2020
CONSULTING - SPECIFYING
engineer
eBook Series

SUMMER EDITION

# HVAC

» *Cooling coil condensate system design*

# Contents

GRUNDFOS

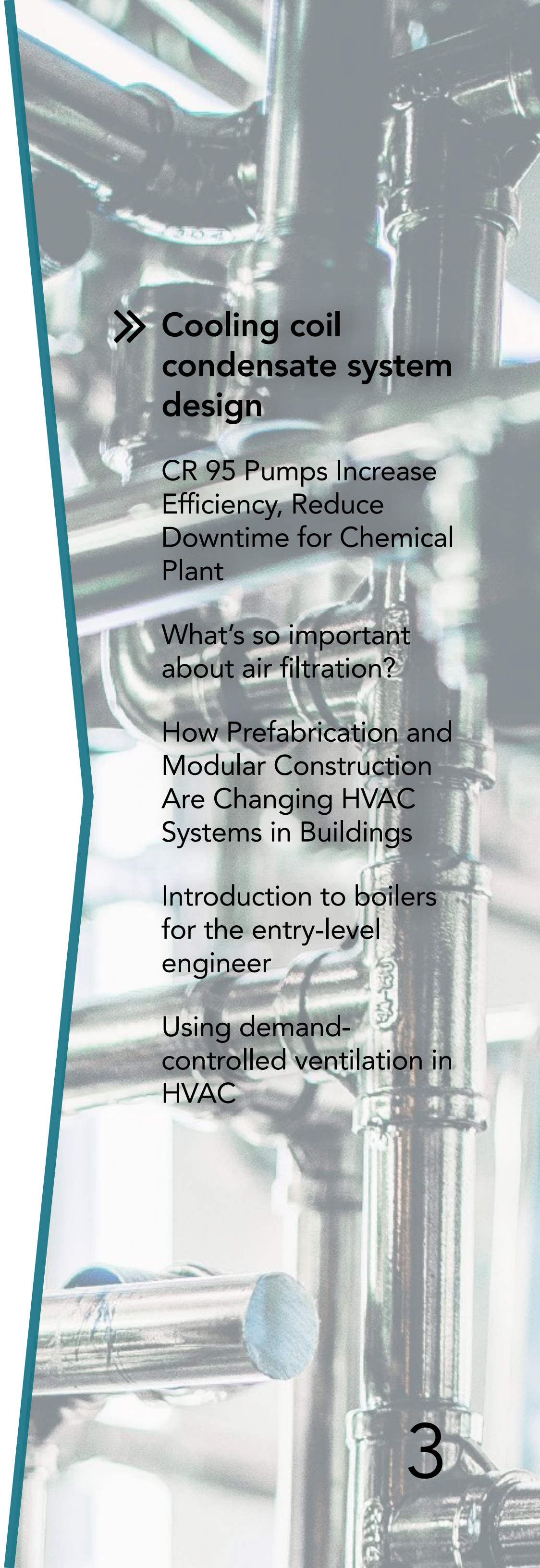
# Cooling coil condensate system design

*Cooling coil condensate is an important aspect of HVAC system design and should be carefully considered to avoid major issues in the future*

One afternoon a mechanical contractor reported a situation on a project. He said the cooling coil drain pan inside the air handler was flooding. He also advised that the condensate pipe was not draining any water. We were surprised and couldn't think about what could have gone wrong. We went to the site and found that drain pan and the air handling unit floor was flooded and the fan inside the air handler was wet. When the coil section door was opened, however, the water in the pan drained very quickly.

We had studied the design of the condensate trap. We inspected the trap to figure that the difference in elevation between the AHU drain pan outlet and the exiting end of the U trap (termed here "H") was zero. The reason this was happening was the coil section was at negative pressure since this was a draw through AHU. Since the "H" of the trap was zero, the suction pressure through the U trap inhibited the draining of any water. This leads to the accumulation of water in the drain pan and resulting flooding inside the AHU (see Figure 1).

Once we fixed the trap, the problem went away. It came at the cost of $2,000, which included the cost to raise the AHU by 4 inches. The client was not happy about the change. There have been other cases where the AHU had to be raised, or condensate pumps had to be installed because the details were not thought out during design. The cost of these changes could be in the tens of thousands of dollars.



Ignoring coil condensate design makes engineers look incompetent. It can cause health issues because of mold and algae growth when not noticed early. Sizing the condensate trap is commonly overlooked, and there is no good literature that covers all aspects of design.

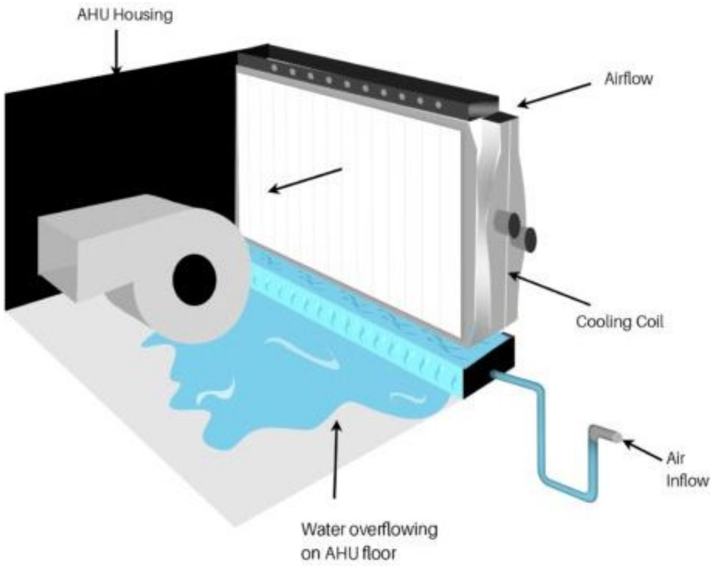


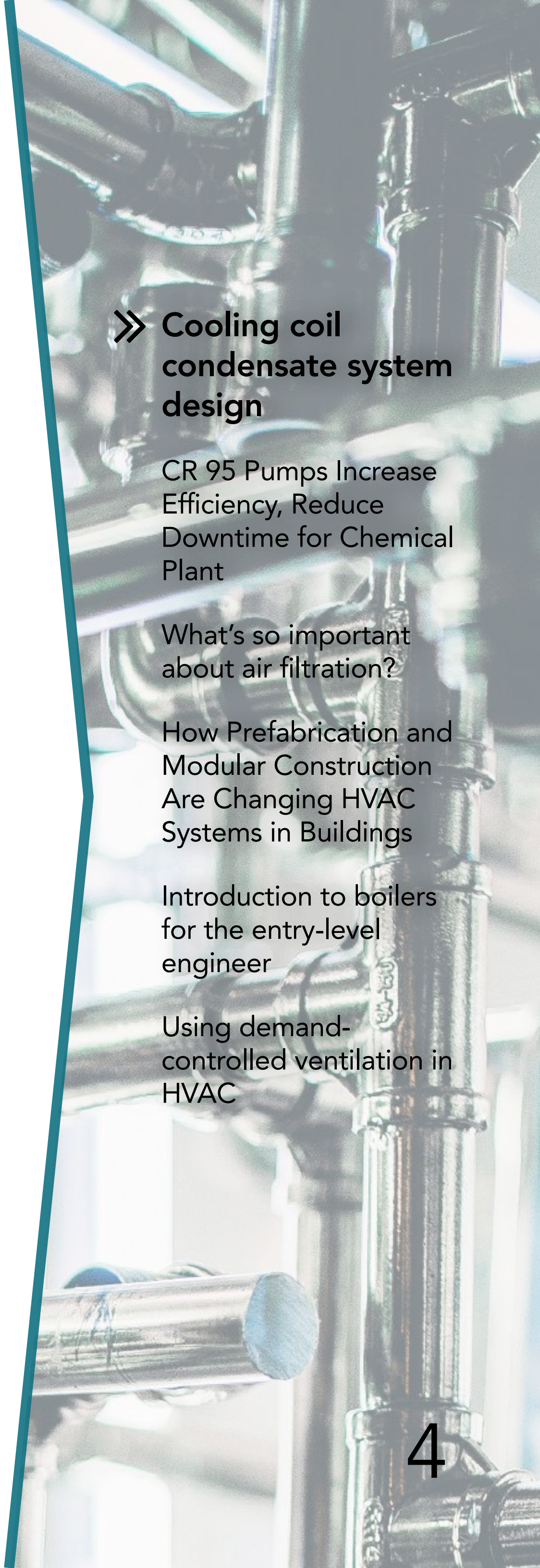
FIGURE 1: Drain Pan Flooding

***Figure 1:*** *Drain pan flooding example illustrates the situation discussed. Courtesy: EXP Global*

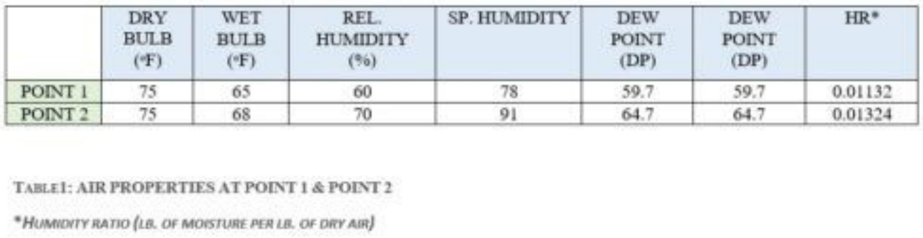
## What is condensation?

