacity of the building's structural system. This load bearing knowledge may limit the equipment selection to a specific AWHP type or indicate that reinforcement of the existing structure is required if either AWHP types are to be considered.

Physical space availability also impacts AWHP selection. AWHPs resemble air-cooled chillers in their basic configuration, however, an AWHP has a larger footprint for a given capacity than a comparably sized air-cooled chiller.

Airflow restrictions are another similarity between AWHPs and air-cooled chillers. Each AWHP manufacturer has minimum distance requirements between the perimeter of their AWHP and surrounding building elements as well as minimum distance requirements between the perimeters of adjacent AWHPs. Installing an AWHP in a "pit" where it is surrounded on all four sides by building elements brings additional minimum distance requirements into consideration. If an AWHP is installed in a pit setting, most AWHP manufacturers will recommend installing the top of the equipment at the same elevation as the top of the surrounding building elements. During equipment evaluation and selection, clearances should be requested from the manufacturers.

Although AWHPs can be installed within a building, for the purposes of this article, we are focusing on AWHPs being provided as standalone, outside of the building envelope. It should be noted that within the UK and Europe, AWHP are typically located and installed within central utility plants..

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A packaged AWHP provides a single large machine capable of a greater heating and cooling output when compared to the modular machine. Packaged machines typically have smaller footprints than modular types providing the same capacity, providing a benefit for overall space consumption and weight distribution. Packaged types also come with fewer components which impacts reliability and regular maintenance.

For example, a typical packaged AWHP might only have a maximum of four compressors where an equivalent modular type could have as many as 16 compressors.

Projects with tight space constraints such as retrofit or a project with limited rooftop or surface areas are good candidates for modular type AWHPs due to their flexibility for design. Modular AWHPs are provided in incremental sizes as low as 25 tons and up to 80 tons. The ability to take a 150-ton building load and split it up among six AWHPs provides the flexibility to space out the modules across multiple locations, versus having to be stacked together on the roof and occupying a large single footprint.

If a split approach is applied to modular machines, additional connections will be required. Each of the individual module typically has two compressors, so in this example, there would be 12 compressors to maintain for the 150-ton machine versus the single large, packaged machine requiring only four compressors. End users and designers must consider the positive and negative aspects of a packaged approach versus a modular approach when preparing to design an AWHP project.

Building load profile when AWHP is specified

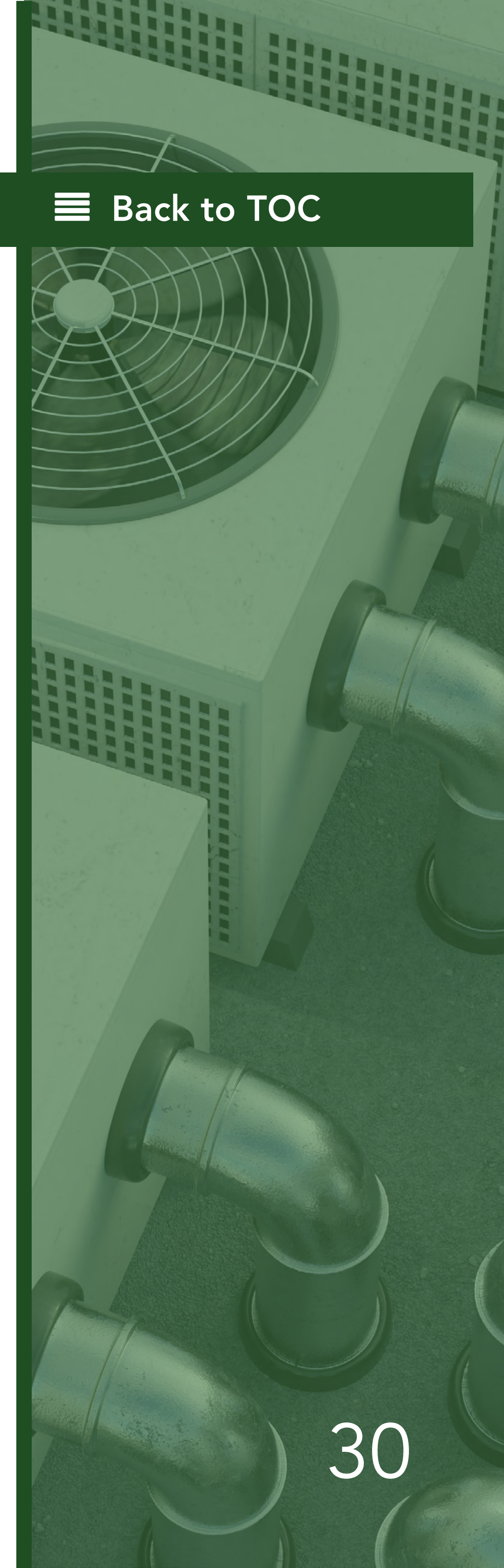
Upon selection of an AWHP approach for a building's heating and cooling demand the next critical step is identifying the building load profile (see Figure 1). If the load profile indicates a simultaneous heating and cooling load all year, it is typically beneficial to use a simultaneous heating and cooling AWHP that allows for production of chilled and heating water and doesn't require switch over from heating mode to cooling mode.

In this approach, the simultaneous heating and cooling AWHP would be paired with supplemental reversing AWHPs that can handle the additional heating load in winter and the additional cooling load in the summer. If the building load profile indicates minimal simultaneous heating and cooling throughout the year, an AWHP that can reverse from cooling mode to heating mode depending on the time of year and the demand should be selected.

A simultaneous heating and cooling AWHP should be selected so that the machine is always running close to 100% of its maximum capacity for both heating and cooling. The optimal operating point of the simultaneous heating and cooling AWHP is a balanced load at maximum capacity.

However, a balanced load is typically not achievable year-round and therefore the simultaneous AWHP should be selected close to the simultaneous heating and cooling demand that the building has throughout the year. Avoid using simultaneous heating and cooling AWHPs for heating only or cooling only applications Instead, use a reversing AWHP that either provides heating only or cooling only.

Simultaneous AWHPs typically need to be supplemented with reversing AWHPs to efficiently meet the building load. Select the simultaneous AWHP(s) to accommodate the shoulder season heating and cooling simultaneous demand. The heating and cooling



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differential between shoulder season and peak heating and cooling loads will be covered by the reversing supplemental AWHPs. Simultaneous heating and cooling AWHPs are capable of handling unbalanced heating and cooling loads unlike heat recovery chillers (HRCs).

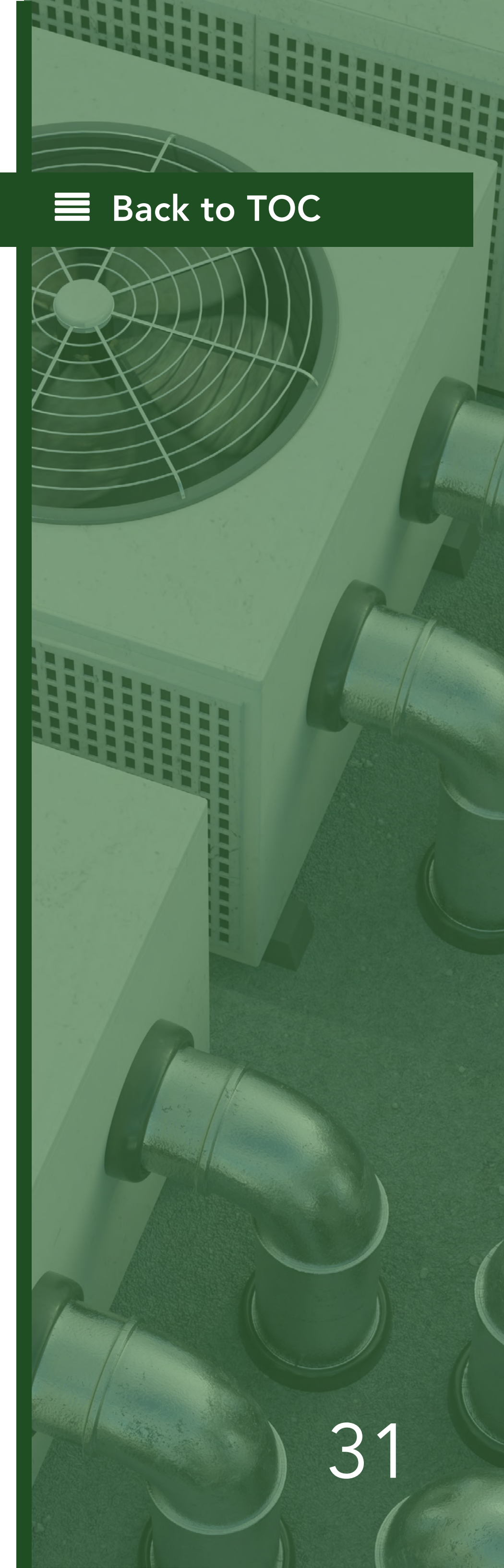
For example, if a building's load demand is only 80% of heating maximum and 40% of cooling maximum, a simultaneous AWHP will be able to provide the building with the high demand for heating and still be able to provide the decreased cooling demand. HRCs only provide their maximum heating capacity while the machine is providing the maximum cooling capacity. As the cooling demand drops so does the heating capacity of an HRC.

Regulatory, operating and design limitations of AWHPs

Jurisdictions throughout the United States are adopting regulatory requirements that may dictate the application of AWHPs. For example, since 2022, the Washington State Energy Code requires a percentage of water be heated using heat pumps. An early step in the design of AWHPs is researching the codes in the jurisdiction of the project.

Once the relevant equipment has been selected for a project, the next step is to examine the operating limitations and design capabilities of the AWHPs along with the intended project design conditions. Consultation with AWHP manufacturers typically starts at this point in the design process.

One of the most critical items when designing an AWHP system is the ambient air temperature due to its importance when the AWHPs are in heating mode. The ambient air temperature will dictate the leaving heating water temperature the AWHP will gen-



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erate. As the ambient air temperature decreased, there is an operating point where the leaving heating water temperature starts to decrease (see Figure 2).

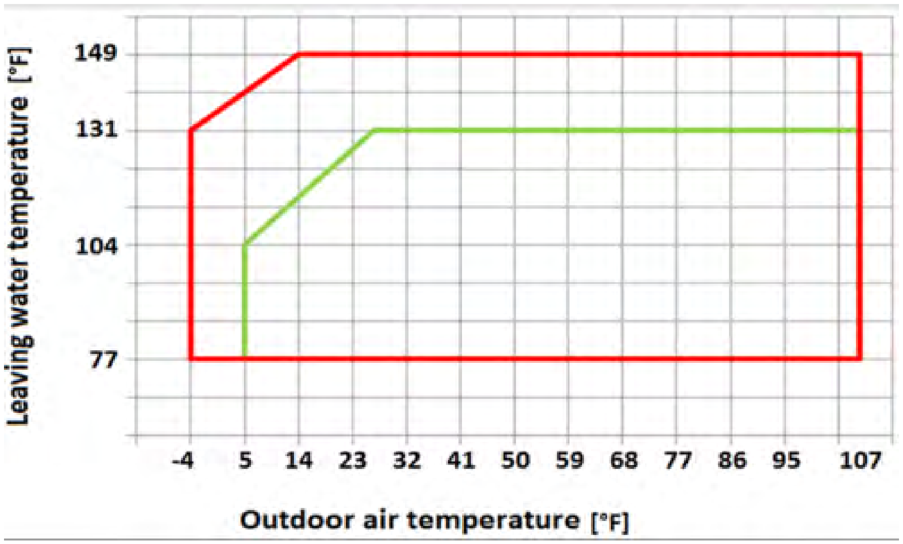

Figure 2: This shows sample ambient temperature versus leaving heating water temperature. The green line represents a standard scroll compressor's operating envelope and the red line represents a vapor injection scroll compressor's operating envelope. Courtesy: Metropolitan Equipment Group

If the ambient air temperature drops below the AWHPs minimum operating point, the AWHP will no longer operate reliably requiring backup heating.

Heating water system temperatures associated with AWHPs differ from typical design practice. In the past many projects used boilers capable of generating heating water from 160° to 180°F. Heating water temperatures of 160° to 180°F will not be possible with the AWHPs currently on the market. A leaving heating water temperature for AWHPs is recommended from 90° to 120°F as good practice.

Another important consideration is the difference between the supply and return water temperatures known as the temperature differential (delta T). Boilers can use a 20° to 30°F delta T. AWHPs either have difficulty or are not capable of handling a 20° to 30°F delta T. A good practice is to design for AWHPs is to have a primary pumping loop

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delta T of between 10° to 15°F paired with a secondary building side pumping loop that operates at a higher delta T.

The points presented above are for AWHPs using standard scroll compressors. However, there are AWHPs available that use vapor injection scroll compressors. Vapor injection compressor machines can provide additional lift to either provide a warmer heating water leaving temperature up to 160°F or provide the standard AWHP leaving water temperature at much lower ambient temperatures down to as low as -0°F ambient. It’s important to consult the AWHP manufacturer on the ambient operating limits. Scroll compressor machines and vapor injection compressor machines are not interchangeable as the system design required is different for each technology.

AWHP selection

After the project criteria and design conditions have been identified the AWHP selection begins. There are a few critical items that must be understood and evaluated before finalizing the equipment selection. AWHPs require a minimum and a maximum system water volume to operate properly, particularly the primary pumping loop system volume.

A good pumping arrangement for AWHPs is to incorporate a constant volume primary loop paired with a variable secondary loop. There are exceptions to a primary/secondary pumping layout where AWHP manufacturers are recommending variable pumping primary loops. This should be reviewed and understood before selection of the machines and consultation with the AWHP manufacturer it is recommended.

System water volume is the most important requirement that an AWHP system needs to operate properly. Failure to meet the active system water volume requirements will result

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in the AWHP machine being unable to provide the proper design leaving water temperatures and could result in premature failure of the machine's components. Depending on the manufacturer and the type of AWHP used, the gallons per ton (gal/ton) will vary.

However, a basic rule of thumb is to provide a minimum of 6 gal/ton for reversing AWHPs and 10 gal/ton for simultaneous heating and cooling AWHPs. The recommended gallons per ton, which represents the total system volume, should not be confused with the system flow, which is represented in gallons per minute, or gpm.

The system volume given in gallons per ton that is required for the AWHP machine is for "active" system volume only. Active system volume is the water that is always readily available to the AWHP system regardless of the load condition on the building. Consult with the AWHP manufacturer to ensure that the active system water volume is sufficient for the application.

AWHPs located outside in colder climate zones can potentially require a glycol solution to offer freeze protection. As with other system types, adding glycol to the system causes less heat transfer to occur in the system and, therefore, there is a sacrifice in overall system performance referred to as "glycol performance penalty." Providing the AWHP manufacturer with the required glycol percentage is critical to being able to account for the glycol performance penalty.

When using glycol in an AWHP system it is good practice to make the primary pumping loop the glycol side and use a heat exchanger to separate the primary side from the secondary side, keeping the glycol from circulating through the entire building. Using the heat exchanger prevents derating any indoor equipment's capacity. AWHP manufacturers may also offer an option for heat tracing and an electric heater for freeze protection. This is an option that should only be considered if the project is in a milder climate and or the project cannot use glycol.

Defrost in AWHPs

When an AWHP is in heating mode, the coils can begin to ice up. To remove this ice buildup, it is necessary to reverse the machine into defrost mode. When using AWHPs for heating, it is very important to look at the defrost cycle along with the defrost penalty for capacity that all AWHPs have between 25° and 40°F ambient air temperature.

In defrost mode, hot refrigerant will pass through the coils to heat them and melt the ice. Reversing the AWHP introduces neutral to cool water into the heating loop, which diminishes the leaving heating water temperature. The active system volume becomes critical because having the proper amount of system volume will lessen the impact of this cooling effect on the overall system.

Without enough active system volume, having an AWHP go into defrost mode could result in a runaway heating water loop. A runaway heating water loop occurs when the leaving water temperature is decreased and as a result the returning water temperature is much lower than design. This cycle continues until the machine leaves defrost mode at which point the return water temperature is too low and the AWHP cannot provide enough lift or heat to get back to the required leaving water temperature.

It should also be understood that in North America, it is not required for AWHP manufacturers to provide their machine's heating performance with a defrost penalty. There will be derated heating performance of an AWHP while it is heating in defrost mode.

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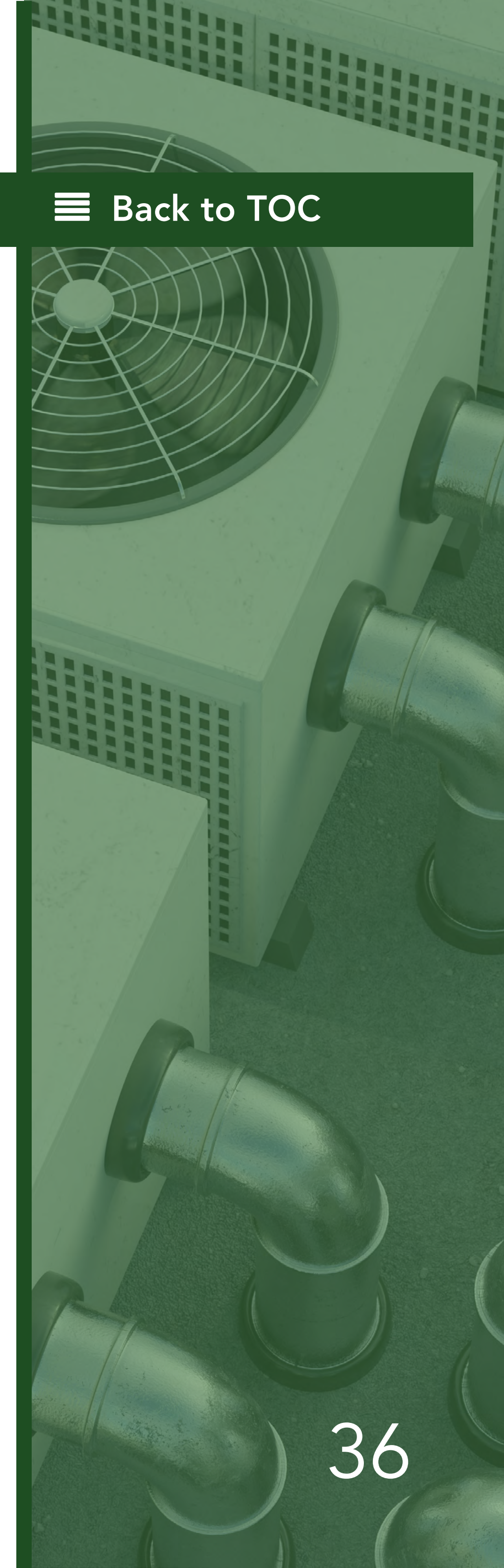

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The AWHP manufacturer should provide the heating performance with the defrost penalty included otherwise there is a risk of having a machine short on heating capacity and undersized by up to 33%.