When people think of condensation, it's common to think of water droplets accumulating on a glass of water with ice or mist accumulating on a car windshield. Humid air condenses easily, which means condensation is much more common in Miami as compared to Phoenix. An air conditioner that moves air at higher velocity produces condensate at a higher rate because condensate volume is proportional to the supply flow rate and the air density. Lower density air will result in a lower condensation rate. In engineering terms, condensation occurs when air hits a surface cooler than its dewpoint temperature. This is what happens at coil surfaces inside an AHU.

Latent heat is transferred by moisture in the air to the coil via the process of condensing on the surface of the cooling coil. Upon completing a psychrometric chart, we can see when relative humidity increases from 60% to 70%, dewpoint increases (see Table 1).



As a result, it becomes easier for water to condense on the cooling coil. The higher relative humidity also means that the moisture content of the air is higher (expressed as the humidity ratio or specific humidity) and thus more moisture can potentially be condensed on the coil.



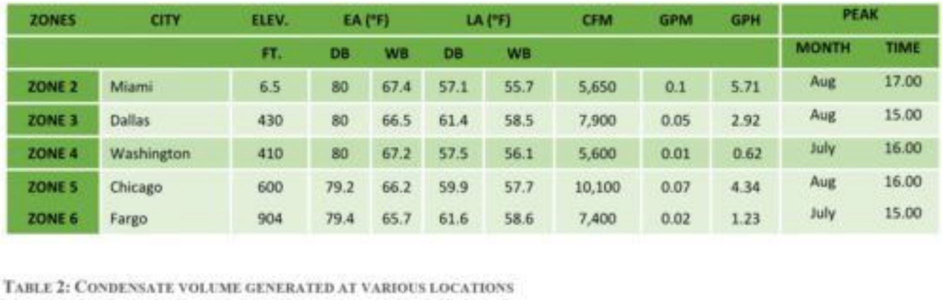
| | DRY BULB (°F) | WET BULB (°F) | REL. HUMIDITY (%) | SP. HUMIDITY | DEW POINT (DP) | DEW POINT (DP) | HR* |
|---|---|---|---|---|---|---|---|
| POINT 1 | 75 | 65 | 60 | 78 | 59.7 | 59.7 | 0.01132 |
| POINT 2 | 75 | 68 | 70 | 91 | 64.7 | 64.7 | 0.01324 |

TABLE1: AIR PROPERTIES AT POINT 1 & POINT 2

*HUMIDITY RATIO (LB. OF MOISTURE PER LB. OF DRY AIR)

**Table 1:** *Air properties shown at points 1 and 2. Courtesy: EXP Global*

The condensate generated gets collected in a drain pan, which is placed below the cooling coil. The pan must be drained continuously to prevent overflowing and causing any equipment damage. Failing to do so leads to unwanted problems, including biological growth such as algae. Using a mathematical formula to calculate condensate volume can help users find the right medium.



| ZONES | CITY | ELEV. | EA (°F) | | LA (°F) | | CFM | GPM | GPH | PEAK | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | FT. | DB | WB | DB | WB | | | | MONTH | TIME |
| ZONE 2 | Miami | 6.5 | 80 | 67.4 | 57.1 | 55.7 | 5,650 | 0.1 | 5.71 | Aug | 17.00 |
| ZONE 3 | Dallas | 430 | 80 | 66.5 | 61.4 | 58.5 | 7,900 | 0.05 | 2.92 | Aug | 15.00 |
| ZONE 4 | Washington | 410 | 80 | 67.2 | 57.5 | 56.1 | 5,600 | 0.01 | 0.62 | July | 16.00 |
| ZONE 5 | Chicago | 600 | 79.2 | 66.2 | 59.9 | 57.7 | 10,100 | 0.07 | 4.34 | Aug | 16.00 |
| ZONE 6 | Fargo | 904 | 79.4 | 65.7 | 61.6 | 58.6 | 7,400 | 0.02 | 1.23 | July | 15.00 |

TABLE 2: CONDENSATE VOLUME GENERATED AT VARIOUS LOCATIONS

**Table 2:** *Condensate volume generated at various locations. Courtesy: EXP Global*

Condensate volume can be calculated for specific situations. This is based on 2017 ASHRAE Fundamentals, Chapter 1 Section 8: numerical calculation of moist air properties.

From the above equation, we can conclude the volume of condensate generated is a measure of the specific humidity of air entering the AHU, which is a function of the dry bulb and wet bulb of the air and local elevation. To put this in perspective, condensate volume generated for an identical building with identical occupancy and orientation in five different climate zones was compared. A commercial–grade load calculation software to perform these calculations was used. Ventilation rate was calculated per Chapter 4 of 2015 International Mechanical Code. Assumptions are listed below. See results in the Table 2:

Use: Office building

Building size = 10,000 square feet, Occupancy = 250 square feet/person, Miscellaneous load = 1 workstation/person

The identical orientation of the building for all zones

U values for roof, walls, windows as per the 2013 edition of ASHRAE 90.1: Energy Standard for Buildings Except Low-Rise Residential Buildings.

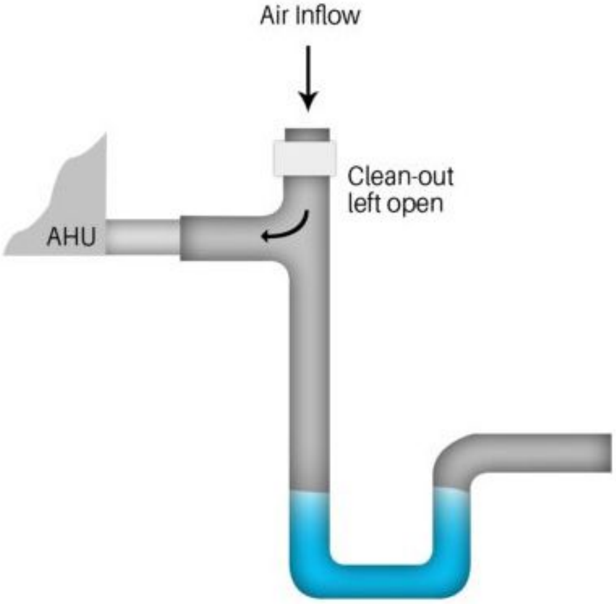


FIGURE 4A: CLEANOUT LEFT OPEN

***Figures 4A, 4B and 4C:*** *Example of problems due to incorrect design and installation of condensate piping. 4A shows the cleanout left open; 4B has no trap installed; 4C has a trap with H = 0. Courtesy: EXP Global*

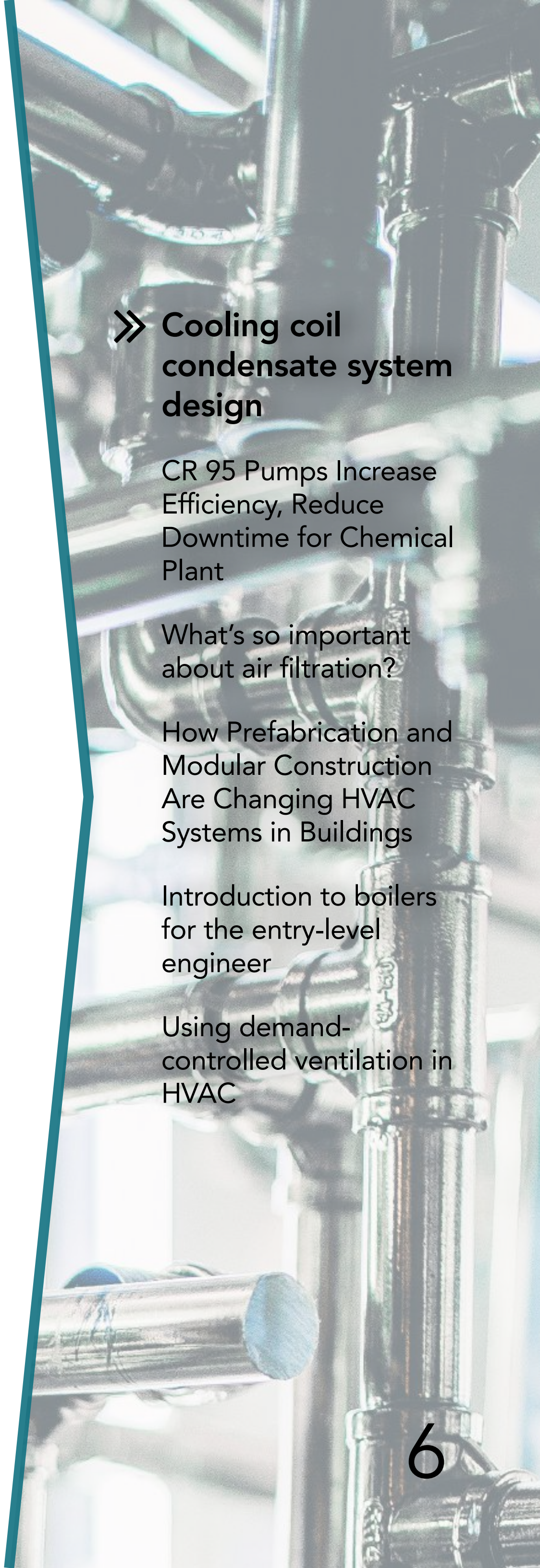


Table 1 gives an overview of how the amount of condensate collected varies in different climatic conditions.

There could be various scenarios where incorrectly installed trap and condensate piping can lead to issues. Following are most common causes issues observed:

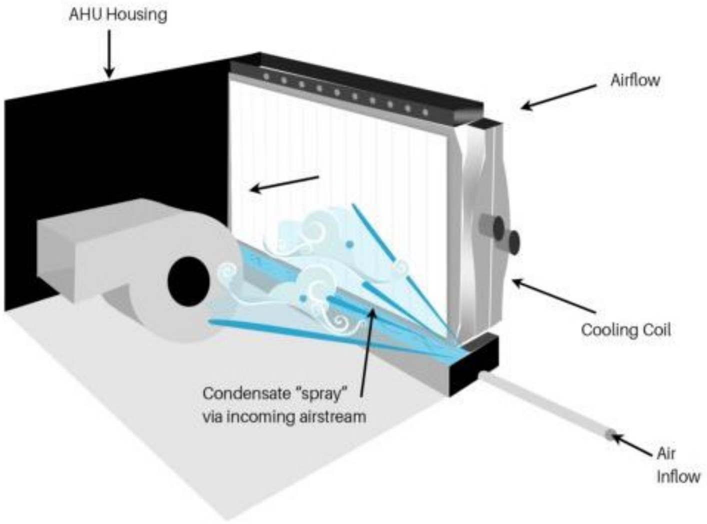


FIGURE 4B: NO TRAP

***Figures 4A, 4B and 4C:*** *Example of problems due to incorrect design and installation of condensate piping. 4A shows the cleanout left open; 4B has no trap installed; 4C has a trap with H = 0. Courtesy: EXP Global*

**No trap/trap too short:** The water in the drain pan will not drain, causing flooding and air spray effect inside the AHU (see Figures 4B and 4C). The negative pressure will cause the air to backflow into the system. This incoming air stream due to the negative pressure created by the draw–through fan could have enough velocity to pick up droplets from the water at the bottom of the drain pan and cause a spray/mist (see Figure 4A). The mist carried by air can make the fan and ductwork wet and create humidity issues in space.

**Shared trapping:** Having a single trap for multiple units is a poor way to design a condensate trap. There can be a scenario where the fans of connected units are operating at different static pressures. The unit operating with greater static pressure will result in drawing air through the drain line of another unit. It can lead to a similar effect as described in Figure 4B.

**Air locking in the pipe due to improper supports:** Incorrectly supporting of condensate pipe will result into sagging of the pipe creating an airlock, which can, in turn, result in flooding of the pan as shown in Figure 4C.

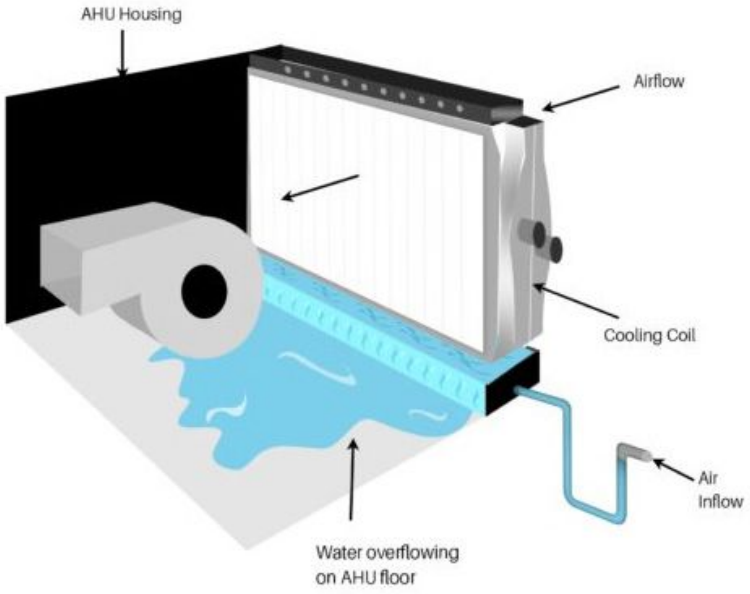


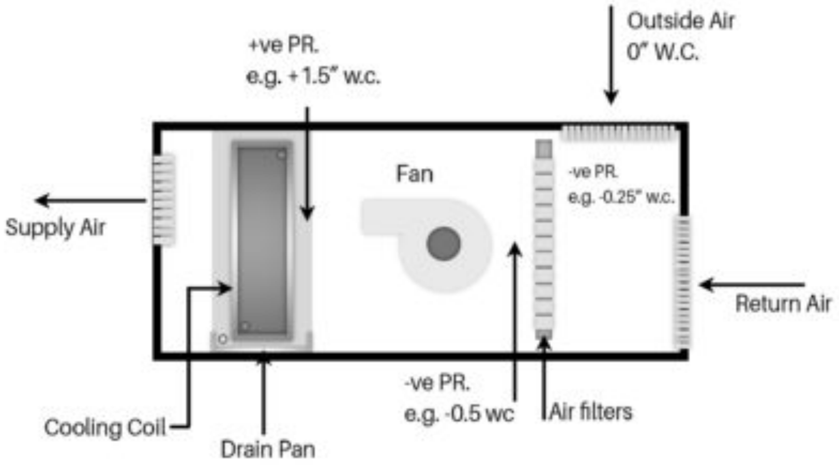
FIGURE 4C: TRAP WITH H=0

***Figures 4A, 4B and 4C:*** *Example of problems due to incorrect design and installation of condensate piping. 4A shows the cleanout left open; 4B has no trap installed; 4C has a trap with H = 0. Courtesy: EXP Global*

**Inadequate slope:** Condensate usually travels by gravity, and therefore piping should be pitched in the direction of flow per IMC (see code requirement section below). This is a commonly observed issue. Designers usually find during construction that condensate piping cannot be pitched due to several site-specific conditions. Engineers often specify condensate pump during construction to resolve this issue.

**Condensate pump integral to precision cooling units:** Several times the condensate pumps inside the computer room air conditioning or other precision cooling units do not have enough head to pump water to the floor drain that is 100 feet away. Evaluating this during design can prevent a headache and costly change orders.

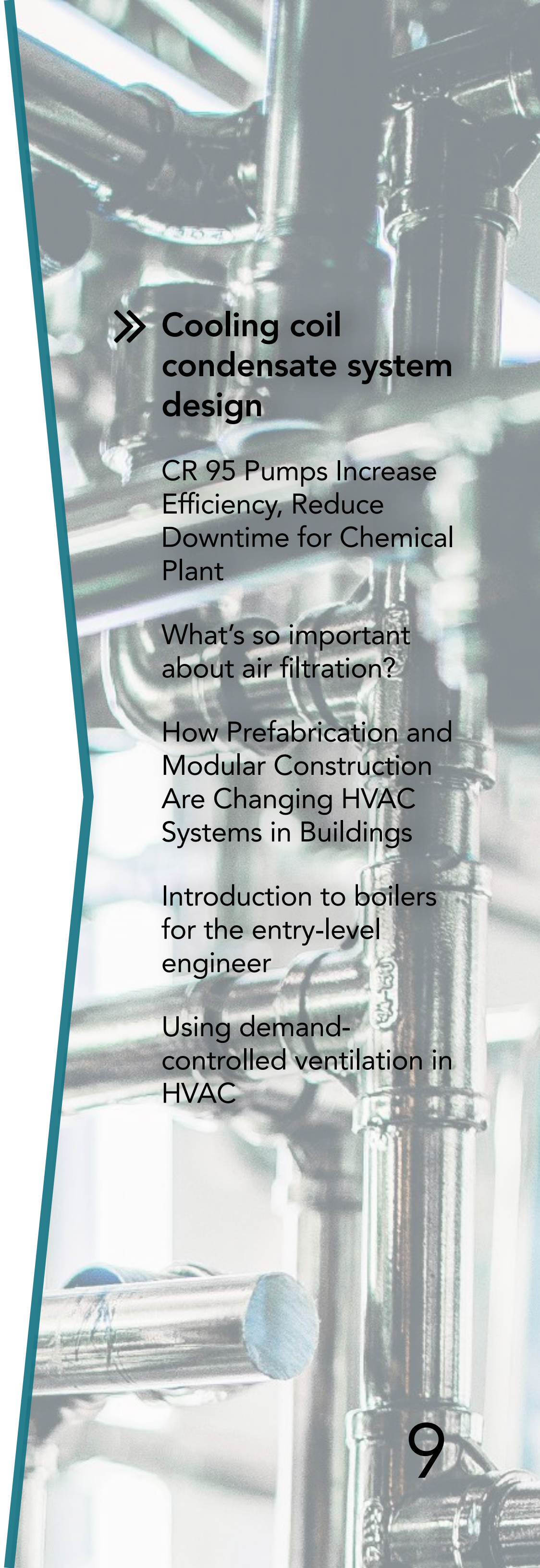
## Designing a trap



***Figures 5A, 5B and 5C:*** *Examples of blow-through AHUs in different stages. 5A is a general example of a blow-through AHU. 5B shows a trap for a blow-through AHU with the fan off; 5C shows it with the fan started. Courtesy: EXP Global*

For blow-through units, the trap must be designed as shown in Figures 5B and 5C to avoid the problems associated with condensate traps. Ideally, it is recommended to have ½ inch of safety factor for any unaccounted increase in pressure. This also would take care of any increase in pressure drop due to dirty filters over the period. When the fan starts, it would create a positive pressure (blow-through fan) and pushes the water away from the pan, resulting into proper draining of the system.