European manufacturers are required to include the defrost penalty in their reported performance. It is best practice to request defrost penalty information from AWHP manufacturers during the design process.

Ongoing AWHP operations

AWHP systems should include the ability to monitor return water temperatures to verify that the system is functioning properly. The return water temperature sensor is a remote device that is not manufacturer provided. When finalizing AWHP selections, it is a good practice to explore the additional accessories that can be provided by the manufacturer.

- Request that the AWHP manufacturer provide its machines with integral constant volume primary pumps. Most manufacturers can provide integral pumps including a redundant pump for N+1 redundancy.

- Explore the option for an integral buffer tank. Otherwise, the designer will either need to provide an external buffer tank or enlarge system piping to provide the minimum system volume.

- Designers should consider the AWHP manufacturers' integral control panel when using multiple AWHPs. These multimachine control panels can operate all the AWHPs evenly and at their most efficient operating point when compared to controlling the AWHPs with a building automation system.

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As an alternative to the manufacturer-provided accessories listed above, some of the components can be provided by the installing contractor and field installed in the hydronic distribution system. For example, a four-port buffer tank can be used to mechanically separate the primary and secondary pipe systems. With this approach, the four-port buffer tank can be provided with the ability to install the return water temperature sensor in a factory provided opening rather than in a field installed opening located in the return piping.

When retrofitting AWHPs in existing systems, the original operating parameters need to be considered. If the system was originally designed with coils using 180°F supply heating water and 50°F return heating water, the coils in the entire heating water system may require replacement. Alternatively, measures to raise the supply heating water temperature may be implemented.

In conclusion, AWHPs are an easy solution to provide heating, which helps decarbonize a facility if the above measures are observed and incorporated into the design of system. However, application of AWHPs requires a rethink of previous system parameters. When using AWHPs, they system can heat with lower heating water temperatures and cool with higher chilled water temperatures than the industry has used in the past.

Mark Ridenour, PE, and Andrew Peck

Mark Ridenour, PE, *is Mechanical Engineering Principal at HDR Inc.* ***Andrew Peck*** *is Senior Sales Engineer and the Vice President of Engineering at Metropolitan Equipment Group.*

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Enhancing High Efficiency HVAC Systems with Cottonwood Filter Screens: A Comprehensive Approach for Design / Build Engineers

Randy Simmons
President
Air Solution Company

In the rapidly evolving landscape of HVAC systems, the transition towards high-efficiency mechanical systems continues to gain momentum. These systems, designed to provide superior energy savings and environmental benefits, are equipped with advanced refrigerants and features such as micro-channel condenser coils. While these components are pivotal for increasing efficiency, they also introduce vulnerabilities in terms of maintenance and longevity. This article advocates for the integration of cottonwood filter screens into high-efficiency HVAC systems, highlighting their significant advantages in protecting and enhancing system performance.

Addressing the Vulnerability of Micro-Channel Condenser Coils

Micro-channel condenser coils are a hallmark of high-efficiency HVAC systems. These coils are more susceptible to fouling because of their compact and delicate nature. When these coils become fouled—clogged with dirt, debris, and other airborne parti-

cles—the system's efficiency plummets. This not only undermines the energy savings promised by manufacturers but also leads to increased operational costs and reduced equipment life expectancy. The interval between maintenance cycles often results in the equipment operating under compromised conditions for extended periods because they tend to foul out sooner between maintenance cycles vs. Std. efficiency systems.

The Protective Role of Cottonwood Filter Screens

Cottonwood filter screens provide a simple yet effective solution to this problem. By installing these screens, engineers can prevent the fouling of micro-channel coils from the outset. These screens are designed to trap airborne debris at the point of entry, ensuring that the delicate coils are shielded from particles that could clog or damage them. This external layer of protection is crucial, given the fragile nature of micro-channel coils, which are easily damaged during cleaning processes. Traditional cleaning methods can be too harsh on these coils, leading to further maintenance issues and potential system failures.

Extending the Life of Internal Filtration Systems

Beyond protecting the condenser coils, cottonwood filter screens have a cascading positive effect on the entire HVAC system, particularly the internal air filtration units. By stopping larger particles at the entry point, these screens ensure that only finer particles reach the internal filters, such as pleated models. This significantly reduces the burden on these filters, prolonging their service life by up to 60%. The reduced frequency of filter replacements not only lowers the cost of ongoing filtration but also contributes to environmental conservation by reducing waste.

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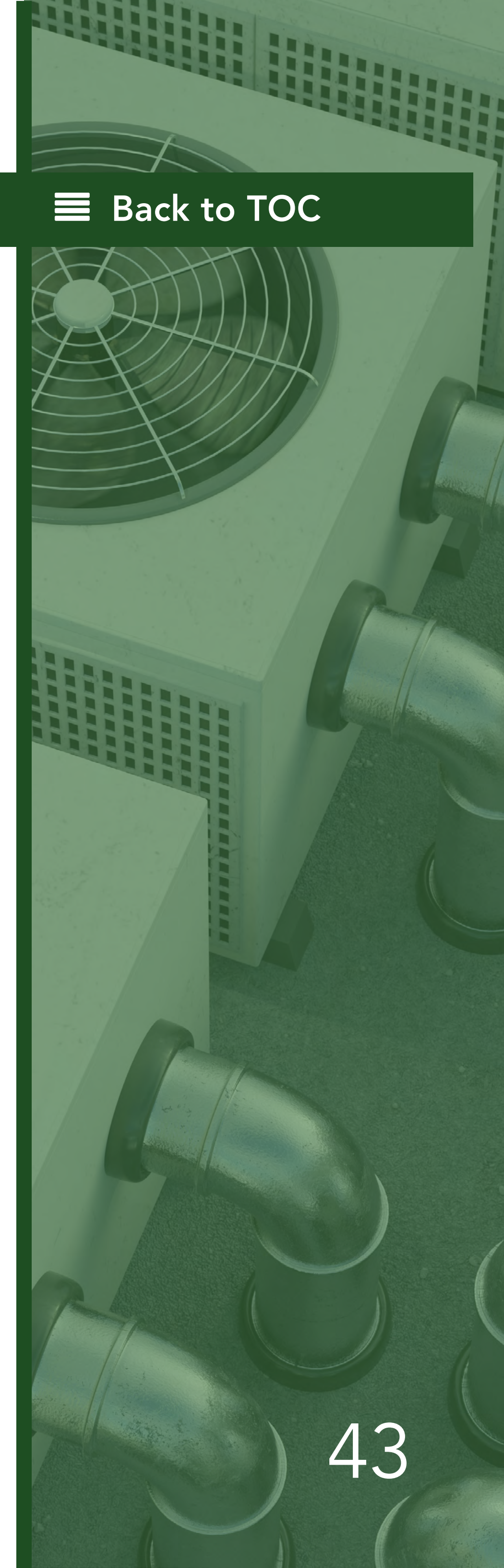
Improving Indoor Air Quality (IAQ)

Perhaps the most significant impact of integrating cottonwood filter screens is the improvement in indoor air quality (IAQ). By filtering out a substantial number of airborne debris before it can enter the building envelope, these screens ensure that the internal filters are more effective in capturing the remaining particulates. This results in cleaner, healthier air within the indoor environment, which is crucial for buildings frequented by individuals with allergies or respiratory issues.

The Critical Role of Cottonwood Filter Screens in Cooling Towers

Cooling towers are fundamental components of process and environmental cooling systems, facilitating heat rejection through the evaporation process. The key to their efficiency lies in the Fill-Pack, which enables efficient heat transfer by maximizing water and air contact. However, airborne debris can get lodged in the Fill, building up over time and impeding the Fill's ability to facilitate evaporation effectively. This accumulation reduces the cooling efficiency of the tower by diminishing airflow, cooling capacity, tower cleanliness and evaporation.

Cottonwood filter screens play an essential role in maintaining the integrity and performance of cooling towers. By stopping debris at its point of entry, these screens prevent it from accumulating in the basin, thus avoiding clogs in strainers, blow-down valves,



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and heat exchangers, all crucial components of the water flow loop. Cottonwood Filter Screens not only maintain the cooling tower's efficiency but also reduces maintenance costs and downtime.

Enhancing Cooling Tower Safety and Water Treatment Efficacy

Beyond efficiency, the use of cottonwood filter screens in cooling towers enhances system safety and environmental compliance. By reducing the organic load within the cooling tower, these screens lower the nutrient source for bacterial growth, such as Legionella, the bacterium responsible for Legionnaires' disease. This reduction in organic material decreases the demand on biocide treatments, enhancing the efficacy of water treatment programs and ensuring compliance with health and safety regulations.

Economic and Environmental Benefits

The integration of cottonwood filter screens in both high-efficiency HVAC systems and cooling towers presents significant economic and environmental benefits. By extending the life of internal components and reducing the frequency of maintenance and replacement parts, these screens offer a cost-effective solution to enhancing system performance. Furthermore, the improvement in air and water quality directly translates to a healthier environment and better compliance with environmental standards.

Strategic Benefits of Cottonwood Filter Screens for HVAC Design Engineering Firms

In the competitive landscape of HVAC system design and engineering, ensuring long-term customer satisfaction and minimizing post-deployment issues are critical for

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maintaining a firm's reputation and operational efficiency. Cottonwood filter screens, already established as essential for protecting high-efficiency HVAC systems and cooling towers, also offer substantial benefits to design engineering firms by addressing maintenance-related callbacks and complaints, which are often costly and unbillable. When specifying the filter screens, it is crucial that you obtain detailed engineering specifications from the manufacturer which include features and performance characteristics because there is typically more to the screens than meets the eye. In the case of Air Solution Company, the industry leader in cottonwood filter screen production, their screens are comprised of an engineered mesh that are specifically designed for use on high volume, high velocity air movement systems with very low air resistance and impact on static pressure. If cottonwood filter screens are only vaguely specified without performance and feature characteristics, those bidding on a solution could simply get window screen / bug screen / pet screen or some other form of mesh from a building supply company and unwittingly wind up doing harm to fans and compressors while providing inadequate filtration.

Reducing Post-Deployment Callbacks

It is not uncommon for design engineering firms to receive distress calls from building owners within a year or two of deploying an HVAC system, complaining about insufficient cooling or system inefficiency. Often, these issues lead to the firm dispatching engineers to investigate the problem, pulling them away from current projects. This not only disrupts ongoing work but also incurs costs that are typically not billable to the client. In many cases, the root cause of these performance issues is traced back to insufficient maintenance practices.

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Simplifying Maintenance with Cottonwood Filter Screens

Cottonwood filter screens can dramatically simplify the maintenance of HVAC systems. These screens are designed to be easily accessible and cleaned with basic tools such as brooms, brushes, leaf blowers, or garden hoses. By incorporating these screens into the initial system design, engineering firms can significantly reduce the likelihood of performance degradation due to clogged or fouled components while making it optimally easy to perform maintenance as needed.

Benefits to Design Engineering and Services Firms

1. **Increased Customer Satisfaction:** By integrating cottonwood filter screens, firms can enhance the reliability and efficiency of the HVAC systems they design, leading to higher customer satisfaction and reduced complaints. This reliability can become a key selling point that differentiates the firm in the market.

2. **Reduced Unbillable Work:** Fewer maintenance-related callbacks mean fewer disruptions to current projects and a reduction in unbillable labor, enhancing the firm's profitability and efficiency.

3. **Enhanced Reputation:** A firm that designs systems which consistently perform as expected and require minimal intervention is likely to build a stronger reputation, leading to more business opportunities and referrals.

4. **Long-Term Cost Savings for Clients:** By advocating for the installation of cottonwood filter screens, engineering firms not only protect the mechanical integrity of the systems but also provide a cost-effective solution for their clients, reducing their long-term operational and maintenance costs.

5. **Sustainability and Compliance:** With a reduced need for frequent cleaning and maintenance, there's a lesser environmental impact, aligning the designs with sustainability goals and compliance with environmental regulations.

Conclusion

For HVAC design engineers, the inclusion of cottonwood filter screens in the systems they design offers a win-win scenario. Not only do these screens protect and enhance the performance of the HVAC systems, but they also safeguard the firm from the costs and disruptions associated with maintenance-related callbacks. By simplifying the maintenance process, cottonwood filter screens ensure that the systems continue to operate efficiently, reducing the need for engineering interventions post-deployment and solidifying the firm's reputation as a provider of reliable and easy-to-maintain HVAC solutions. This strategic decision not only enhances customer satisfaction but also contributes positively to the firm's bottom line and market standing.

For more Information and to obtain Engineering Specifications Contact:
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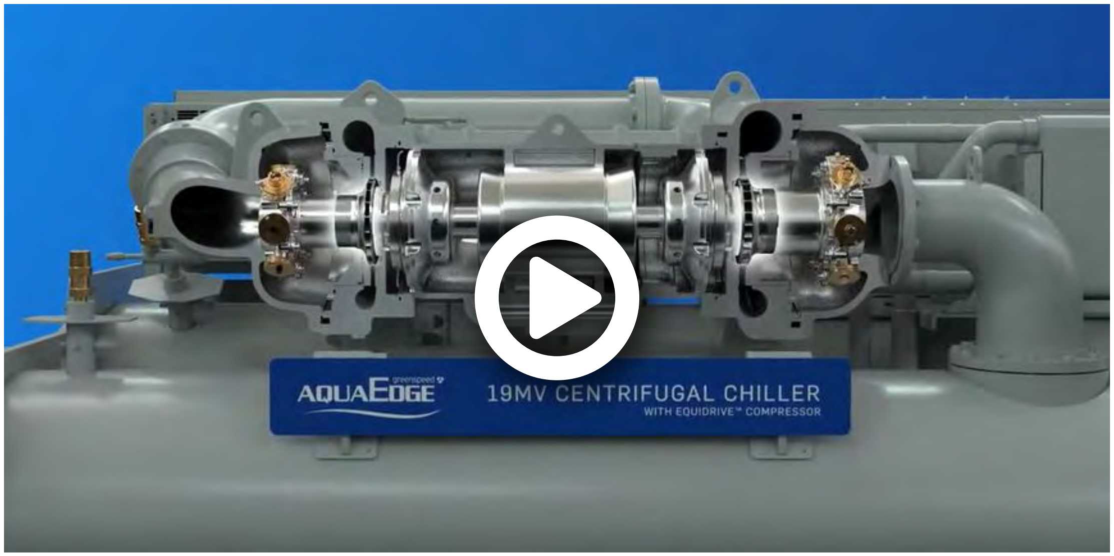

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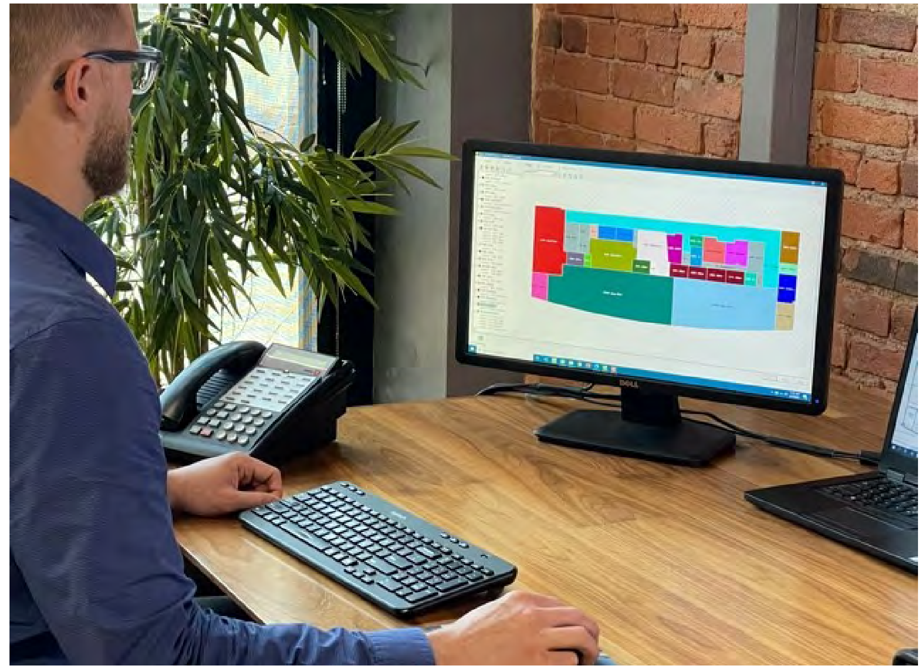

A Carrier engineer demonstrates the use of Hourly Analysis Program (HAP) software to design an effective HVAC system and compare various alternatives for a corporate office building.

Building environments are undergoing profound transformations. Regardless of type—commercial, data center, healthcare, industrial, educational, government, hospitality, or retail—each has unique HVAC system efficiency, sustainability, and reliability demands. As disparate as these structures are, many have one component in common... chillers.

While chillers are considered the heart of any building's applied HVAC system, the heart of any chiller... is its

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compressor. It's responsible for driving the refrigeration cycle, ensuring precise temperature to meet the demands of modern spaces.

For over a century, compressors have had their own trajectory of technological evolution. Understanding compression technology, the categories of compressors, and their unique operational attributes will help contribute to making the right recommendations for any chiller's application.