For draw-through units, the trap must be designed as shown in Figures 6B, 6C and 6D to avoid issues discussed earlier. The recommended safety factor of 1 inch is a perfect balance between the increase in pressure due to any unaccounted components and efforts to keep the overall length feasible. When the fan starts, it creates a negative pressure (draw-through fan) and the size of the trap, "H+1" (inches water column) provides enough head to make sure water is not backed up into the system, thereby ensuring proper functioning of the system.



## Code requirements

Code requirement and enforcement within the U.S. varies from one location to another. The authority having jurisdiction has the governing authority and has the authority to override or modify requirements listed in the national codes. IMC is a widely referenced code in the U.S. Most AHJs have adopted the code with some region-specific modifications.

In addition, industry good practices have been used to complement it so they can use good judgment, sound engineering principles, and local practices instead of blindly following suggestions.

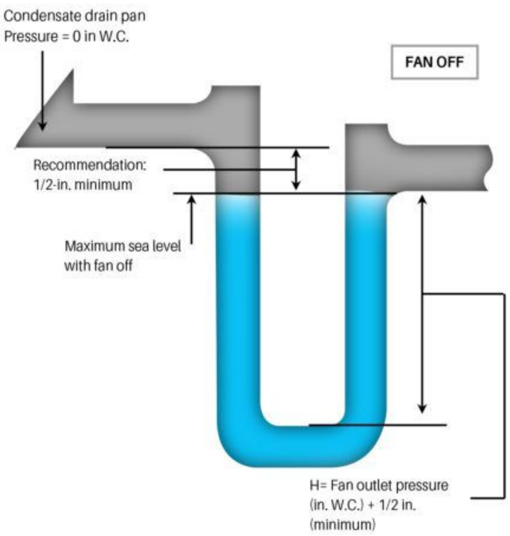
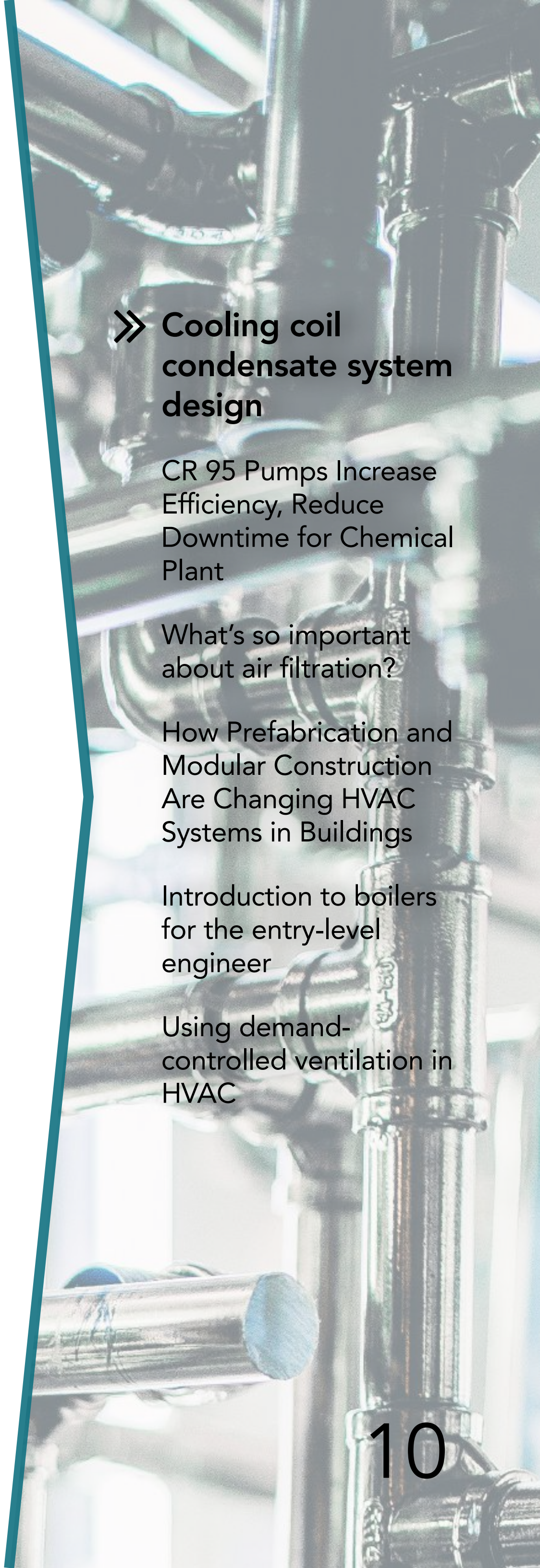


FIGURE 5B: TRAP FOR BLOW THRU AHU FAN OFF

***Figures 5A, 5B and 5C:*** *Examples of blow-through AHUs in different stages. 5A is a general example of a blow-through AHU. 5B shows a trap for a blow-through AHU with the fan off; 5C shows it with the fan started. Courtesy: EXP Global*

## Condensate disposal

The IMC code is vague as it relates to condensate disposal. It says that condensate must be disposed into an "approved location" and that it should not dump on walkways, streets or alleys as to "cause a nuisance." This leaves a lot of wiggle room for interpretation and much authority to the AHJ and design professionals to establish what is and what isn't an "approved location."



Here are a few guidelines:

- Do not dump condensate around foundations, basements or other areas that could cause ponding, erosion and/or leakage.
- Do not dump condensate from a large rooftop units to prevent pounding. Route it to nearest roof drain.
- When discharging into a shared drain or sewer system ensure that it is not piped in such a way that waste fumes could enter the system or occupied space.

Don't dump condensate in places that could create trip hazards.

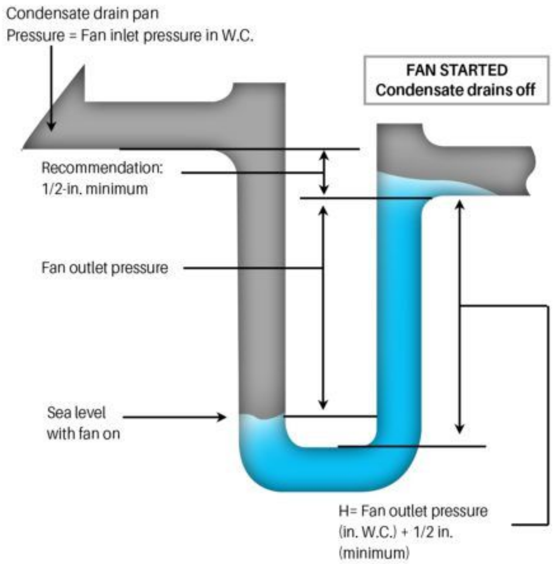
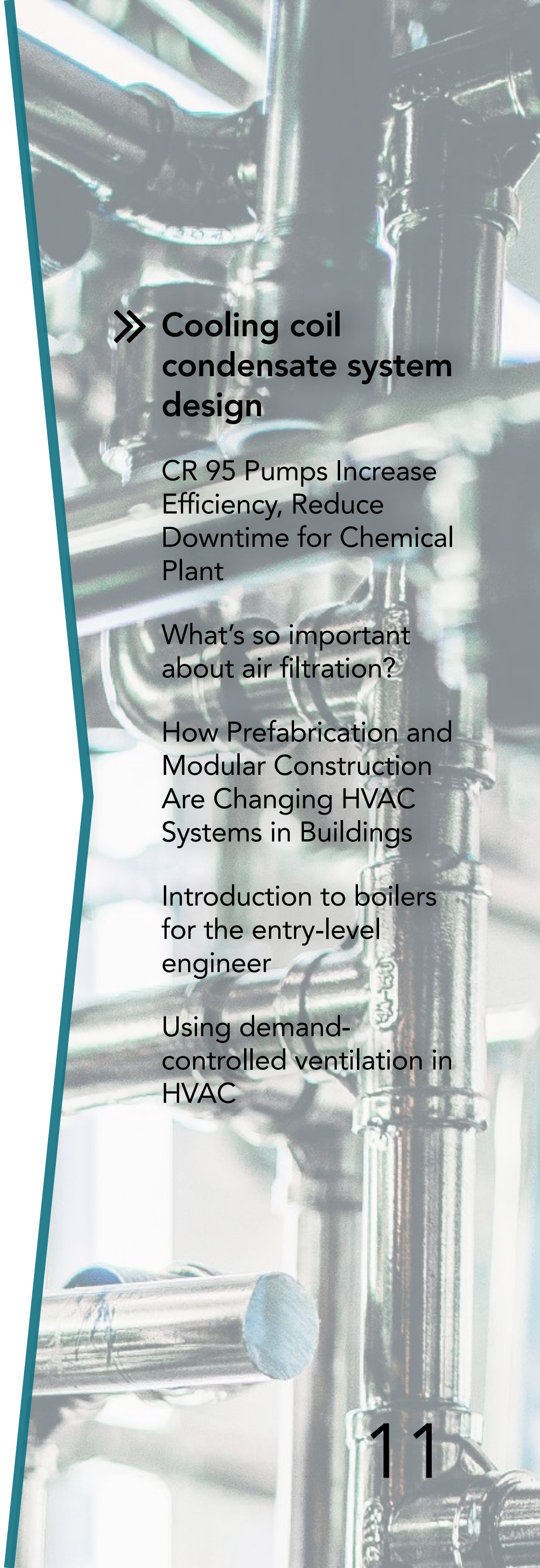


FIGURE 5C: TRAP FOR BLOW THRU AHU FAN STARTED

***Figures 5A, 5B and 5C:*** *Examples of blow-through AHUs in different stages. 5A is a general example of a blow-through AHU. 5B shows a trap for a blow-through AHU with the fan off; 5C shows it with the fan started. Courtesy: EXP Global*

## Drains

2015 IMC 307.2.2 requires that an air conditioning condensate drain inside diameter should not be smaller than ¾ inch and should not be smaller than the drain pan outlet diameter. Three-quarters of an inch is sufficient for up to 20 tons according to the IMC unless the drain outlet size is larger than ¾-inch. Use Table 307.2.2 for condensate pipe sizing.

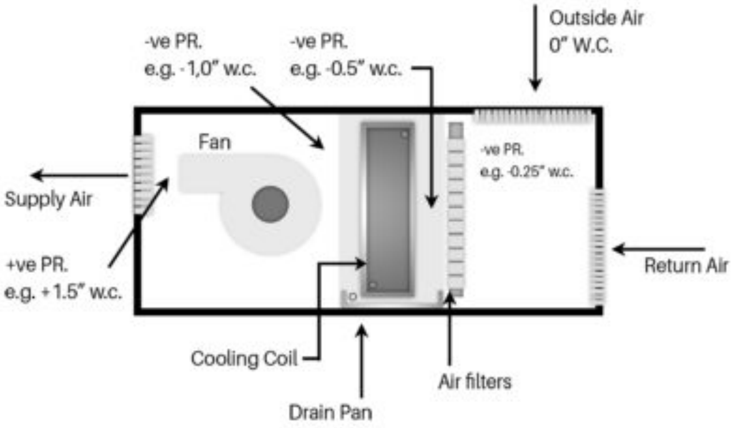


2015 IMC dictates a 1% minimum pitch of the drain which is equal to 1/8 inch fall for every 12 feet of horizontal run. Wherever practical, it is safer to use ¼ inch of fall per foot to ensure proper drainage.

Drains can be made from many materials such as acrylonitrile butadiene styrene, chlorinated polyvinyl chloride, polyvinyl chloride, steel and copper. However, PVC is by far the most common. When a drain line is PVC, the IMC dictates that it should be supported every 4 feet when horizontal (while maintaining proper pitch) and every 10 inches of vertical run.

2015 IMC 307.2.5 states that the condensate assembly must be installed in such a way that the drain line can be "cleared of blockages and maintained" without cutting the drain.

Connecting condensate line to a sewer pipe in the building shall be carefully evaluated for approval and compliance by AHJ. Where con-



***Figures 6A, 6B, 6C and 6D:*** *Examples of draw-through fans in different stages. 6A is a general example of a draw-through fan. 6B shows the fan in an off stage; 6C shows the fan when it is started; 6D is a draw-through with condensation drains. Courtesy: EXP Global*

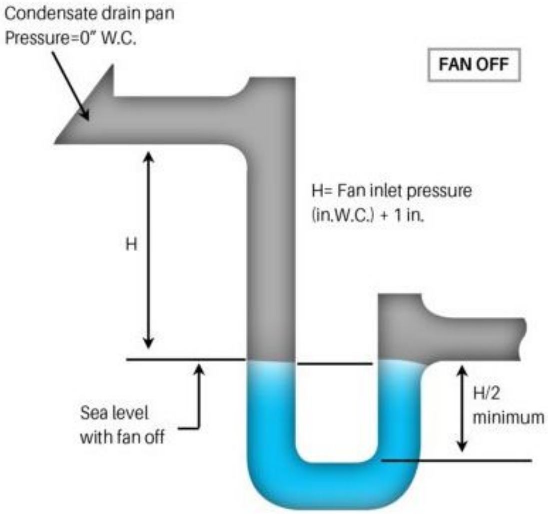


FIGURE 6B: DRAW THRU AHU FAN OFF

necting to sewer line is allowed, an air gap fitting should be provided at the connection.

Venting after (downstream of) the trap is a really good idea in most applications because it helps prevent airlock that can occur due to double traps and shared drains as well as prevent syphoning. This vent is after the trap and must remain open to be effective. The vent opening should always rise above the trip level of the condensate overflow switch when it is in the primary drain line or pan or above the secondary/auxillary overflow port on the primary drain pan. This helps ensure that if a backup occurs, the water properly trips the switch instead of overflowing out of the vent. While venting is a common best practice, it is not part of the IMC.

2015 IMC does not directly state that the drain line must be insulated. When routing condensate pipe through concealed areas, it is a good practice to insulate them to eliminate any chances of condensation. In mechanical rooms, insulation will prevent any sweating, and prevent potential trip hazards. In most situations, ½–inch fiberglass

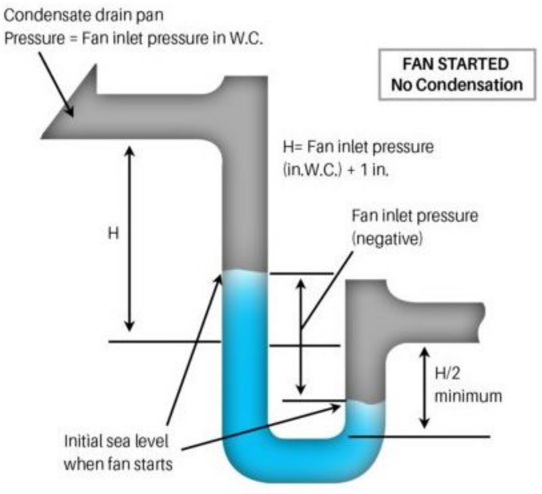


FIGURE 6C: DRAW THRU AHU FAN STARTED

***Figures 6A, 6B, 6C and 6D:*** *Examples of draw-through fans in different stages. 6A is a general example of a draw-through fan. 6B shows the fan in an off stage; 6C shows the fan when it is started; 6D is a draw-through with condensation drains. Courtesy: EXP Global*

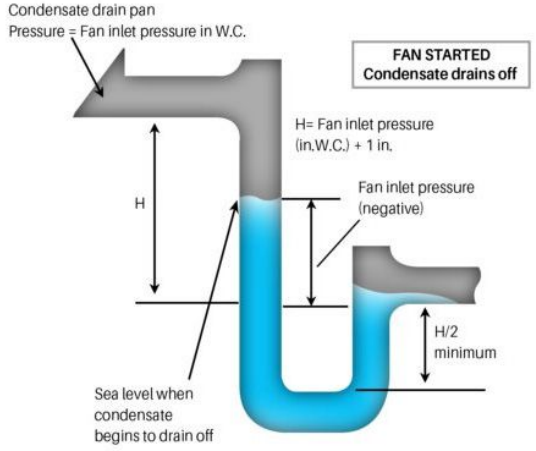
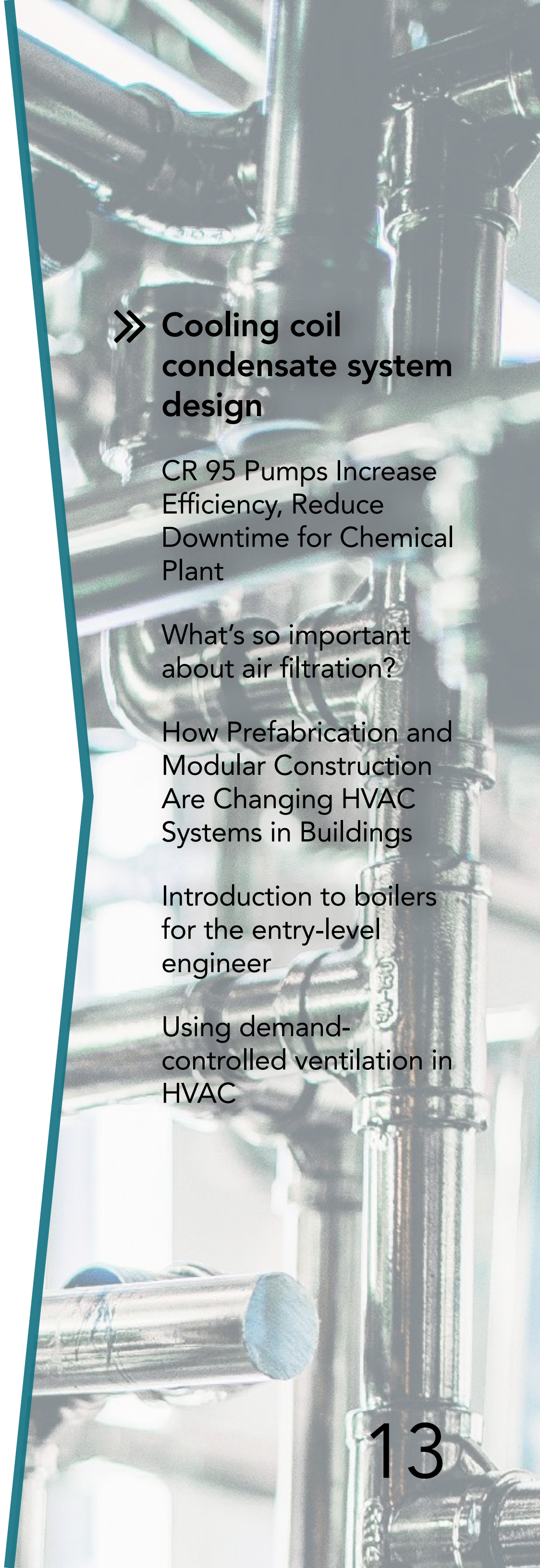


FIGURE 6D: DRAW THRU COND. DRAINS OFF



or flexible elastomeric pipe insulation (minimum R-2) with a vapor barrier would be sufficient. Some municipalities do require drain inside the structure be insulated to prevent condensation.