The Compression Process

Compressors drive the refrigeration cycle by pressurizing refrigerants and enabling heat exchange. Common types include **centrifugal, screw, reciprocating, scroll, and rotary**, each suited for different applications, capacities, and efficiency requirements. Refrigerant in chillers absorbs heat, which changes the refrigerant from a cold liquid to a low-pressure, warm gas. This gas then enters the compressor, which does as its name conveys… it compresses the gas.

Compressors use two different methods for compressing gas. Centrifugal compressors accelerate the gas, increasing its kinetic energy. The gas velocity is then decelerated, converting that kinetic energy into pressure (potential) energy. This conversion of velocity to pressure is a fundamental tenet of Bernoulli's principle.

Screw, reciprocating, scroll, and rotary compressors compress refrigerant using the principles of Boyle's Law, which states that the pressure exerted by a given mass of an ideal gas is inversely proportional to the volume it occupies (if the temperature and amount of gas remain unchanged within that enclosed space).

For all of these compressor types, once the compressor creates the high-pressure gas, the refrigerant enters the condenser. There, its energy is removed, and the refrigerant is condensed into its liquid form once again. Then, the expansion valve lowers the pressure and temperature of the liquid, turning it into a low-pressure liquid, which is sent back to the evaporator to repeat the heat transfer process.

The following five compressor types represent the latest technology found in today's commercial chillers, each performing distinct compression functions for consideration when specifying chillers.

Compressor Types, Refrigerant Cycles, and Applications

1. Centrifugal

Centrifugal compressors are the preferred choice for large-scale chiller systems in high-capacity environments. They utilize a high-speed impeller(s) to accelerate refrigerant and convert kinetic energy into pressure. Their design allows for rapid cooling, smooth operation, the ability to handle large cooling loads efficiently, and exceptional energy performance.

The Refrigerant Cycle Process:
A centrifugal chiller's compressor changes the velocity of the refrigerant gas from a low velocity to a high velocity, then slows it back down again, minimizing turbulence and friction.

In a centrifugal compressor, the refrigerant cycle process begins when low-pressure, low-temperature refrigerant vapor (usually after absorbing heat from the chilled water

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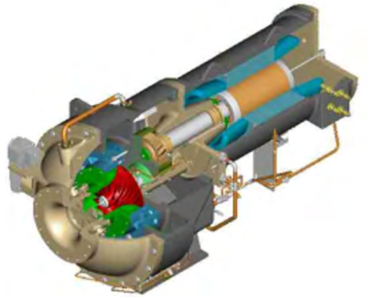
circuit) enters the centrifugal compressor at the center or inlet of its impeller. Once inside the compressor, the impeller rotates at an extremely high speed. This high velocity rotation applies centrifugal force to the refrigerant vapor, accelerating it radially outward from the impeller's center to its edges.

As the refrigerant is pushed outward, its velocity increases, converting kinetic energy into pressure energy. The high-speed refrigerant vapor is then passed through a diffuser, which further 'slows down' the refrigerant. As its velocity decreases, the refrigerant's kinetic energy is converted into higher pressure by a relationship of changing dynamic pressure to static pressure. This high-pressure refrigerant is essential for the subsequent stages of the refrigeration cycle because it can now release heat in the condenser.

The high-pressure refrigerant flows to the condenser, where it releases heat to the surroundings (either using water or air as a cooling medium). As the refrigerant cools, it condenses into a high-pressure liquid, ready for the next steps in the cycle.



Economizer Cycle: After the condenser, the high-pressure liquid is routed to an economizer, where the pressure is reduced to an intermediate level slightly higher than the first stage discharge. This creates flash gas, which is routed back to the compressor and mixed with the first stage discharge gas before entering the second stage. The gas is then compressed back to condensing pressure. The economizer cools the remaining liquid refrigerant, increasing system capacity and reducing the total work of the refrigeration cycle. Increased capacity and reduced work enhance overall cycle efficiency.

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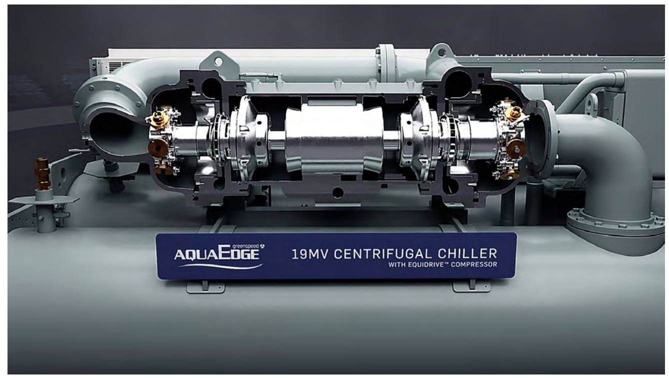
After the refrigerant leaves the economizer, it is throttled down to a low-pressure liquid by an expansion valve, then evaporates in the evaporator, absorbing heat from the chilled water. The refrigerant vapor then re-enters the centrifugal compressor to repeat the cycle.



Two-Stage Centrifugal Compressors:
A two-stage centrifugal compressor is designed to compress refrigerant in two stages, improving efficiency and performance. A two-stage centrifugal compressor compresses refrigerant in two steps, using impellers and economizing to achieve a high pressure at the exit, which improves cooling capacity and energy efficiency in large-scale chillers.

Here's a detailed breakdown of its structure and function:

Inlet Guide Vanes (IGVs): The refrigerant enters the compressor through inlet guide vanes, which help control the refrigerant flow and direct it optimally into the impellers. Adjusting these vanes can modulate compressor capacity.

First Stage Impeller: The first stage consists of an impeller, which rotates at high speed. As refrigerant enters the impeller, it is accelerated outward due to centrifugal force, increasing its pressure and velocity.

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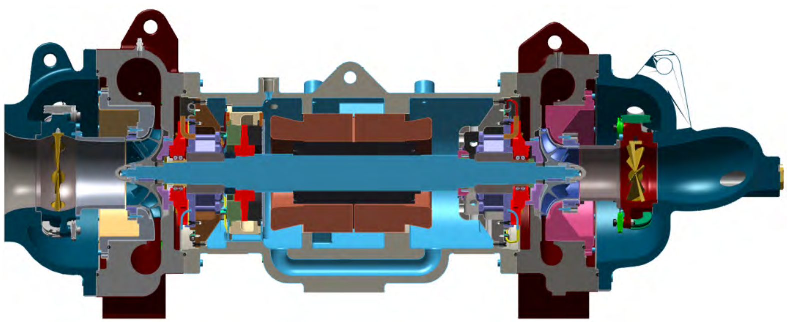
First Stage Diffuser and Volute: The compressed refrigerant exits the first stage impeller and enters a diffuser, which converts the kinetic energy of the high-velocity refrigerant flow into higher pressure. The refrigerant then passes into the volute, a casing that directs it toward a pipe that feeds the second stage of compression. In this intermediate connection between stages, the flash gas from the economizer is mixed in, cooling the refrigerant before it enters the second stage.

Second Stage Impeller: The refrigerant enters the second stage impeller, where it undergoes further compression. This second stage increases the refrigerant's pressure to the desired level required for effective cooling in the chiller.



Second Stage Diffuser and Volute: The compressed refrigerant exits the second stage impeller and enters a diffuser, converting high-velocity flow into higher pressure. It then passes into a volute. The diffusers and volutes of both stages are designed to optimize energy conversion.

Centrifugal Applications

Commercial Buildings: Large office buildings, hotels, and shopping malls, where consistent and efficient cooling is needed.

Industrial Facilities: Factories and manufacturing plants, particularly those with significant cooling loads.

Data Centers: Hyperscale or enterprise where cooling systems must manage immense heat loads and provide dependable and safe cooling under fluctuating server loads.

Medical Facilities: Hospitals or medical complexes that demand precise temperature control and reliability for patient care and sensitive equipment environments.

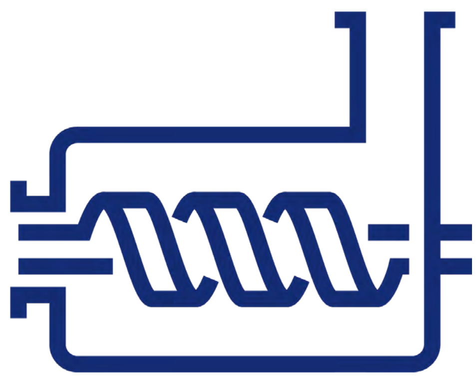
District Cooling Systems: Multiple buildings in a municipal district, campuses, such as universities or business complexes.

On an historical note, in May 1922, Willis Carrier unveiled his single most influential innovation, the centrifugal refrigeration machine (or "chiller"). His invention would give rise to an HVAC company that inspired an entire industry essential to global productivity and personal comfort.

Today, Carrier's AquaEdge® 19MV water-cooled centrifugal chiller with magnetic bearings leverages Equi-Drive™ two-stage back-to-back compressor technology for high performance and reliability across a wide operating range.

2. Screw

Known for efficiency, reliability, and the ability to handle a wide range of cooling capacities, screw compressors help deliver consistent performance, adapt to variable loads, and may support the reduction of operating costs. Utilizing two interlocking, helical rotors (or three for the AquaEdge® 23XRV) that compress refrigerant



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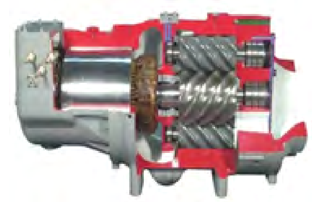
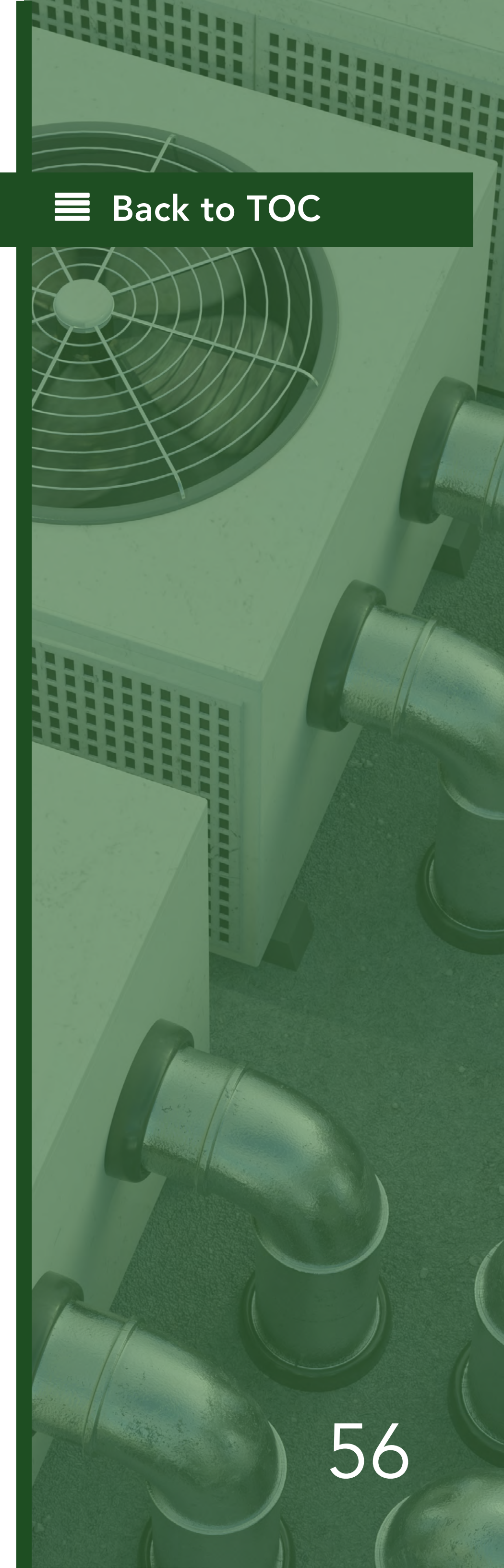
smoothly and continuously, screw compressors are highly durable. Fewer moving parts deliver a robust solution with consistent performance over long periods.

The Screw Compression Process:
Low-pressure refrigerant gas enters the compressor through the suction port. The gas is trapped between the interlocking helical rotors which rotate to compress the refrigerant. As the rotors turn, the gas is progressively compressed in decreasing volume along the length of the screws. This continuous, smooth compression process reduces pulsation and mechanical stress.

At the end of the compression process, the refrigerant exits through the discharge port and check valve. The internal check valve prevents the screw compressor from rotating backwards on shutdown. The high-pressure refrigerant is then directed to the condenser, where it releases heat and condenses before continuing through the refrigeration cycle. The design of the discharge port is critical to optimizing the performance of the compressor and the chiller in which it is installed.

Tri Rotors:
Tri-rotor screw compressors feature three intermeshing rotors—a center screw which engages with a screw on either side. They work together under very tight tolerances to compress the refrigerant. This configuration allows for a more even distribution of the compression radial load on the center rotor's bearings, which tend to experience high loads. As a result, fewe bearings are necessary on the center rotor, enhancing overall efficiency.





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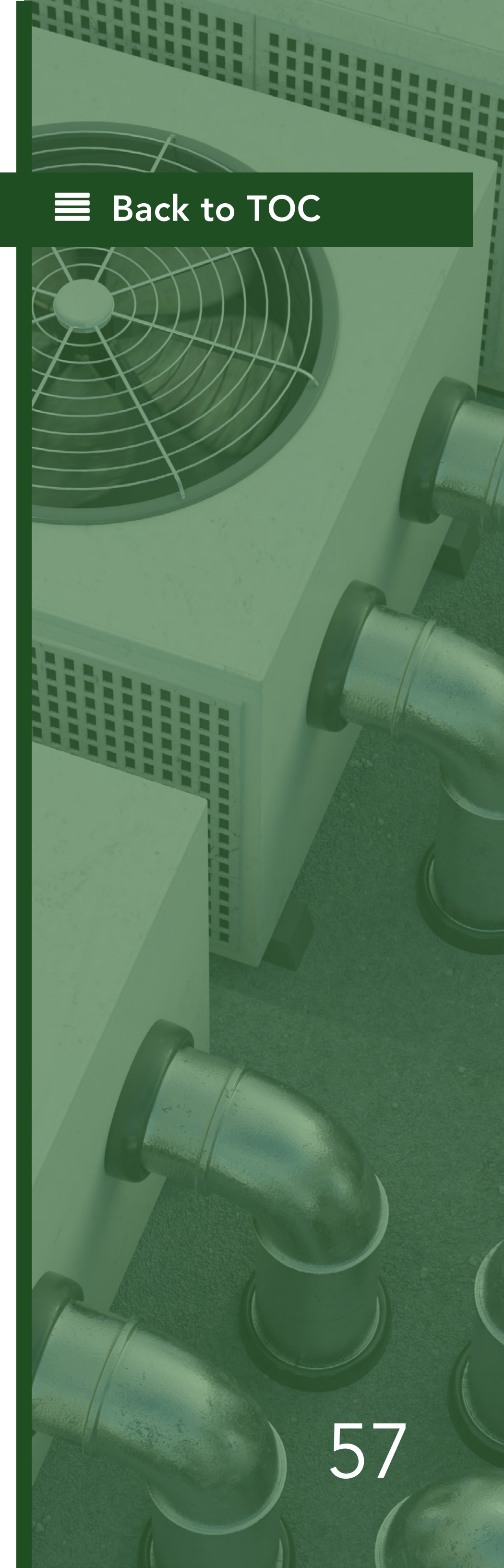


Screw Applications

Commercial Buildings: Large office complexes must maintain consistent cooling for varying occupancy levels. In hotels, screw compressors ensure efficient, quiet operation in systems that must handle fluctuating comfort demands.

Data Centers: Colocation or edge facilities demand reliable, 24/7/365 cooling for mission-critical environments with high heat loads.

Manufacturing Plants: High production facilities which must maintain precise temperature control and continuous cooling in production processes.

Hospitals: Complexes which require precise robust, reliable and efficient cooling for medical equipment, patient rooms, and operating suites.

Universities: Large campuses which need scalable and efficient cooling solutions for classrooms, labs, and dormitories.

Shopping Malls: Large retail spaces which must meet the cooling demands of varying occupancy levels.

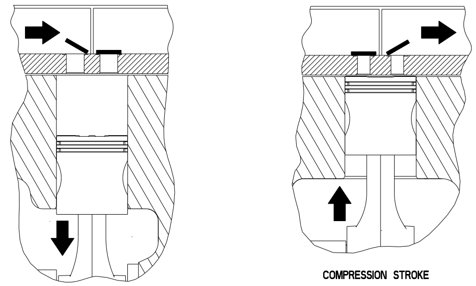
Theaters and Arenas: Venues must have low-noise, high-efficiency performance, especially during peak usage periods.

Carrier's AquaEdge® 23XRV chiller is a versatile, water-cooled screw chiller with variable-speed technology. Designed to enhance reliability and efficiency across various operating conditions, it features a tri-rotor screw compressor known for its efficiency. The

23XRV benefits from this advanced, brilliantly simple compression technology, with only the screw rotors and a variable speed electric motor as moving parts.

3. Reciprocating

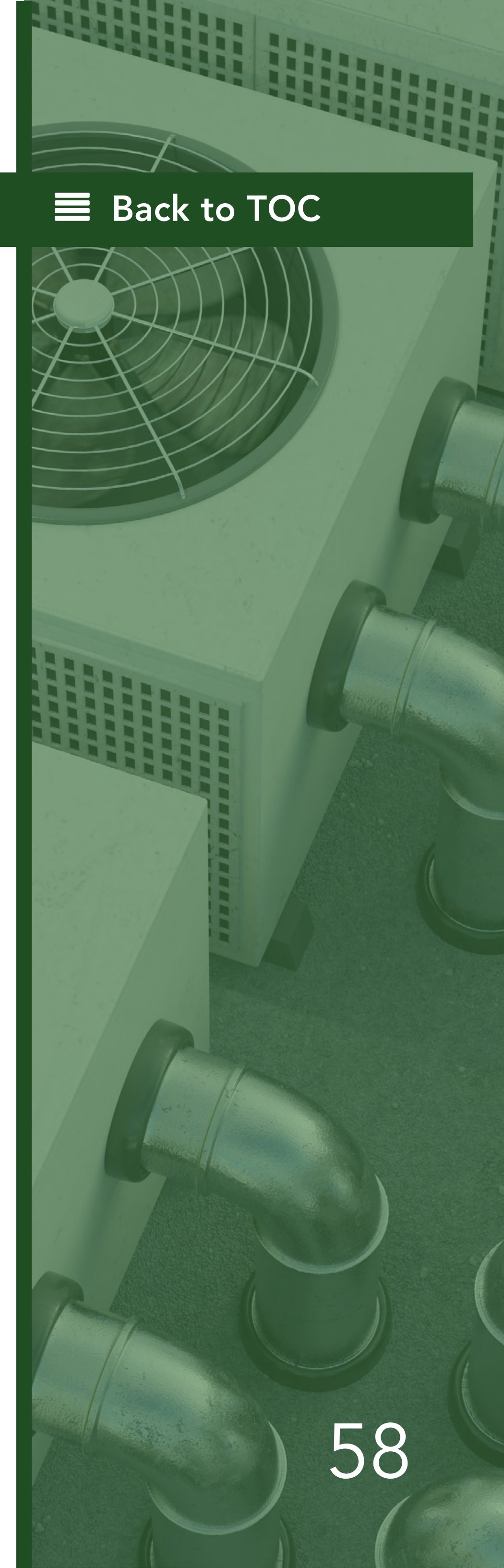
Reciprocating compressors are positive-displacement compressors that use pistons housed within cylinders which move back and forth (reciprocate) to compress the refrigerant. Used in small to medium-capacity chillers (typically up to 200 tons), their robust design and ability to reach a range of capacities for variable-load applications, make them versatile solution.



Each cylinder has an intake (suction) and exhaust (discharge) valve. These valves are spring-loaded and automatically open and close based on pressure differences, allowing refrigerant in and out of the compression chamber.

Suction Stroke: As the piston moves downward in the cylinder, the pressure inside the cylinder becomes lower than that in the suction plenum. This pressure difference causes the intake valves to open, allowing refrigerant vapor to flow into the cylinder from the evaporator side.

Compression Stroke: When the piston reaches the bottom dead center and starts moving upward, the intake valve closes. This action reduces the cylinder's volume, compressing the refrigerant and increasing its pressure and temperature.



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Discharge Process: As the piston nears the top of the compression stroke, the cylinder pressure exceeds the pressure in the cylinder head, causing the discharge valve to open. The high-pressure refrigerant then flows out of the cylinder and into the condenser.

The Refrigerant Cycle:
In the evaporation phase, the refrigerant absorbs heat and evaporates at low pressure in the evaporator. Next, the reciprocating compressor raises the refrigerant pressure and temperature to prepare it for condensation. During condensation, the high-pressure refrigerant releases heat and condenses back into a liquid. During expansion, the refrigerant's pressure and temperature are reduced, enabling it to absorb heat again in the evaporator.

This cycle repeats continuously, with the reciprocating compressor driving the flow and pressure changes. The suction and discharge valves of reciprocating compressors make them highly adaptable to changing operating conditions.

Reciprocating Applications

Small- to Mid-Sized Office Buildings: Buildings with variable occupancy and cooling demands benefit from load flexibility. Relatively compact, they are suitable for smaller buildings.

Data Centers: Smaller data centers or server rooms, the staging capability of reciprocating compressors helps meet varying cooling loads in these environments.

Hospitality: Public areas, restaurants, and conference rooms often experience fluctuating cooling loads due to varying occupancy rates. Well-suited to handling

The 06E reciprocating compressor from Carlyle, a Carrier company, features a high-flow, automatically reversible oil pump and an oversized sump, to support reliable lubrication and enhanced efficiency even under challenging conditions.

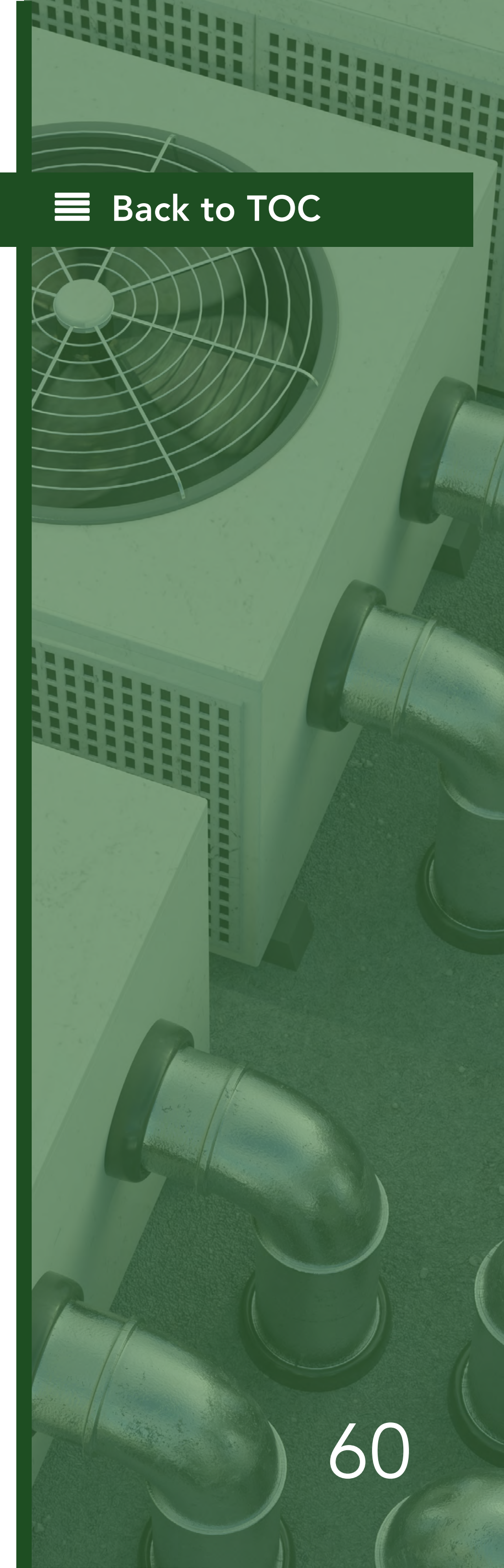
these variable loads and can be staged on and off as needed.

Marine: Effective for marine HVAC systems, providing reliable cooling performance in compact spaces with the ability to adapt to varying load demands.

4. Scroll

Scroll compressors are positive displacement compressors commonly used in commercial HVAC chillers due to their efficiency, reliability, and quiet operation.

Its working principle revolves around the interaction of two spiral-shaped components—one stationary (fixed scroll) and one that moves in an orbiting motion (orbiting scroll). The orbiting scroll rotates around the fixed scroll, which compresses the refrigerant and draws it toward the center. This compresses the refrigerant by progressively reducing the volume of gas between the scrolls.



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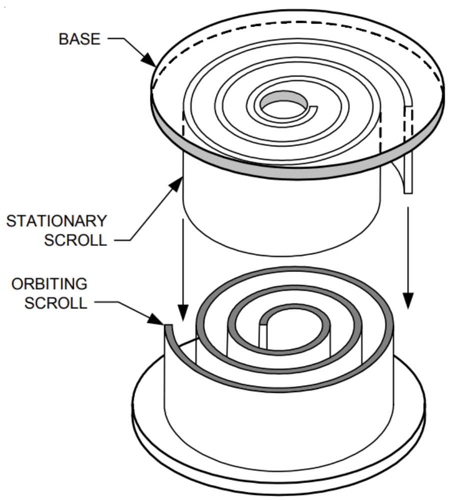
The Refrigerant Cycle

Suction Process: The refrigerant vapor enters the compressor through a suction port and fills the outermost sections between the fixed and orbiting scrolls. At this stage, the vapor is at low pressure and temperature.

Compression Process: As the orbiting scroll moves in a circular path, it traps the refrigerant between the scrolls, pushing it towards the center. This reduces the volume of the refrigerant vapor, causing its pressure to rise. The continuous movement of the orbiting scroll allows for a smooth and quiet compression process, a key advantage of scroll compressors.

Discharge Process: Once the refrigerant reaches the center of the scroll set, it is fully compressed and at a higher pressure and temperature. The compressed refrigerant is then released through a discharge port and sent to the next stage of the refrigeration cycle, the condenser. An internal check valve prevents the scroll compressor from rotating backwards on shutdown.

The scroll compressor is responsible for circulating refrigerant through the system, enabling the chiller to absorb heat from the building and reject it outside. Scroll compressors are known for their energy efficiency, especially in partial-load conditions, making them ideal for applications that demand consistent performance and lower operational costs.



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Scroll Applications

Scroll compressors are ideal for light- to medium-duty applications due to their compact design and low noise levels. They offer both cost-effectiveness and longevity, maintaining high efficiency across a wide range of operating conditions. With fewer moving parts, scroll compressors may offer an extended lifespan and help reduce maintenance costs.

Office Buildings: Provides efficient cooling for workspace environments, where consistent temperatures are needed for employee comfort.

Hospitality: Hotels which require quiet operation— essential for guest comfort—and energy efficiency.

Retail: Shopping malls, department stores, and smaller retail spaces which require climate control for customers.

Healthcare: Small to mid-sized hospitals, clinics, and medical offices to maintain strict temperature requirements.

Educational: Schools, universities, and training centers to maintain consistent temperatures for classrooms, libraries, and administrative spaces.

Data Centers: Smaller data centers and telecommunications facilities to maintain the cooling needed for IT equipment.

Restaurants and Commercial Kitchens: Food service establishments for efficient cooling in dining areas and kitchen environments.

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These compressors are found on both Carrier's small air- and water-cooled chillers, including the AquaSnap® 30MP water-cooled chiller. Designed for faster, more cost-effective installation, the AquaSnap® 30MP chiller is trim enough to fit through a standard size door or elevator and can also be easily connected in a series to provide greater capacity.

Apartment Complexes and Multi-Family Housing: Residential buildings to provide cooling to common areas and, in some cases, individual apartments.

Scroll compressor chillers are especially popular in applications where energy efficiency, low maintenance, and reliable performance are key considerations.

5. Rotary

Rotary compressors are an economical choice for smaller light commercial and residential applications where moderate to low cooling loads are required. Typically found in smaller specialty chillers, rotary compressors are known for their durability and smooth operation and deliver a balance of efficiency, quiet operation, reliability, and compact design.

They use an eccentric rotor that traps the gas against a vane to compress the refrigerant. They layout may have a stationary vane that slides within the housing or rotating vanes that slide within the eccentric rotor.

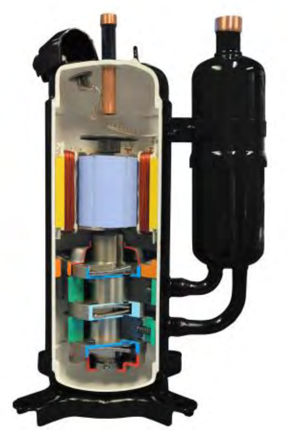
Intake Phase: The compressor's rotor begins to rotate within a cylindrical chamber. As it rotates, it creates a small gap where refrigerant gas enters through an intake port and creates a trapped volume between the cylinder walls, eccentric rotor and sliding vane.

Compression Phase: Inside the chamber, the rotor continues rotating, pushing the refrigerant gas toward a smaller space. This decreases the volume of the chamber, compressing the refrigerant gas and increasing its pressure and temperature.

Discharge Phase: As the rotor continues to rotate, it pushes the compressed refrigerant toward the discharge port. Once the pressure within the space increases above discharge pressure, the high-pressure refrigerant exits the compressor through a discharge valve to flow through the rest of the cooling system, typically to a condenser, where it dissipates heat.

Rotary Applications

Residential: Popular in dehumidifiers, window air conditioners, and duct-free split systems. Multi-family residential buildings which require decentralized cooling between units.



Light Commercial Buildings: Smaller settings that require a lighter cooling capacity, often a small space that requires cooling within a larger unconditioned space.

Data Centers: Smaller data centers and IT rooms where reliability and temperature control is critical but cooling needs are small.

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Healthcare: Smaller medical clinics with medical imaging equipment and laboratories where compact and precise cooling systems are needed.

Manufacturing: Smaller-scale manufacturing applications which require light-duty process cooling.

Hospitality: Restaurants and kitchens for food storage and kitchen cooling where space is limited.

Selecting the right compressor is crucial for achieving precise, energy-efficient, and reliable cooling. Furthermore, it's not just about meeting current cooling needs—it's about futureproofing for energy efficiency, scalability, and sustainability. Today's compressor choices will impact your client's operational costs, environmental impact, and equipment longevity. Your expertise on this topic will help create environments where comfort, technology, efficiency, and sustainability converge. Refer to the chart on the next page to help you navigate future compressor decisions with confidence.

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Compressor Technology Comparison

Compressor Type	Characteristics	Applications	Typical* Building Types
Centrifugal	Rapid cooling, smooth operation, handles large cooling loads efficiently, exceptional energy performance.	Commercial Applied	Large office buildings, hotels, shopping malls, factories and manufacturing plants, hyperscale or enterprise data centers, hospitals/medical complexes, municipal district, campuses, and business complexes.
Screw	Efficient, reliable, wide range of cooling capacities, consistent performance, adapts to variable loads, helps reduce operating costs.	Commercial Applied	Colocation or edge data centers, manufacturing plants, hospitals, universities, shopping malls, theaters, and arenas.
Reciprocating	Good at partial load conditions, flexible, scalable, compact design, reliable, can handle higher refrigerant pressures.	Light Commercial and Refrigeration	Small- to mid-sized office buildings, smaller data centers or server rooms, hotels - public areas, restaurants, and conference rooms, and marine.
Scroll	Compact design, low noise, high efficiency across a wide range of operating conditions, fewer moving parts increase lifespan and help lower maintenance costs.	Light- to Medium-duty	Office buildings, smaller data centers, hotels, shopping malls, department stores, smaller retail spaces, small to mid-sized hospitals, clinics, schools, universities, commercial kitchens, and apartment complexes.
Rotary	Durable, smooth operation, delivers a balance of efficiency, quiet operation, reliability in a compact design.	Very Light- to Medium-duty	Small office buildings, retail stores, small data centers and IT rooms, small medical clinics, laboratories, small-scale manufacturing, multi-family residential buildings, restaurants and kitchens.

*Represents sample building types. For specific applications, contact your Carrier Representative.

Design of RTUs: Best practices

Specifying rooftop units (RTUs) involves much more than choosing unit types

Rooftop units (RTUs) are popular choices for heating, ventilation and air conditioning (HVAC) systems because they optimize space, provide efficient climate control and feature modular designs. They save valuable floor space compared to air handling units (AHUs), which are situated inside a building. Design teams clearly recognize these advantages: Today RTUs cool approximately 60% of floor space in commercial buildings within the U.S., according to the U.S. Department of Energy.

The technology, in short, is proven. But design teams face challenges in terms of choice: With so many options now available, how do you specify the right RTU for a particular project? Following are several considerations to guide these decisions.

When it comes to HVAC equipment on rooftops, there are specific code requirements to ensure safety, accessibility and proper installation. The International Mechanical Code Section 306.5 mandates that if equipment requiring access (such as HVAC units) is located on a roof with a slope of three units vertical in 12 units horizontal (25% slope) or greater, a level platform must be provided on each side of the appliance or equipment. This platform ensures safe access for service, repair or maintenance of rooftop equipment. Equipment must also be installed at least 10 feet from the edge of the roof or proper fall protection must be provided along the perimeter of the roof.

Furthermore, equipment must also be positioned so that water, snow or ice from the roof or eaves cannot fall directly on the unit or be ingested into the outside-air intake. Maintaining sufficient distance between fresh air intakes and exhaust fans is also important to prevent contamination of the fresh air being delivered to the unit.

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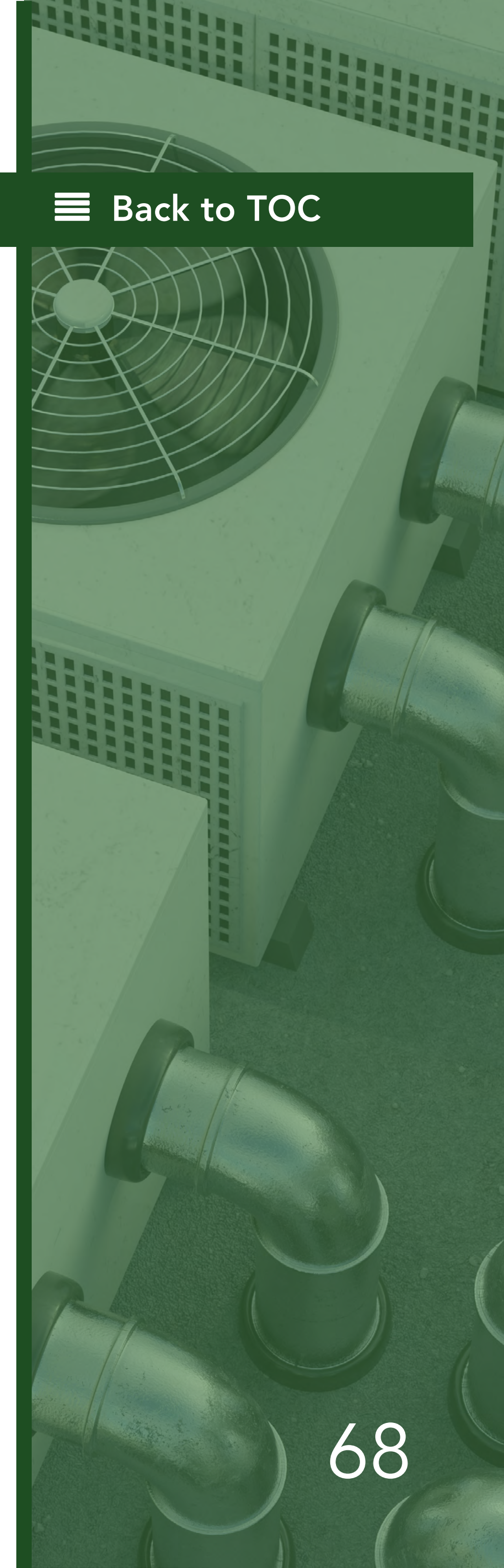
When installing HVAC equipment on new or existing roofs, careful consideration of weight-related factors is essential to ensure safety and prevent damage to the building. Smaller packaged HVAC units typically weigh around 600 pounds, while larger semi-custom or fully custom units can reach up to 65,000 pounds. Understanding the weight of the specific unit you're installing is crucial for proper structural support. Additional structural reinforcement is often necessary to accommodate the weight of large HVAC units. Therefore, HVAC engineers should coordinate carefully with structural engineers to assess the new or existing roof structure and determine if modifications are needed. They should also consider factors such as snow load, wind load and dead load (permanent weight) when calculating the total load on the roof.