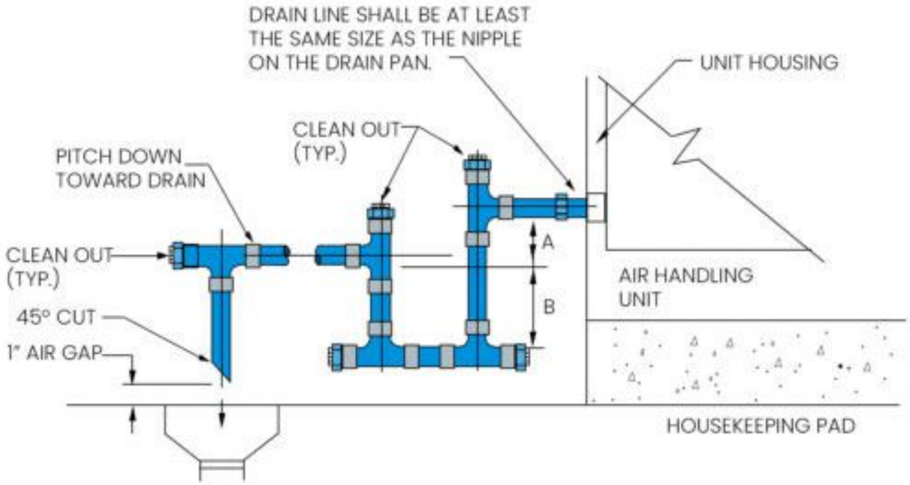
## Four additional best practices to consider

### 1. Trap with tees

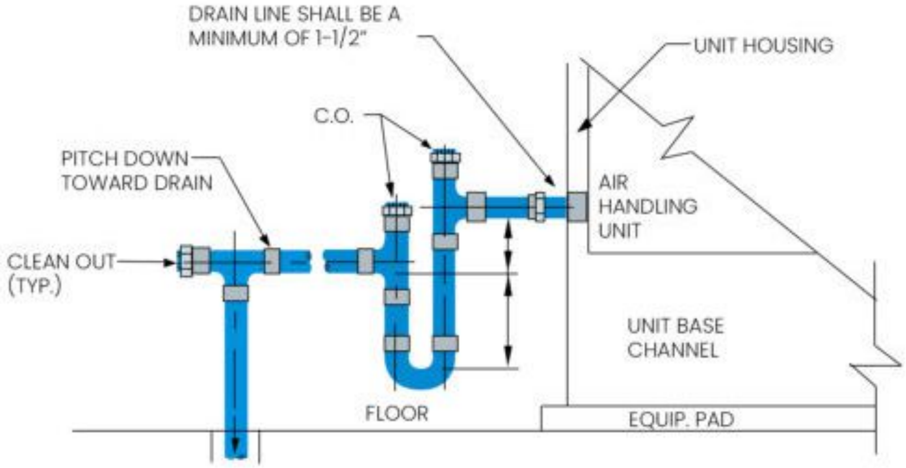
It is always a good practice to provide drain pipes with tees. Tees can be used for inspection purposes and used for priming the pipe.

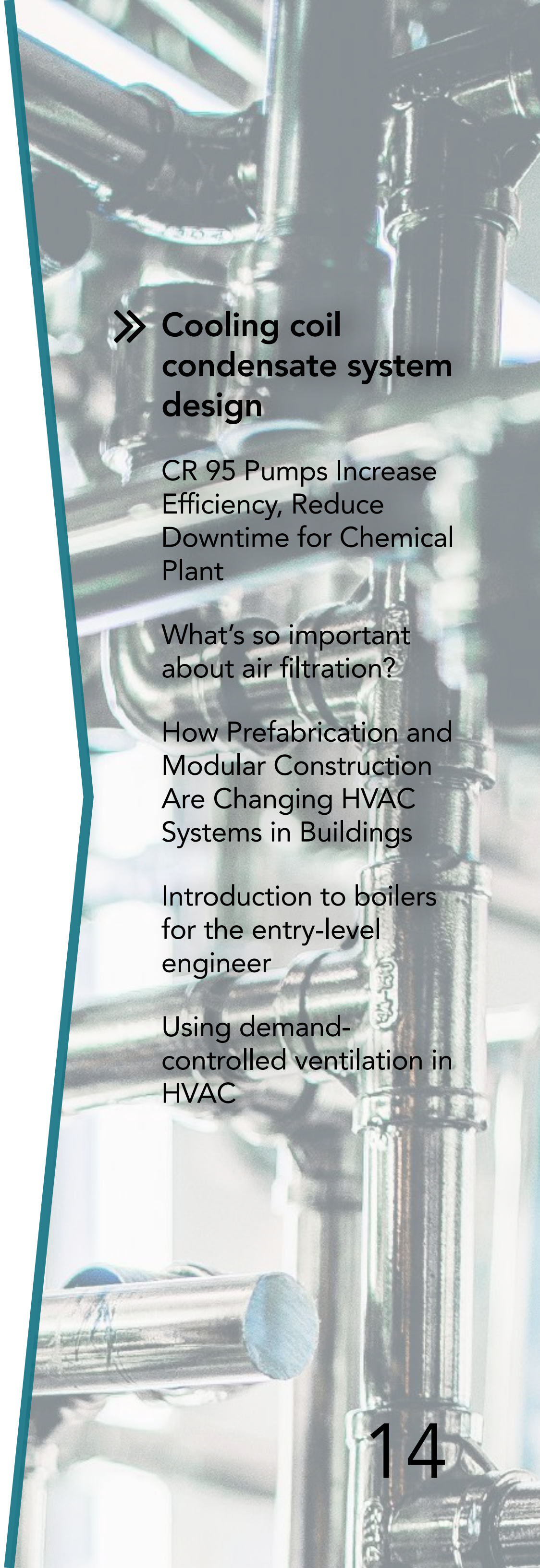
### 2. Condensate pumps

Condensate pumps shall be used where gravity drains are impossible to install. This is commonly seen in residential and



***Figures 6A, 6B, 6C and 6D:*** *Examples of draw-through fans in different stages. 6A is a general example of a draw-through fan. 6B shows the fan in an off stage; 6C shows the fan when it is started; 6D is a draw-through with condensation drains. Courtesy: EXP Global*





commercial sites, where no floor drains were provisioned to drain condensate. The piping from the cooling coil to the condensate pump reservoir should be installed with minimum 1/8-inch slope to enable gravity flow. The condensate shall be collected into the reservoir. Once the water reaches a certain level in the reservoir, the float switch within the pump will turn it on, and water is pumped from the reservoir to a safe location.

### 3. Auxiliary drain pan

Water leaks in applications such as data centers can be very costly. To offset this, users should provide an auxiliary/emergency drain pan under the cooling equipment. The pan can have a water leak detection sensor installed at the lowest point. The sensor can be tied to a building management system and send water alarms. Where required, the signal can also be used to turn off the cooling equipment when water is detected.

### 4. Condensate headers

When multiple units with pumped condensate are headered together, use inverted traps and pitch header in the direction of flow.