Figure 1: This photo shows the hot water and chilled water piping within the service vestibule of a semi-custom unit used on the Hackensack Meridian hybrid OR project. The piping and equipment within the service corridor was designed to allow the maintenance staff to walk within the unit and access all the components. Courtesy: Syska Hennessy

Energy efficiency is yet another consideration. ASHRAE Standard 90.1: Energy



Standard for Buildings Except Low-Rise Residential Buildings serves as a benchmark for energy-efficient building design. It has been updated regularly since its inception in 1975 and remains the energy efficiency guide for most commercial buildings.

The entire HVAC system, including RTUs, variable air volume boxes, building automation systems, ductwork configurations and fans, must meet the requirements outlined in ASHRAE 90.1. Section 6.8 of Standard 90.1 provides specific guidelines related to the minimum efficiency requirements of electrically operated unitary air conditioners and condensing units. These minimum efficiencies must be met for all new equipment installations.

Types of RTUs

The first step for a design team is to select among four overarching categories, which include dedicated outside air systems (DOAS), packaged units, semi-custom units and custom units. Below is an overview of each:

DOAS are used to provide fresh air for ventilation; there is no recirculation. Therefore, they are typically used in conjunction with another type of system that handles heating and cooling loads. Common choices for these supplemental systems are fan coil units, chilled beams terminals and variable refrigerant flow/volume systems, which offer energy efficiency and individual temperature control for each zone.

DOAS are especially advantageous in places like airports, classrooms and conference rooms, where there are higher requirements for outside air used for ventilation. The downside, however, is that they are usually more costly because there is extra piping and equipment involved.

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Packaged units are simple, self-contained units used for light commercial buildings where precision temperature control is not required. They typically range in size from 2 to 150 tons and each unit comprises direct expansion cooling, an electrical or gas heating coil and a single air filter. Additional components and features are available as options, but these units lack the customization available in semi-custom and custom units.

The plus of packaged units is cost-efficiency; they're off-the-shelf. The minus is a dearth of customization options, for the same reason. Furthermore, packaged units are not the most energy-efficient choice. They meet the basic criteria but are unlikely to exceed more ambitious targets for decarbonization.

Semi-custom units are good fits for projects with strict guidelines for filtration and humidification, although they are more expensive than packaged units and DOAS. These units are more robust and provide up to 250 tons of cooling. Because there are more options associated with semi-custom units, they are often used in health care and pharmaceutical environments. In these cases, facility owners and managers understand that the precision associated with the equipment leads to higher costs.

Custom units are, not surprisingly, more costly than semi-custom units. These units are the most versatile and have the capability to incorporate their own heating and cooling equipment, like a small mechanical equipment room within the unit. Expense is one downside; another is lead time. It takes longer to procure the units because they are fully customizable.

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Figure 2: Example of a simple packaged rooftop unit at a branch bank facility. The unit comprises a supply fan, direct expansion refrigerant cooling coil, gas heating, a single air filter and an airside economizer. Courtesy: Syska Hennessy

But they offer many benefits: Custom units can meet stringent criteria for footprints and filtration, they can be built to withstand higher static pressures and lower supply-air temperatures and they can be painted with custom exterior finishes or cladding for aesthetic coordination.

Factors that influence RTU choices

With simpler projects, such as an office or retail space, cost is usually the key consideration and packaged units suffice. These units comply with minimum code requirements across most jurisdictions.

But if a project has higher filtration or humidification requirements, the solution is often a semi-custom or custom unit. Below is a case study that exemplifies the decision-making process:

Syska Hennessy, which served as the mechanical engineer for the fit-out of two hybrid operating rooms at Hackensack Meridian Hospital in Hackensack, New Jersey, chose a semi-custom unit for the project.

That was the logical choice in this instance. The hospital intended these operating rooms (ORs) to be used for both imaging and cardiac catheterization. Since the ORs were relatively large, had a high air-change-rate requirement and required high-efficiency particulate air filtration, they needed fans capable of delivering high airflow and static pressure.

A fan array comprising multiple fans was chosen to increase energy efficiency as well as redundancy in the fan system. The team needed an RTU, therefore that could provide higher static pressure and proper humidification and be equipped with pre-filters and final filters. The unit was constructed with a large maintenance vestibule to house the humidifier system, piping and provide the maintenance staff with protection from the weather while maintaining the unit.

Similar criteria influence choices for other health care projects. But regardless of the unit type, design teams must also consider access for future maintenance and efficiency. Engineers should work closely with vendors to select the correct fans. Otherwise, they face the risk of oversizing, which leads to an excess power draw.

It is difficult to compare custom and semi-custom units with packaged units and DOAS in the realm of energy efficiency because the former two are used with chiller plants, which means that the cooling process happens elsewhere. That said, engineers can choose fans for the semi-custom and custom units that offer higher efficiency — assuming that a client is willing to pay extra.

Once a unit is installed, proper maintenance is required. For example, facility staff should replace filters at proper intervals, because as debris accumulates on the filters,

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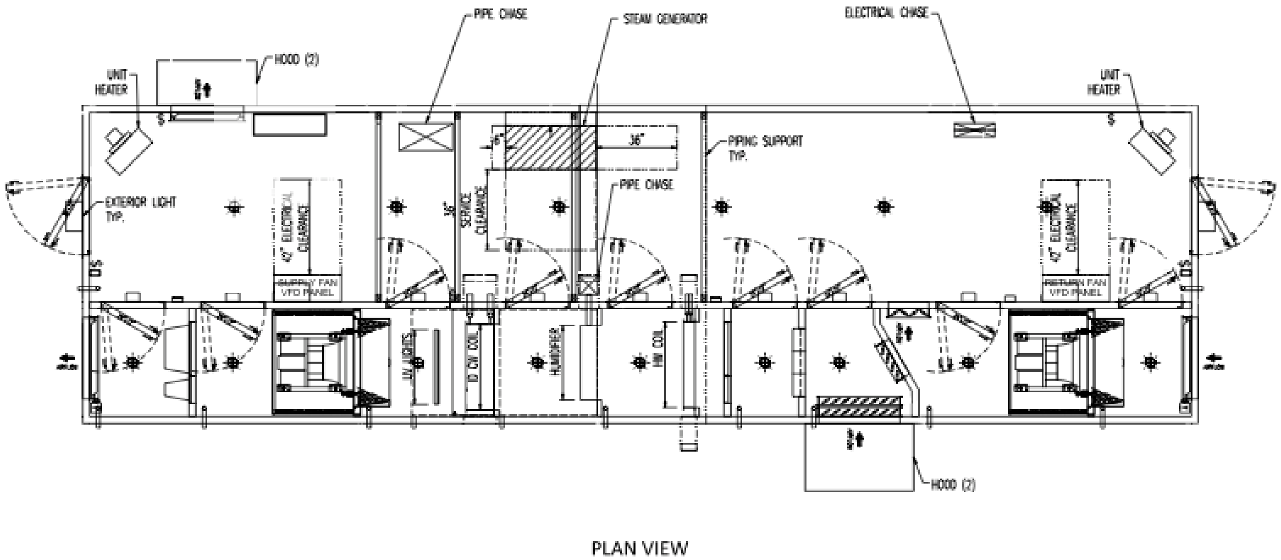

it adds resistance to the air stream, which translates into more energy usage. The manufacturer typically suggests replacement intervals. But with semi-custom and custom units, designers can install a gauge to monitor pressure drops across the filters. Once the gauge measures a certain setpoint, the filters should be changed. It's a more scientific approach toward maintenance.

Figure 3: Design of individual components for the semi-custom unit used on the Hackensack Meridian hybrid operating room project. The unit was designed with a service corridor to protect the maintenance staff from the weather and houses the piping, electrical components and the steam generator serving the unit. Courtesy: Syska Hennessy

Energy efficiency also extends outside the design of the AHU. Ductwork systems must also be rightsized to minimize the amount of static pressure required by the RTU to deliver the proper airflow to the building.

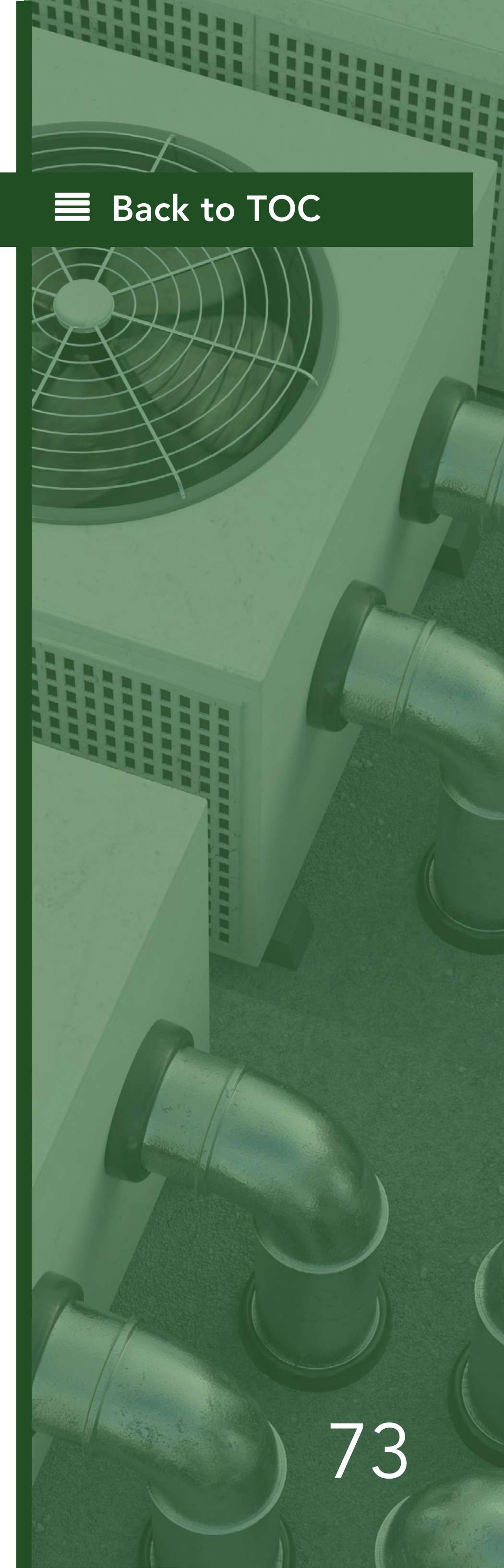

Figure 4: This is one of the operating suites on the Hackensack Meridian hybrid operating room project. Ductwork was routed below the roof from the semi-custom rooftop unit to the two operating rooms. An array of laminar high-efficiency particulate air diffusers were used at the ceiling to supply air to the room, while lower return grilles were used to return air back to the rooftop unit. Courtesy: Syska Hennessy

Emerging technologies

Design teams should also think about future needs and strategies to integrate emerging technologies into their RTUs.

For instance, it is possible to equip

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semi-custom and custom units with energy recovery features. Energy recovery systems use air that is exhausted from a building to pre-treat the air coming into the building, which decreases demand for extra cooling and heating. Energy recovery wheels are becoming more efficient, allowing for better energy transfer.

Figure 5: Shown is an example of a semi-custom unit used for a health care facility. The unit comprises supply and return fans, a direct expansion refrigerant cooling coil, gas heating, pre- and final air filters and an air-side economizer. Courtesy: Syska Hennessy

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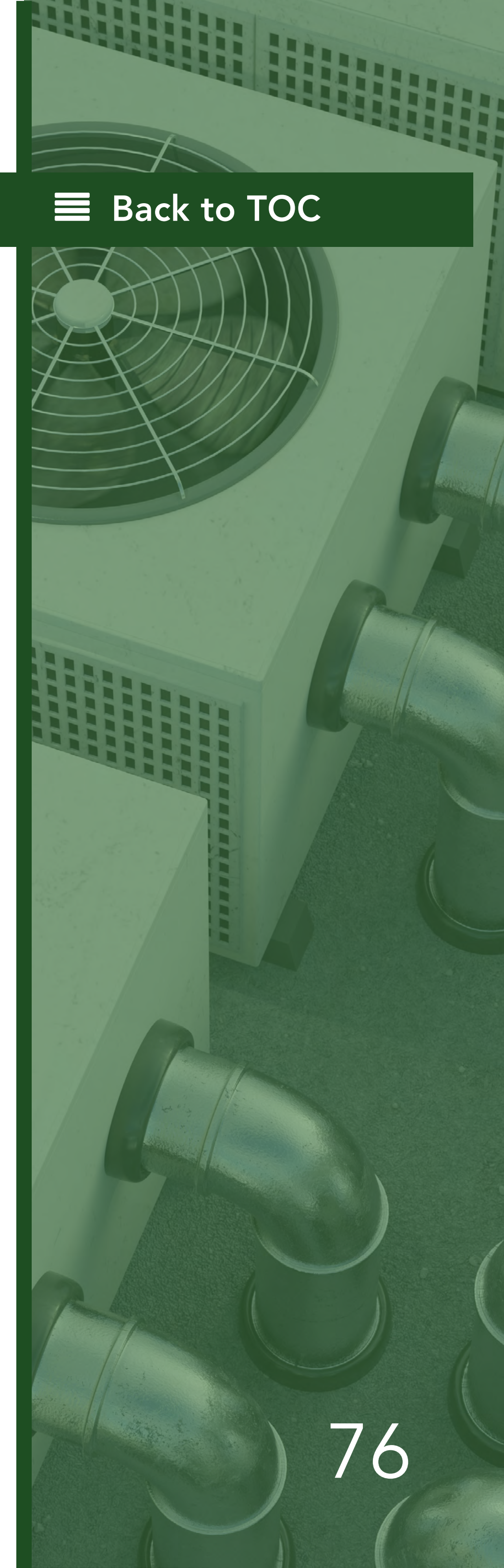
New refrigerants are being developed every few years that are slowly but surely replacing chlorofluorocarbon-type refrigerants, which are detrimental to the environment. Current regulatory requirements are now phasing in the use of mildly flammable A2L refrigerants with lower global warming potential, such as R-400 and R-500 series blends. And the new refrigerants can be included in packaged and semi-custom units.

Additional methods of promoting energy efficiency include upgrading the control systems on basic packaged RTUs with features such as multispeed or variable speed supply fans, modulating outdoor air control dampers, modulating heating coils and employing demand-controlled ventilation.

When it comes to designing RTUs, engineers must consider filtration and humidification requirements, energy-efficiency, the ease of maintenance, the potential for integration with emerging technologies and even aesthetics, while ensuring that solutions do not exceed budgets. Decisions require input from several trades; they cannot be made in a vacuum. The process may be time-consuming, but the end-result is an RTU that satisfies specific facility needs efficiently and lasts for a long time.

Tony Gonzalez

Tony Gonzalez, PE, *is an associate partner at Syska Hennessy. He has more than 25 years of experience in mechanical engineering.*



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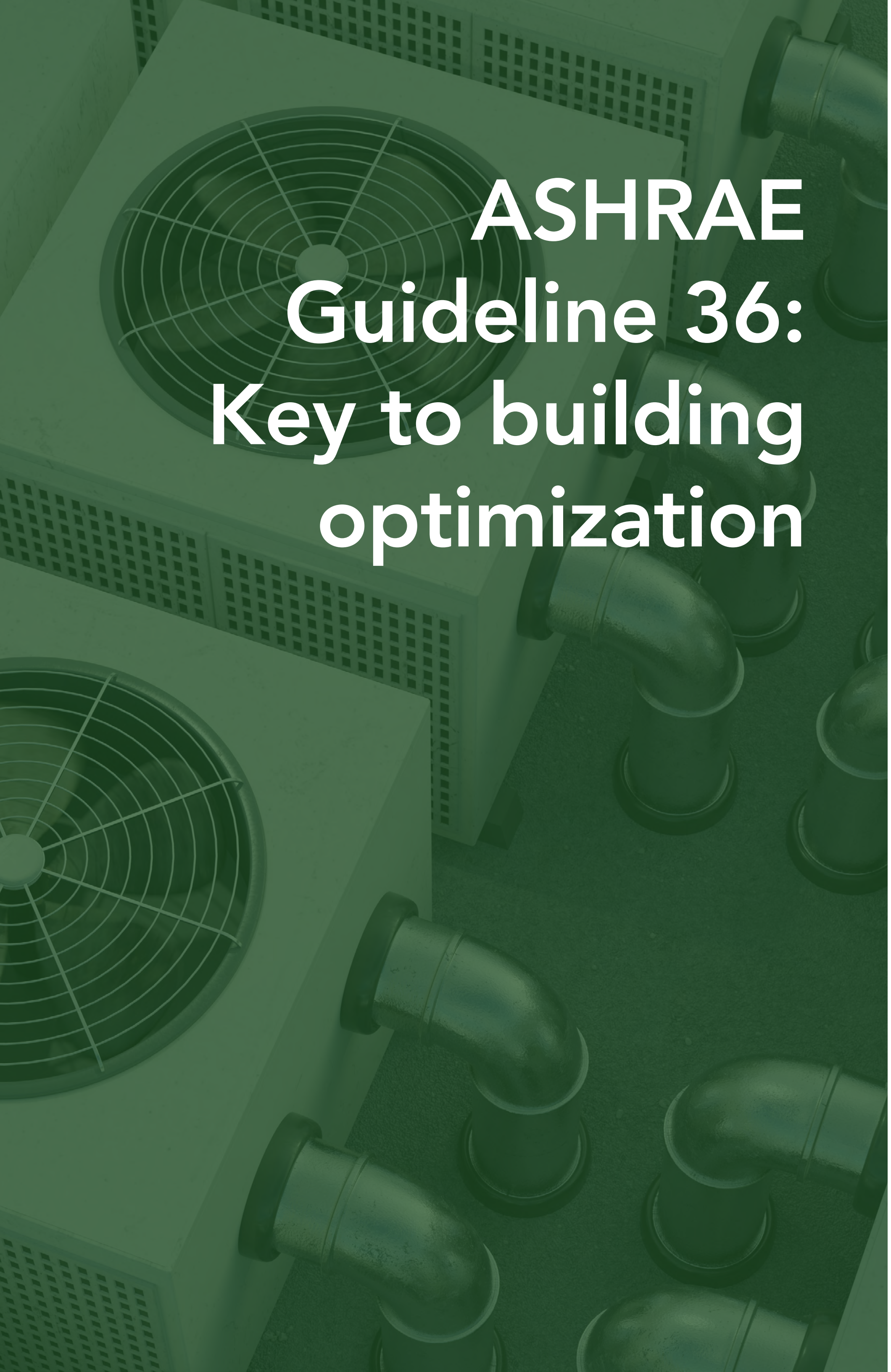
Welcome to EcoStruxure Building Operation - SpaceLogic Insight-Sensor

Introducing the SpaceLogic™ Insight-Sensor, an advanced room sensor for occupancy, anonymous people counting, ceiling temperature, humidity, light, and sound. Maximize comfort, reduce energy use, and improve indoor environmental quality with a modern room solution from Schneider Electric. SpaceLogic Insight-Sensor optimizes room conditions fast and accurately while capturing valuable room data and insights to help achieve green and well-building certifications.



ASHRAE Guideline 36: Key to building optimization

Did you know that nearly **40% of global CO_2 emissions come from buildings?** Even more surprising, **30% of the energy used in these structures goes to waste**. Despite the prevalence of advanced HVAC systems, the building industry is hindered by a cost-driven approach favoring simplicity over efficiency. This is a major driver of energy loss. It's time to rethink how we manage our buildings to reduce waste and create a more sustainable future.

Most commercial buildings have programmable central heating, cooling, and ventilation (HVAC) systems. These systems use control sequences that provide automated direction, such as setting up operational schedules and **planning proactive maintenance**. When used effectively, they can ensure that systems maximize both operational and energy efficiency while also reducing carbon emissions.

Standardization Supports Optimization

However, **the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)** identified that most HVAC control systems were custom one-off implementations unique to each building or structure. They also found that many HVAC control system implementations were simplified during installation. This occurred to reduce costs or to meet the inexpert operational abilities of building management staff.

Projects specified to include high-performance HVAC systems require complex, expert programming, but the needed sequences are high risk and high cost. Therefore, system programming can be difficult to maintain once the commissioning is completed and the experts leave.

Used effectively, HVAC systems and BMS can ensure that systems maximize both operational and energy efficiency, while also reducing carbon emissions. ASHRAE Guideline 36 provides standardization that building managers and operators can use to create and maintain optimized controls.

Given these risks, in most cases, the high cost of entry for optimal performance design and implementation will be removed as part of routine project cost cuts. This leads to subpar building performance and increased emissions.

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By providing a standardized, high-performance sequence of operations, ASHRAE Guideline 36 can lower the cost of high-performance sequences for specifiers by providing a repeatable standardized sequence of operations. This by itself does not get around the fact that implementations will vary depending on who performed the work. Instead, GL 36 recommends that manufacturers perform the programming pre-emptively, making it available to their independent dealers and factory branches at no cost. This approach reduces costs and improves quality control by having the programming only be done once and not multiple times. It also makes future changes easier for staff or contractors.

How ASHRAE Guideline 36 Improves Standardization

Using standardized sequences of operations provides substantial advantages.

- **Reduced engineering time.** Starting with a proven standard sequence already optimized to perform the core task limits the time and the potential for errors.

- **Decreased programming and commissioning time.** Manufacturers pre-program sequences while HVAC control system technicians, along with commissioning agents, use a common document for functional testing.

- **Better control of energy consumption, cost, and system downtime.** GL 36 saves energy by reducing the need for simultaneous heating and cooling and optimizes airflow in VAV systems.

- **Improved conditions for tenants.** In particular, the standardized guidelines can help improve indoor air quality by closely controlling air flow and minimizing carbon dioxide in workspaces.

- **Enhanced communication.** By creating a language of common terms, ASHRAE 36 clarifies communications between specifiers, contractors, and operators.

These factors add up to serious gains: A study funded by the US Department of Energy and the California Energy Commission found an **average savings of 31% in HVAC energy through the use of ASHRAE 36[GS1] .**

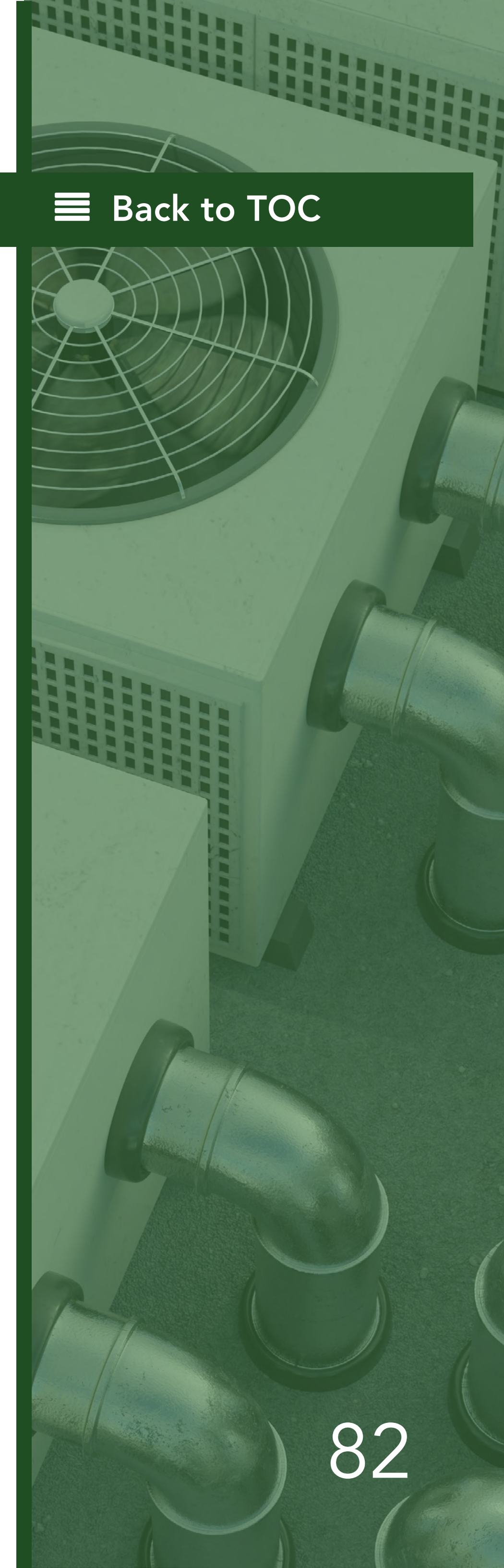
Who Benefits from Implementing ASHRAE Guideline 36

ASHRAE developed Guideline 36 to reduce the custom one-off nature of HVAC control systems and their associated cost by providing a standardized high-performance sequence of operations that can be utilized by multiple stakeholders. Ultimately, the HVAC control system manufacturer is providing the resources necessary for standardized programming and quality control to properly implement GL 36 SOO.

This approach provides major benefits to stakeholders throughout the process:

- **Design Firms:** ASHRAE GL 36 reduces the firm's need to spend designing and commissioning HVAC SOO without sacrificing quality. GL 36 complies with other established ASHRAE standards and CA title 24. ASHRAE Standards 90.1 (energy code) and 62.1 (ventilation) have started to reference GL 36 as a recommendation for implementing the codes in the respective standards.

- **Facility Managers:** GL 36 sequences ensure occupant comfort and provide **energy-efficient operations** while also allowing facility managers to perform their duties more efficiently.



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- **Executives:** GL 36 standardizes operations between multiple facilities while conserving energy and providing increased occupant well-being and comfort.

Specifying ASHRAE Guideline 36

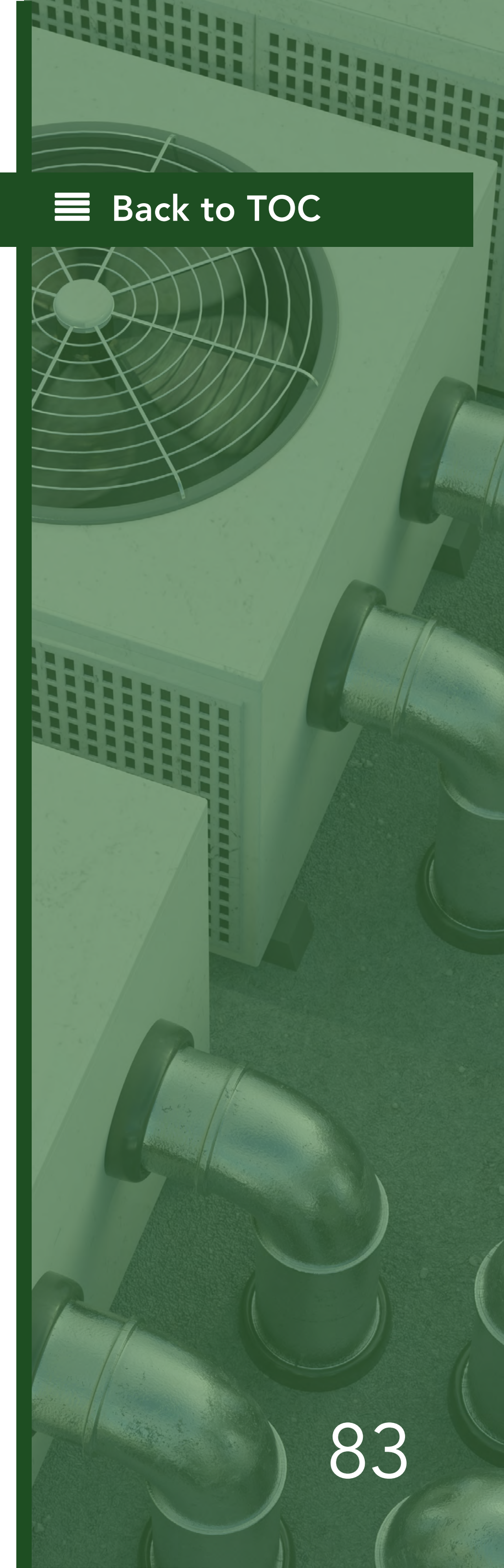
The benefits of ASHRAE Guideline 36 are clear, and the adoption of the guideline has increased as energy efficiency standards continue to advance in response to evolving emissions requirements. However, appropriate due diligence must be done when considering using GL 36 for a retrofit or brownfield project. Mature HVAC control product lines may not be able to support the advanced sequences of GL 36, and, in some cases, modernization of the HVAC control system may be required to fully comply with GL 36 on a retrofit project.

As of today, the guideline is still under revision, and it does not support certain kinds of HVAC mechanical equipment. Consultation with your manufacturer to learn best practices and whether the sequence implementation complies with GL36 is recommended.

When putting together a request for a proposal or specification document, make sure to be as detailed as possible when adding GL 36 content by including some of the following:

- Simply referring to the need to comply with the GL 36 in your spec or RFP.

- Referencing the specific section number– e.g., “Comply with ASHRAE Guideline 36 2021, section 5.5.”



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- Copy and paste from the original GL 36 document into your document, then edit as needed.

- Use a specification design tool. Check out the **Schneider Electric one** here.

For more information

To learn more, access our free and secure **Spec Designer tool**. With embedded ASHRAE 36 guidelines, this tool simplifies specification writing, helping you navigate the vast number of products, services, and technologies that are offered today.

Raf Sowacki, Digital Energy Division Northeast Consultant Solutions Architect
Raf Sowacki *is Schneider Electric's Digital Energy Division Northeast Consultant Solutions Architect. He offers solutions to support engineers in designing high-performance technologies to access data, sustainability, and innovation. His passion for serving others through his professional and personal life is what drives him. He partners with MEP consulting engineers to support them with education, tools, and resources in Smart Building Design, Predictive Analytics, Cybersecurity, and more. This includes vertical markets in commercial properties, data centers, healthcare, higher education, aviation, and government.*

Raf has supported facility managers throughout his career, starting as a technician and then becoming Service Operations Manager for a facilities systems EcoXpert integrator. He was the technology leader in the organization, where he was the single point of contact for all technical inquiries about computer networking, programming, BMS architecture, and general technology. Raf has an AAS degree in Electrical Engineering Technology from Nassau Community College.

Evaluating and selecting energy-efficient fans with fan energy index

Fan energy index (FEI) is a useful tool for engineers looking to compare the energy efficiency of fan system

For many years, brake horsepower (BHP) has been used as the primary fan energy metric to compare fan power requirements and schedule fans. However, BHP is an incomplete measurement of the total energy consumed by a fan system. It accounts for the aerodynamic and bearing losses of the fan system, but it ignores other components such as belts, pulleys, motors and variable frequency drives (VFDs).

In 2017 the Air Movement and Control Association International (AMCA) introduced the fan energy index (FEI) in ANSI/AMCA Standard 208 to provide a comprehensive fan system energy metric. In 2021, ANSI/AMCA Standard 214 was released, providing a test procedure for FEI calculations that could be incorporated by regulating bodies and energy codes. FEI provides a single energy metric that describes the full fan system, including the impact of any belts, pulleys, motors or VFDs. Anything between incoming power and outgoing air power affects the FEI value (see Figure 1).

What is FEI?

FEI is referred to as a “wire-to-air” metric because it considers the efficiency from the input power to the output power of a fan and converts it into a simple ratio. This ratio compares the electrical input power of a reference fan against the actual input power required by a selected fan at a specified duty point. AMCA 214 defines the calculation of the reference fan’s electrical input power as well as the testing and calculation of a fan’s actual electrical input power. Fan manufacturers calculate and present FEI val-

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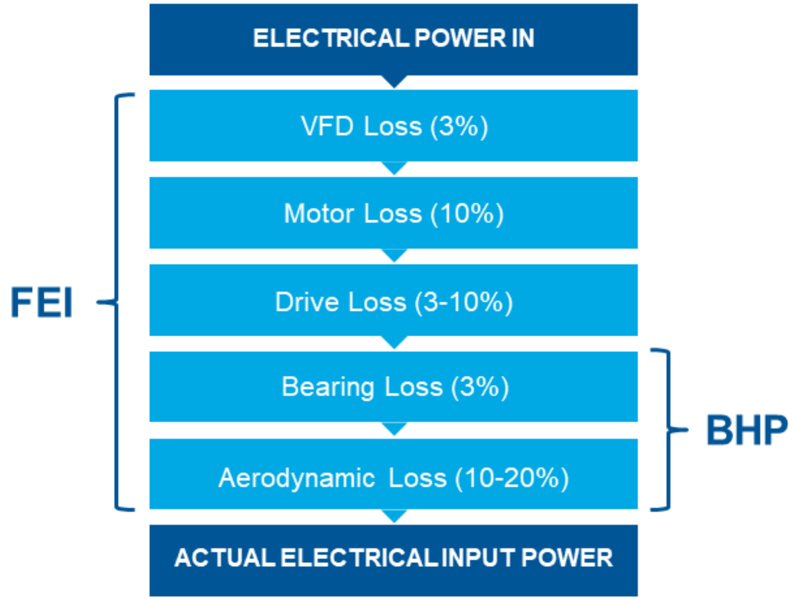

Figure 1: This image compares FEI fan power consumption with brake horsepower. Courtesy: Greenheck

ues in their product data. The baseline input power is uniform for comparable fans at a given duty point, making FEI an excellent comparison of a fan's wire-to-energy consumption across manufacturers. It also provides a more comprehensive energy metric that better describes the fan system on equipment schedules. A fan system with an FEI of 1.10 will use 10% less energy than the baseline fan or any fan with an FEI of 1.00.

FEI in fan system selection

While fan type is determined by the application, duty point and space constraints, FEI can be used to optimize the energy consumption of the fan system once the model has been determined. FEI allows the engineer to evaluate the energy impact of several fan system characteristics including impeller type, motor type and fan size. In general, a higher FEI value indicates a better overall selection.

Figure 2 is a sample fan equipment selection showing three similar inline fans at 3,500 cubic feet per minute and 1.5 inch static pressure, all with 1.35 bhp. The larger FEI value differentiates which fan uses the least energy. In this case, it is EF2, which uses an

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electronically commutated (EC) motor. EF1 and EF3 use traditional induction motors and incur losses due to VFDs. In addition, EF1 and EF3 feature different synchronous motor speeds, with one being a 4-pole and the other a 6-pole. FEI considers the input power of these different motor types to determine which fan uses the least energy. FEI quickly highlights inferior fan systems during the submittal review. Without FEI, these selections would appear the same if only BHP were compared.