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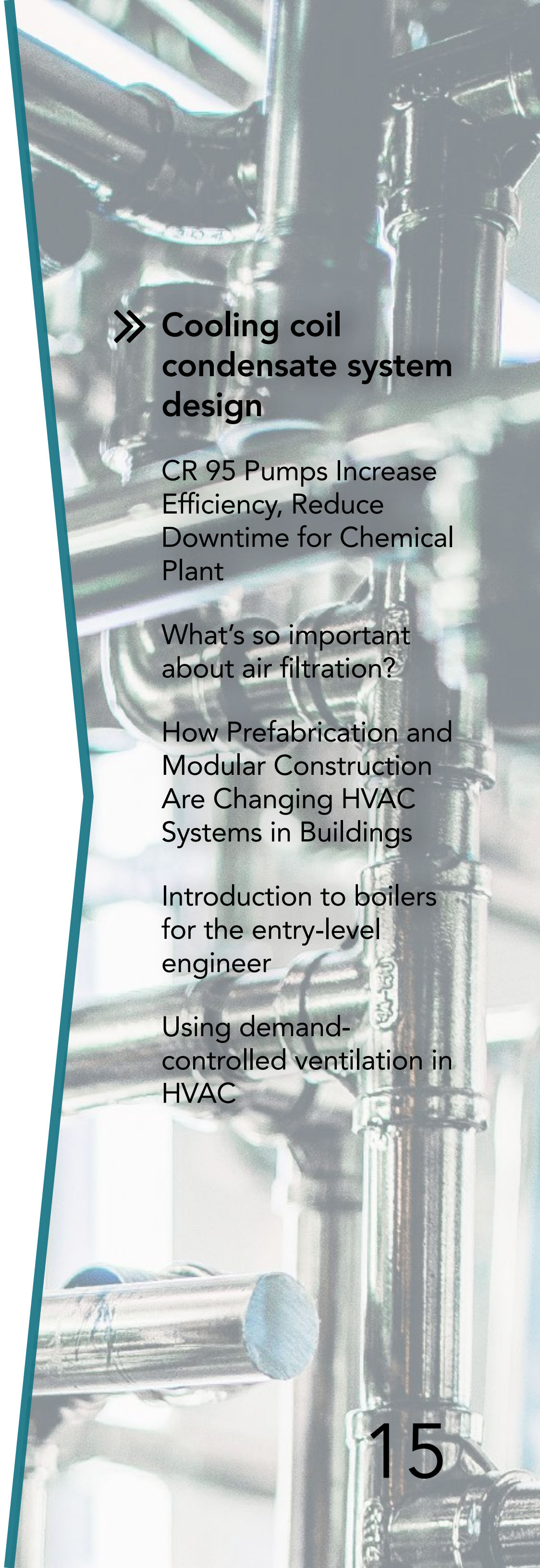
***Sushil Kumar*** *is a senior mechanical engineer and project manager at EXP Global. Sagar Kanchi is a mechanical engineer at EXP Global.*



GRUNDFOS

## CR 95 Pumps Increase Efficiency, Reduce Downtime for Chemical Plant

*For a growing chemical processing and distribution company that was experiencing downtime and costly repairs, Grundfos' Hydro MPC BoosterpaQ — featuring the new CR 95 — offered the perfect solution.*

# What's so important about air filtration?

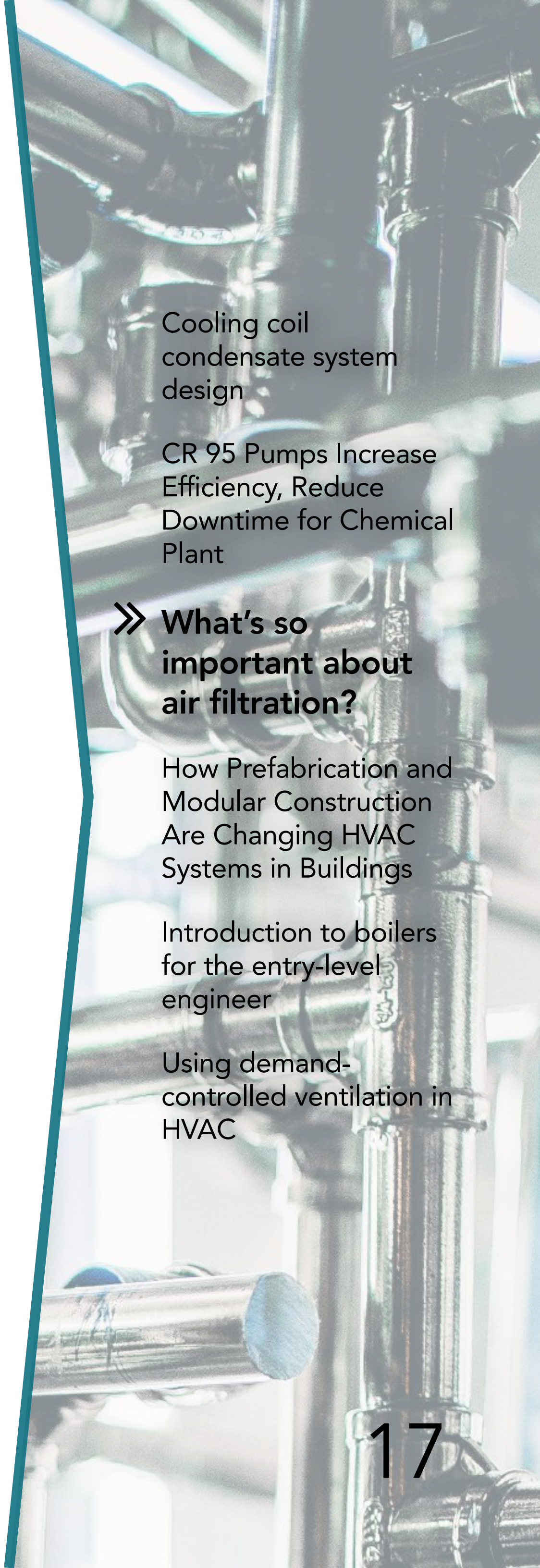
*Filters are ubiquitous in air handling systems, so it's helpful to understand the different options for filters and to learn about how they function*

Almost every air handling system has some level of air cleaning capability. Air filtration refers to removing airborne particles using media filters. From a high level, air filtration is provided in a heating, ventilation and air conditioning system for two main reasons: to protect equipment components from accumulating dirt/debris and to reduce the quantity of air contaminants inside the building environment.

In the most basic sense, air filters work by capturing a portion of the particles in the air that passes through the filter. While the basic concept of air filtration remains the same, the mechanism used to capture particles and the quantity/size of particles captured can vary considerably between different filters.

As described in Chapter 11 of the 2017 ASHRAE Handbook: Fundamentals, air contaminants can either be in the form of particles or gases and vapors. Gases and vapors exist in air as individual molecules, whereas particles are significantly larger than individual molecules. Given their relatively small size, gases and vapors are typically not removed from air through traditional media filtration and are not explored as part of this article.

Airborne particles can consist of many different materials. These particles can either be produced outdoors or inside the building. Outdoor particles can be produced from natural processes (such as wind, volcanic activity or decay of organic materials) or human activities (such as construction, agriculture, industrial plants and transportation). Particles



also can be produced inside the building from building occupants, material off-gasing and building activities. Airborne particles can be composed of solids, liquids or a combination of the two and can be broken into the following categories:

- Dusts, fumes and smokes.
- Mists, fogs and smogs.
- Bioaerosols (i.e., viruses, bacteria, mold spores, allergens, dander and endotoxins).