	Model Name ↑	Actual CFM	Total External SP (in. wg)	Inlet Sones	Motor Size (hp)	Bhp	FEI
EF1	SQ-16-M2	3,500	1.500	16.6	1.5	1.35	1.29
EF2	SQ-16-M2-VG	3,500	1.500	16.6	2	1.35	1.40
EF3	SQ-16-M2	3,500	1.500	16.6	2	1.35	1.28

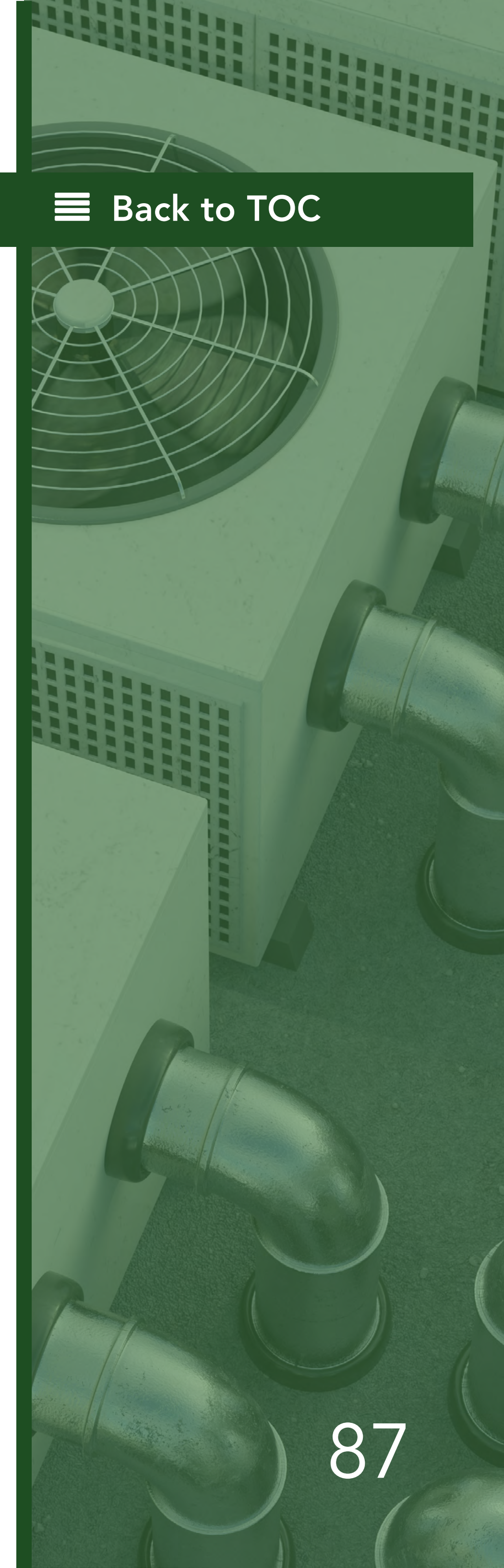
Figure 2: A sample fan equipment selection with three similar inline fans at 3,500 cubic feet per minute and 1.5 inch static pressure, all with 1.35 bhp. Courtesy: Greenheck

Using FEI in fan system selection

Higher FEI offers additional advantages for evaluating and selecting the optimal fan system for the application including:

- Higher FEI values equate to lower energy consumption, which means lower operating costs and carbon emissions.

- Higher FEI fans may have a more forgiving selection point. By optimizing FEI, the fan selection likely becomes more central in the fan curve, as shown in Figure 3. This provides more forgiveness against unforeseen static pressure impacts in the field.



- Higher FEI fans are usually quieter. FEI can be increased by upsizing the fan and reducing the fan speed, resulting in quieter operation.

FEI quickly highlights inferior fan systems during the submittal review. A small difference in FEI can indicate a significant difference between comparable fan systems. If there is a noticeable difference between FEI values in seemingly similar fan systems, check the following:

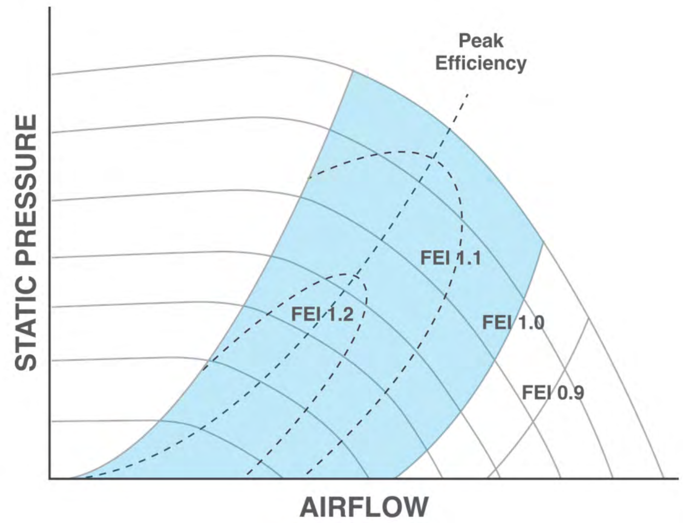


Figure 3: A fan curve that shows a fan operating at multiple speeds. Courtesy: Greenheck

- Are both fans using the same drive type (direct versus belt)?

- Are both systems using the same motor technologies (EC versus induction)?

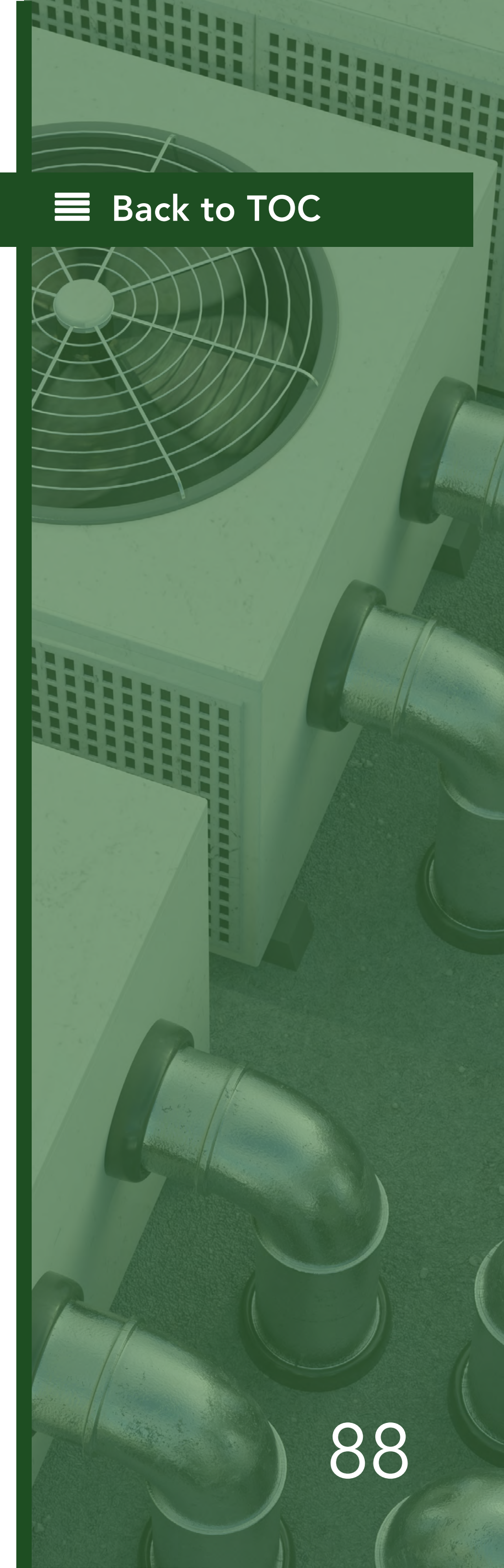
- Are the motor voltage, phase, horsepower (hp) or poles different?

- Are all fan controls, like VFDs, being included?

- Did the sound increase?

- Is there a difference in impeller technology (mixed flow versus centrifugal)?

- Are the fans the same type?



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FEI in codes and standards

FEI is currently included in energy codes and standards. FEI was incorporated into the 2019 version of ASHRAE Standard 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings. In 2021, FEI was included in the International Energy Conservation Code (IECC-21). Both ASHRAE 90.1-2019 and IECC-21 set minimum FEI values for compliance. Many states have already adopted 90.1-2019 and IECC-21, and several others are in the process of doing so.

There are exceptions to FEI requirements in the ASHRAE Energy Standard code for out-of-scope cases or where other considerations apply, including:

- Non embedded fans with a motor nameplate horsepower of less than 1.0 hp (0.75 kW) or with a fan nameplate electrical input power of less than 0.89 kW.

- Embedded fans and fan arrays with a combined motor nameplate horsepower of 5 hp or less or with a fan system electrical input power of 4.1 kW or less.

Embedded fans that are part of the equipment listed under Section 6.4.1.1. of ASHRAE 90.1-2022.

- Embedded fans included in equipment bearing a third-party-certified seal for air or energy performance of the equipment package.

- Ceiling fans, i.e., nonportable devices suspended from a ceiling or overhead structure for circulating air via the rotation of fan blades.

- Fans used for moving gases at temperatures above 482 F (250 C).
- Fans used for operation in explosive atmospheres.
- Reversible fans used for tunnel ventilation.
- Fans outside the scope of AMCA 208.
- Fans when operating during emergency conditions.

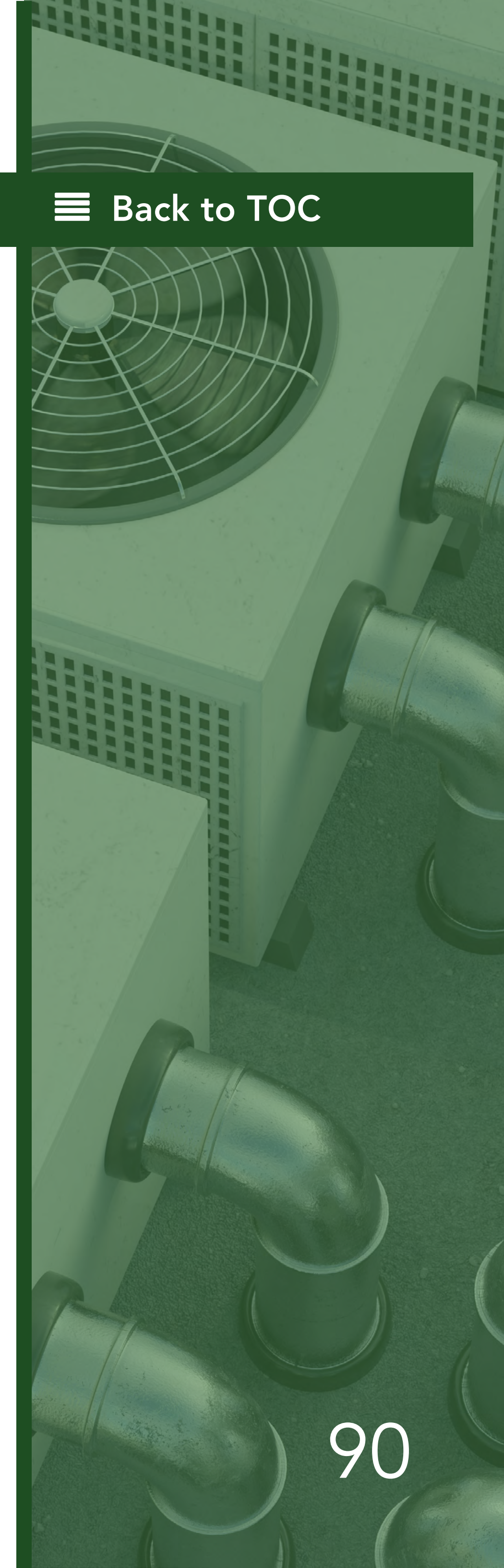
The Department of Energy (DOE) is expected to federally regulate fan products using FEI in 2029. The DOE may require minimum FEI values above those established in ASHRAE 90.1-2019 and they may be unique for each fan type. The DOE will also have FEI requirements for fans embedded in nonregulated equipment.

FEI recommendations

FEI is a powerful engineering tool for designing energy-efficient, code-compliant ventilation systems.

The following are suggested to keep up with rapidly changing codes around FEI:

- Even if your state has not yet adopted a code that requires FEI, update equipment schedules to include FEI. This will keep you ahead of code and regulatory requirements and ensure optimal fan performance on your projects.
- Schedule duty point FEI values by using up-to-date manufacturer fan selection tools to optimize FEI and ensure compliance.



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- Use caution when presented with value-engineered alternatives with lower FEI values as this may indicate a significant change.

- Schedule and hold duty point FEI values to prevent inferior fans from making their way into your design.

- IECC mandates third-party certification to comply with code requirements. Specify AMCA-certified FEI values to ensure the fans selected will perform as advertised.

Ken Kuntz

Ken Kuntz *is Greenheck's Director of Strategic Technologies, Regulatory Development and Testing. He has served in various engineering roles within Greenheck for the past 17 years and holds a bachelor's degree in mechanical aerospace engineering from the University of Missouri.*

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Considerations for successful planning and design of CHP systems

Combined heat and power systems provide solutions for lowering utility costs, increasing electrical and heat source reliability and providing resilience for continued facility operation

Combined heat and power (CHP), or cogeneration, is a process where electricity and usable heat are produced coincidentally. The benefit of CHP is increased energy use efficiency compared to traditional utility power generation from the grid and heat from a local source – such as a facility steam boiler. Limiting factors preventing widespread expansion in the early development days included the physical separation of power-generating facilities from industrial hosts and utility control of the sale of generated electricity to customers.

However, CHP has always been popular in heavy industrial or campus facilities, where substantial amounts of electricity and thermal energy are used continuously.

CHP plants offer upward of 80% increased overall efficiency, which reduces energy cost, lowers emissions, lessens the greenhouse gas footprint through less fuel consumption and improves reliability by locating a backup source of electrical generation at the host site to protect against grid outages.

CHP basics

The U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, defines the CHP process as "the concurrent production of electricity or mechanical power and useful thermal energy (heating and/or cooling) from a single source of energy."

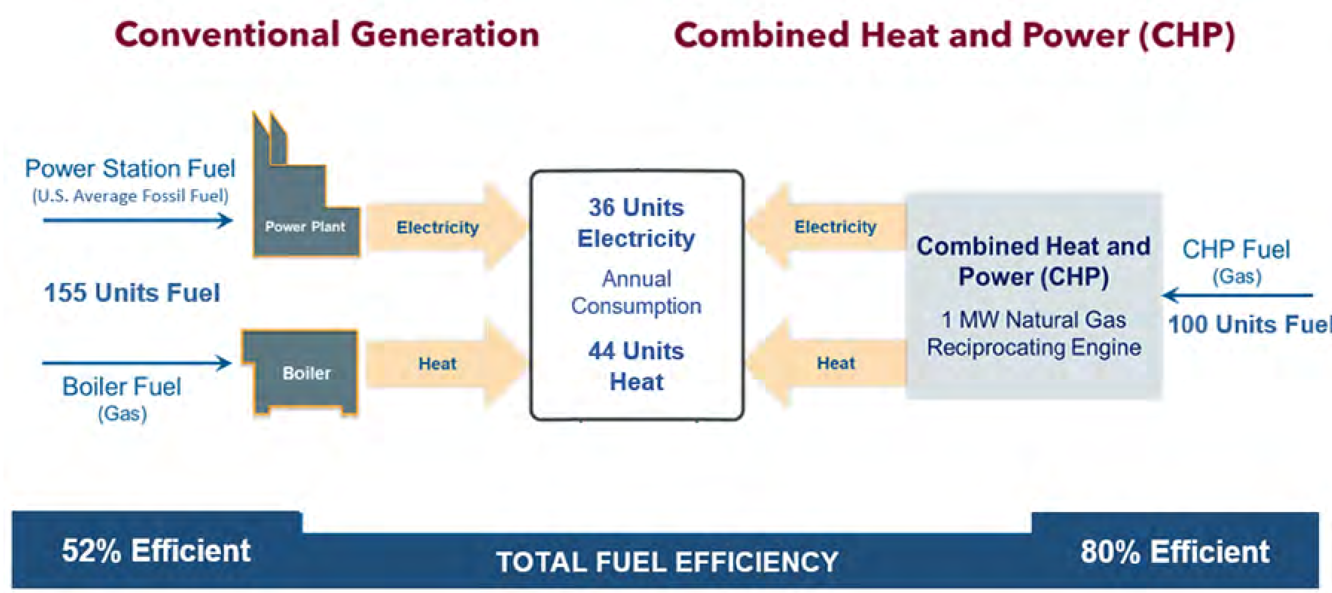
While this basic definition allows for several different input fuels to have a variety of outputs, this article is based on natural gas as the input fuel and electricity with a heat supply as the output.

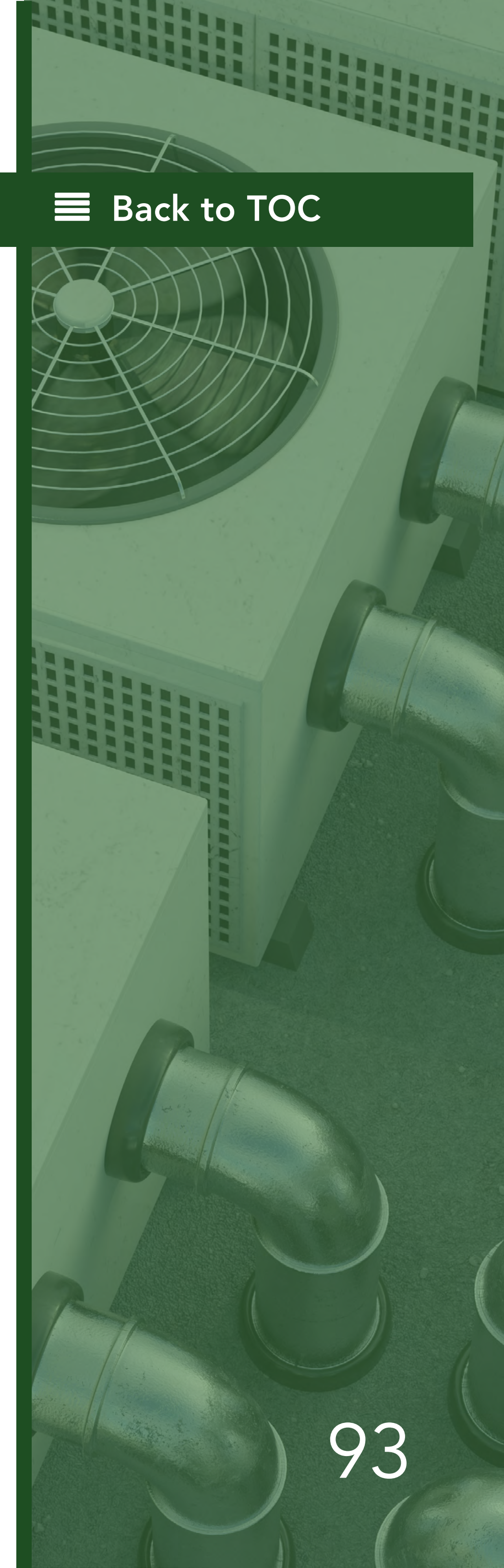
Current CHP trends

Because natural gas is the most common fuel for CHP facilities, recent trends are driven by low natural gas prices, the desire to lower greenhouse gas footprint and financial incentives from the government's green energy initiatives. Proponents of CHP have stipulated that distributed generation, meaning noncentralized electrical power generation, helps avoid the need for new electrical transmission and distribution infrastructure and eases power grid congestion.

With the rapid advancement of electric vehicles and renewable energy generation, the country's electrical transmission

Figure 1: This diagram shows energy efficiency by source use for conventional power generation as compared with combined heat and power. Courtesy: PEC – A Zero6 Energy Company





and distribution infrastructure will be pushed to the limit and CHP can assist in this transition.

CHP projects may be implemented for a variety of facility types and for a variety of sizes depending on parameters. There are drivers for each system type and size that are based on the specific site needs, including financial restrictions, owner needs and process requirements.

In most cases, large CHP projects are the most viable and successful because of economies of scale. Large-scale energy cost savings in fuel and electricity provide enhanced payback when compared to overall capital expenditures and the level of effort required to execute a successfully CHP project. Additionally, large CHP hosts or owners are often familiar with the integration and operation of these types of complex facilities.

Small CHP projects have been more successful recently due to the fully integrated packaged designs developed by equipment integrators. These small CHPs are marketed as either containerized or “plug-and-play,” where a host can simply purchase a fully integrated package and install the CHP within their existing system infrastructure. Examples of these types of systems are microturbines with heat recovery, reciprocating engine generators with hot water heat recovery systems and waste heat packages that produce usable energy from heat that would normally be exhausted to the atmosphere.

CHP success factors

Numerous factors contribute to the successful implementation of a CHP project, but the following are generally most prevalent:

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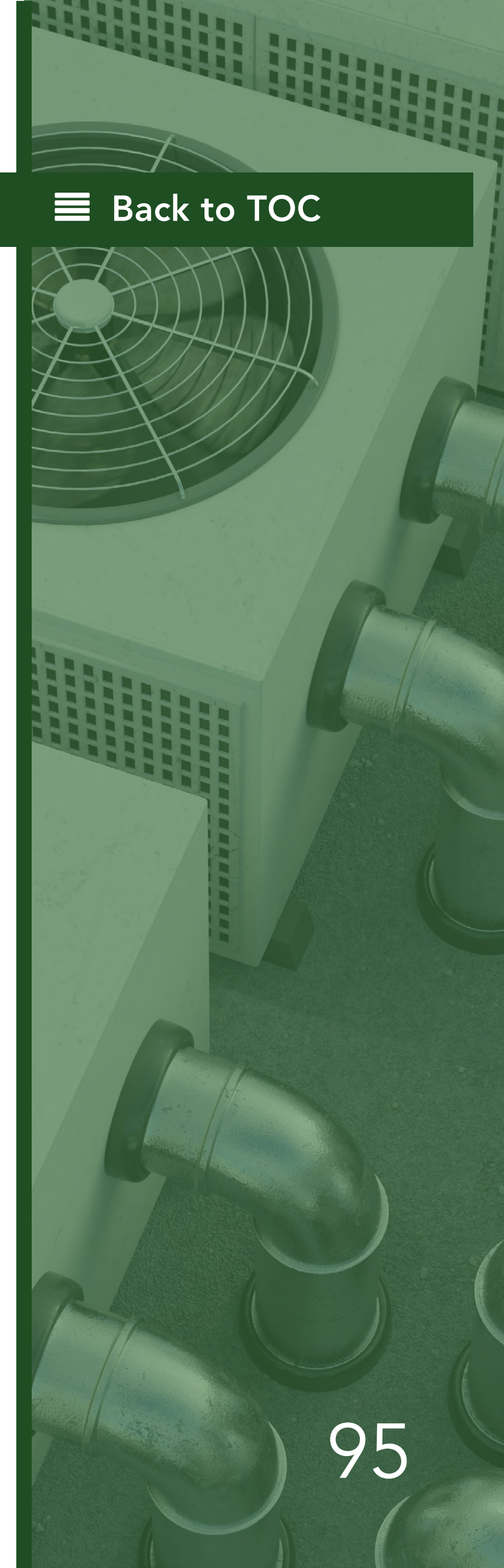

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- The project is in an area where the electrical utility is a proponent of CHP or open market electrical interconnection conditions exist. Many projects fail because the interconnection of a distributed generation asset is blocked by the utility, even if the host's desire is only to serve internal, "behind the meter" electrical demand. Islanding or disconnecting from the utility completely often derails projects because of the high cost of redundant generation assets and reliability risk factors.

- There is continuous electrical and thermal energy demand of reasonable size. Electrical and thermal demand needs to "match" in a certain range. Projects are generally not successful if one or the other is abnormally small. A CHP design configuration can be selected as more "electrical power dense" or "thermal concentrated," but generally a continuous demand of some minimum size is required for a CHP to make sense.

- Payback on CHP energy cost savings are attractive enough from a capital expenditure standpoint. A CHP host can either deploy available capital or enter a contract to buy energy from a third-party-owned CHP on the host site. In many cases, the host's core business is completely unrelated to the CHP and the savings payback potential is not worth that capital commitment. Many hosts prefer to deploy available capital to their core business interests. Additionally, signing long-term agreements, generally 15-20 years, with a third party is often challenging from a business commitment and financing perspective. However, if energy cost is a substantial component of the host's operating cost structure and the savings payback is significant, a CHP project can be successful.

- The host is motivated by outside factors. This may include emissions reductions, desire to lower their greenhouse gas footprint, necessary replacement of existing energy infrastructure or expansion of energy users such as electrical and thermal as part of a facility expansion.

Design considerations for CHP systems

There are numerous design considerations when planning for a CHP facility. The considerations are typical for most large and small CHP systems and are driven by equipment options, local building codes and owner needs. The design team for a CHP system needs experienced project partners to successfully implement a system, whether a standalone structure or an integrated system.

Combined heat and power systems include many different systems, each individually addressed in building codes. These systems include boilers, turbines and electrical distribution gear. These systems are supported by other building utilities including natural gas distribution, ventilation systems, lighting, fire alarm, security/surveillance and general plumbing systems. There are numerous sub-sets of these main systems to support the overall process system of CHP.

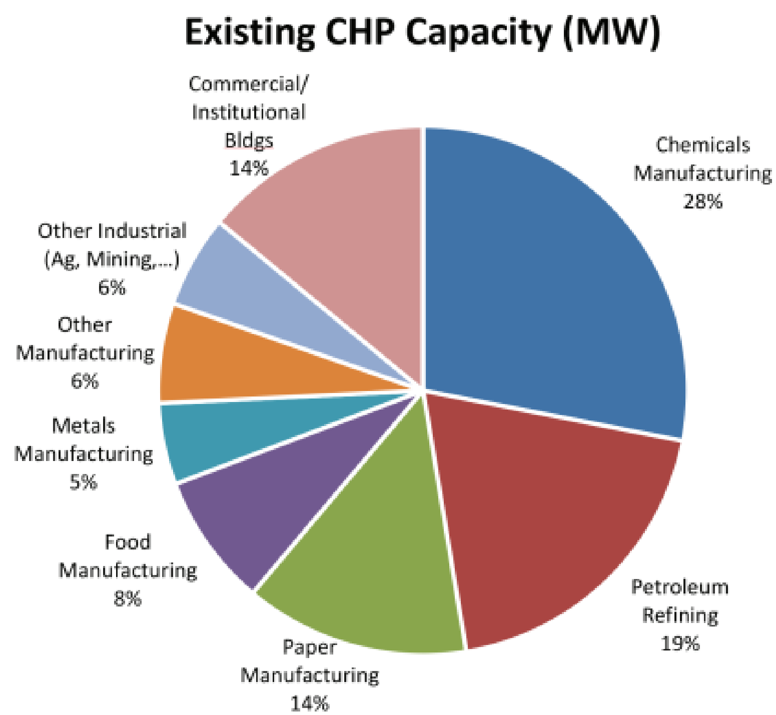

Figure 2: A diagram that separates out the percentage of combined heat and power currently in use. Courtesy: PEC – A Zero6 Energy Company

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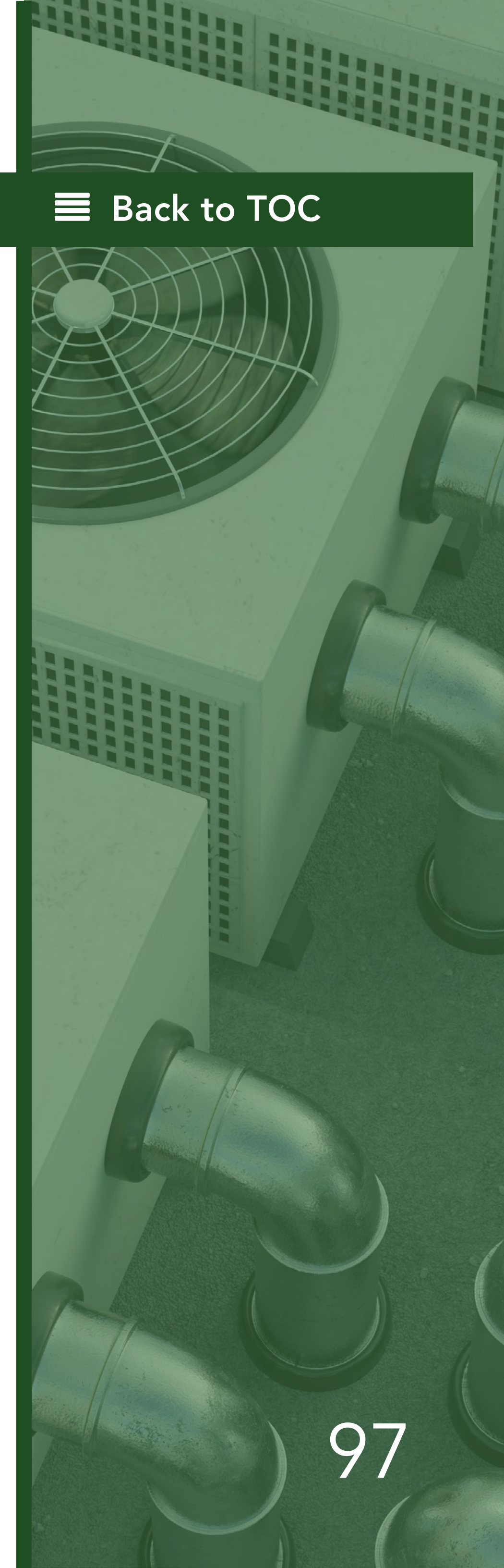
Figure 3: A model of the combined heat and power cycle for the Dearborn Central Energy Plant. Courtesy: PEC – A Zero6 Energy Company

Available CHP equipment, including specialized boilers, turbines and electrical gear, will primarily drive the building layout. This equipment is typically specialized for the specific installation and requires close coordination with the equipment manufacturers to ensure the systems can provide the required capacity and capability. Building size will further be driven by the available space on a site. Often a single-story structure will be the most cost-effective, but site constraints require a multistory building to house the equipment.

A CHP facility needs to house the primary process equipment and allow for the utility connections to serve this equipment. As mentioned, there are several sub-systems required to support a CHP process that require space in and around the building in addition to the space requirements for the direct process equipment.

Sub-system space considerations include:

- **Input fuel source:** An example of this is natural gas that requires space for a large meter assembly on the building exterior and close coordination with the supplier



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to ensure adequate supply during normal operation and through any unexpected events that may affect the distribution system.

- **The transformation, metering and distribution of electrical power:** This electrical distribution needs to comply with utility requirements for metering, isolation and other standards. Commonly, electricity is generated through a turbine utilizing boiler steam or hot water from a generator or engine jacket. This hot temperature medium is then fed through a turbine generator to produce electricity. The electricity from the turbine may be medium voltage that requires transformers and other gear in a separate electrical room to convert it into a usable type for the building or campus.

- **Support space for CHP operators:** While the CHP process may be set up to be automated, operators are still required to perform maintenance, oversee the process and be available to address operational issues as they occur.

Codes and standards to consider when designing CHP systems

An important part of the design for a CHP process is compliance with local building codes. Different areas in the U.S. utilize different versions of codes, some current, some a few years old. Generally, in the U.S. compliance with International Code Council (ICC), such as the International Building Code, International Mechanical Code and the International Energy Conservation Code, are the minimum requirement, though some areas of the country utilize uniform codes or other standards. The design team must identify early on which codes are in effect for the project location, especially if the design team includes project partners from different areas of the country.

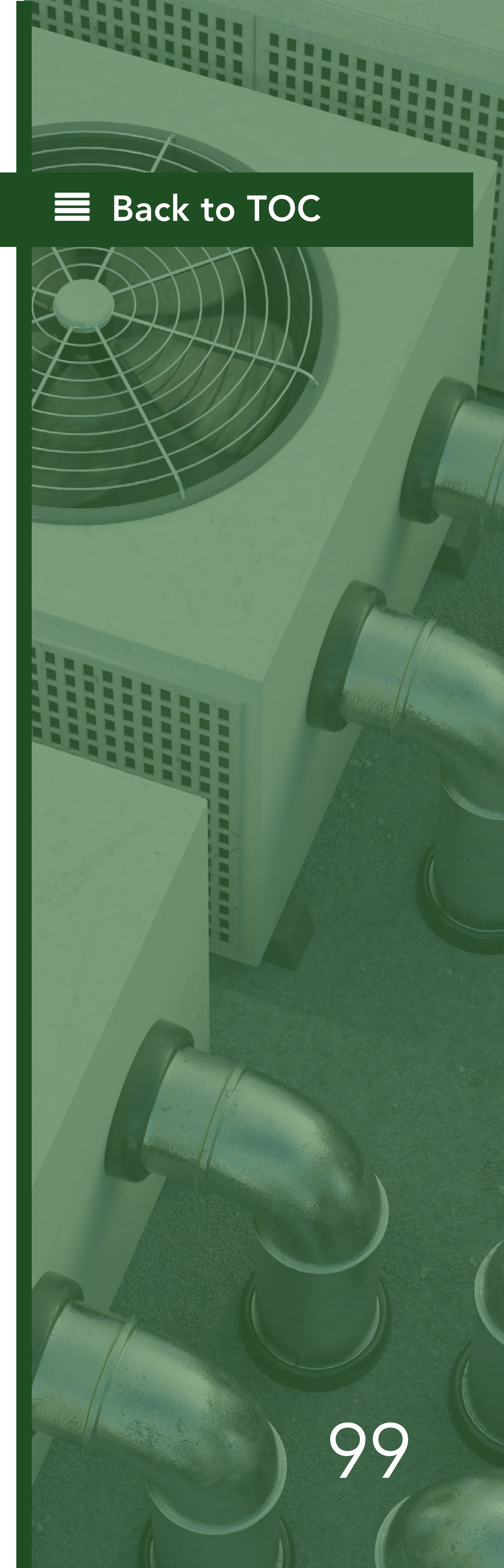

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Figure 4: The University of Wisconsin Charter Street Heating Plant is based off a "thermal concentrated" combined heat and power design. Courtesy: PEC – A Zero6 Energy Company

Commonly, utilizing the ICC codes for the specific years adopted by the local authority having jurisdiction (AHJ) will provide 70% of the project's code requirements. The AHJ may provide other information that is focused directly on CHP systems, such as New York City's Building Code and Energy Code, which provides specific separation and efficiency requirements that must be met for code compliance. Another source of information for planning and design of CHP systems is located in the National Fire Protection Codes (NFPA), including NFPA 13: Standard for the Installation of Sprinkler Systems, NFPA 70: National Electrical Code and NFPA 110: Standard for Emergency and Standby Power Systems. It is important that the design team carefully considers other NFPA standards that may apply to the project and ensure that the design meets a standard of care by using the best resources available.

Additional CHP requirements and considerations

Owner requirements may be considered the most important part of the design process, because without these requirements the project may not exist. The project owner could be a system developer, process company or other organization providing project

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funding. There are a few common goals of a CHP project including: to increase electrical reliability on a site with the benefit of an additional heat source, to provide the facility with the ability to go off-grid and be standalone from the local electrical utility or to increase project resilience for the facility in the aftermath of a natural disaster by quickly reengaging the process and systems at a facility.

There are many resources beyond building codes to consider when designing CHP systems. The Environmental Protection Agency provides basic resources for planning and designing CHP systems focused on increasing reliability and resilience in buildings, particularly for protecting buildings during and after natural disasters.

Environmental compliance is an integral part of establishing a CHP system for a facility. Compliance standards vary throughout the country and each location may have specific requirements beyond those of federal or state codes. It is imperative that the project team include an early review of allowable discharge limits, site approval and general conformance with land use requirements before starting a CHP project. These requirements may greatly affect the size and location of a CHP project as well as the construction and operation of the facility.

Jason Gerke, PE, CxA, LEED AP BD+C and Anthony Chmielewski

Jason Gerke, PE, CxA, LEED AP BD+C, *is Practice Area Leader – MEP | Principal, at GRAEF,* ***Anthony Chmielewski*** *is a Principal at PEC - A Zero6 Energy Company.*

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