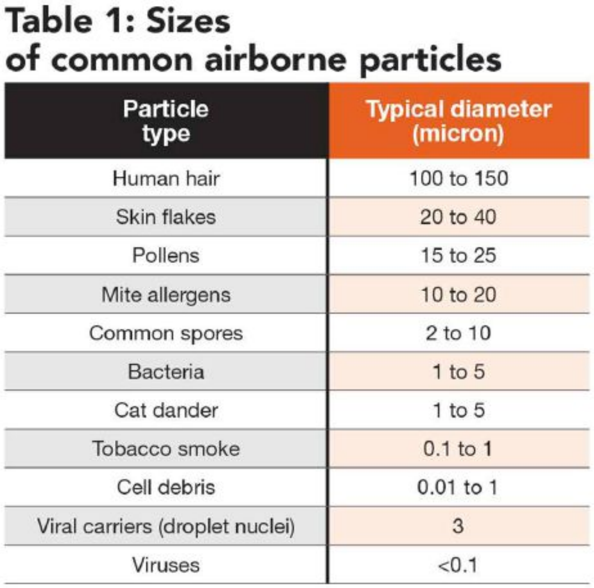


**Table 1: Sizes of common airborne particles**

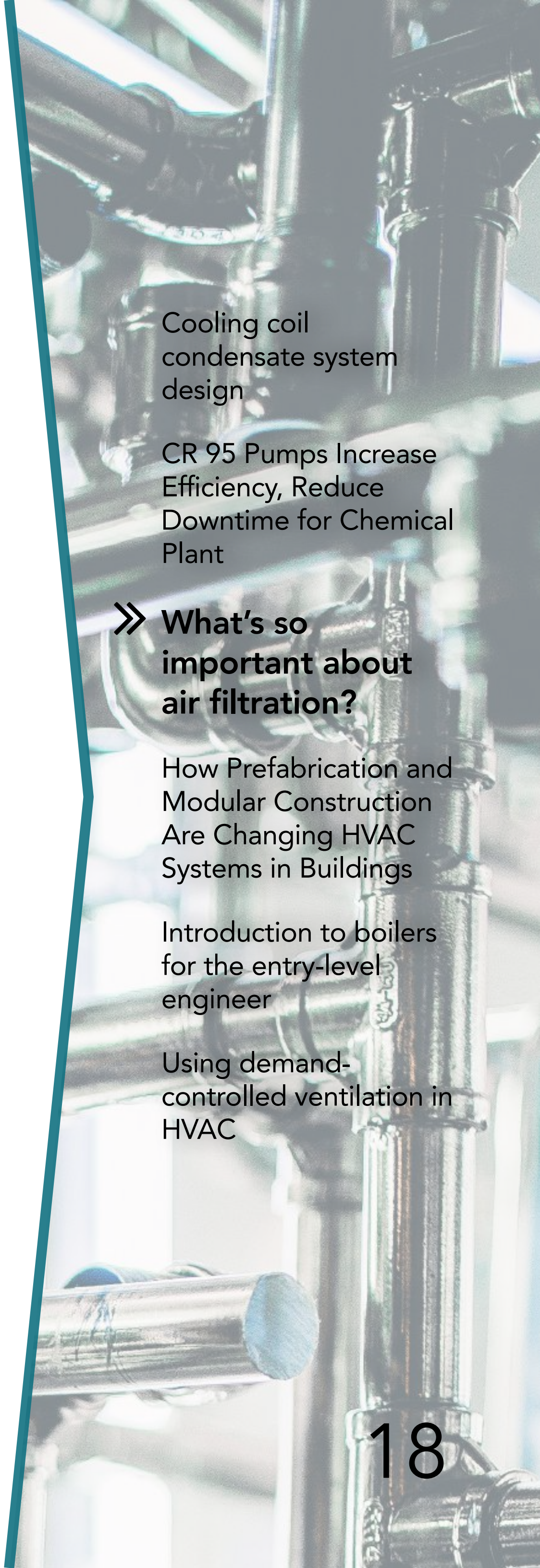
| Particle type | Typical diameter (micron) |
|---|---|
| Human hair | 100 to 150 |
| Skin flakes | 20 to 40 |
| Pollens | 15 to 25 |
| Mite allergens | 10 to 20 |
| Common spores | 2 to 10 |
| Bacteria | 1 to 5 |
| Cat dander | 1 to 5 |
| Tobacco smoke | 0.1 to 1 |
| Cell debris | 0.01 to 1 |
| Viral carriers (droplet nuclei) | 3 |
| Viruses | <0.1 |

***Table 1:** Typical sizes of common airborne particles are indicated. Courtesy: IMEG Corp.*

Additionally, the sizes of various airborne particles can vary considerably. See Table 1 for typical sizes of some common airborne particles.

The portion of air particles captured and the size of captured particles determines the removal efficiency of an air filter. The most widely used air filter efficiency scale in the HVAC industry is the minimum efficiency reporting value scale developed by ASHRAE. The MERV scale ranges from MERV 1 to MERV 16, with increasing MERV ratings corresponding to higher capture efficiency of more and smaller particles.

The testing procedures and parameters used to determine the MERV ratings of air filters are governed by ASHRAE Standard 52.2: Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size. Table 2 provides a high-level summary of the ASHRAE 52.2 MERV performance requirements as well as the types of



particles filtered by each rating.

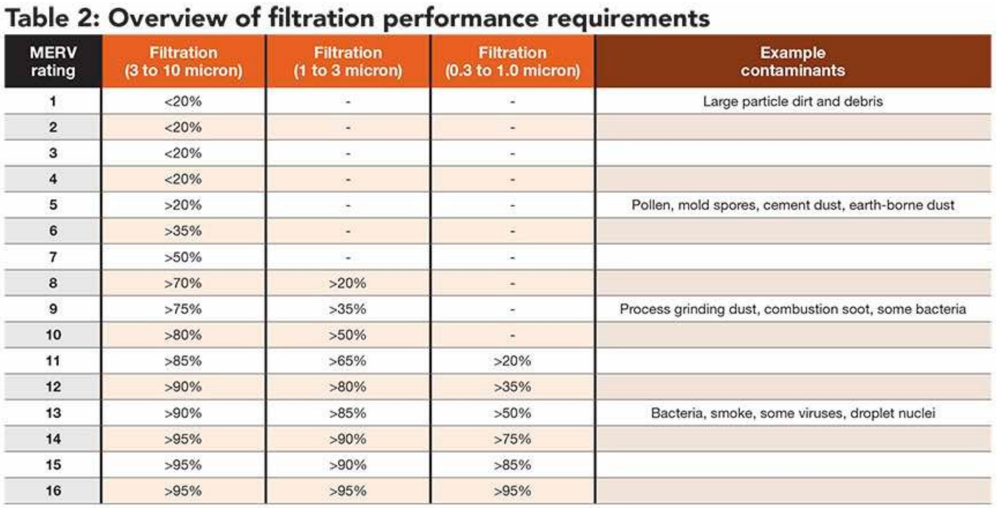


**Table 2: Overview of filtration performance requirements**

| MERV rating | Filtration (3 to 10 micron) | Filtration (1 to 3 micron) | Filtration (0.3 to 1.0 micron) | Example contaminants |
|---|---|---|---|---|
| 1 | <20% | - | - | Large particle dirt and debris |
| 2 | <20% | - | - | |
| 3 | <20% | - | - | |
| 4 | <20% | - | - | |
| 5 | >20% | - | - | Pollen, mold spores, cement dust, earth-borne dust |
| 6 | >35% | - | - | |
| 7 | >50% | - | - | |
| 8 | >70% | >20% | - | |
| 9 | >75% | >35% | - | Process grinding dust, combustion soot, some bacteria |
| 10 | >80% | >50% | - | |
| 11 | >85% | >65% | >20% | |
| 12 | >90% | >80% | >35% | |
| 13 | >90% | >85% | >50% | Bacteria, smoke, some viruses, droplet nuclei |
| 14 | >95% | >90% | >75% | |
| 15 | >95% | >90% | >85% | |
| 16 | >95% | >95% | >95% | |

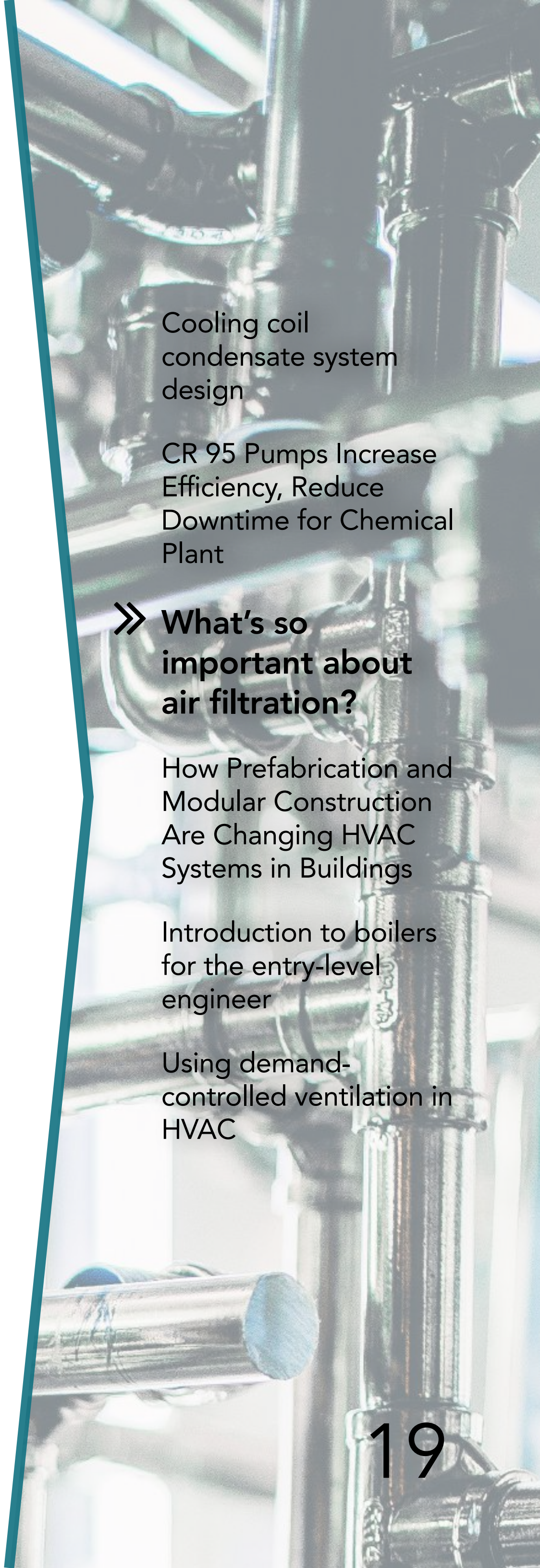
***Table 2:** An overview of filtration performance requirements for various MERV ratings is from ASHRAE Standard 52.2-2017. Courtesy: IMEG Corp.*

Filtration efficiencies above the highest MERV rating (MERV 16) are typically defined by high-efficiency particulate air and ultralow penetration air filters. HEPA filters are defined by the United States Department of Energy Standard DOE-STD-3020-2015 as filters that remove at least 99.97% of airborne particles with diameters greater than or equal to 0.3 microns. This size range includes all bacteria, mold spores, dander and some smoke and fumes (see Table 1).

ULPA filters remove at least 99.9995% of airborne particles 0.12 microns or larger, with increasing levels of ULPA filtration efficiencies beyond this base level. ULPA filtration levels are defined by the Institute of Environmental Sciences and Technology Recommended Practice IEST-RP-CC001 and European Standard CSN EN 1822-1.

## Media filtration mechanisms

There are a variety of mechanisms by which the air particles are captured in a media air



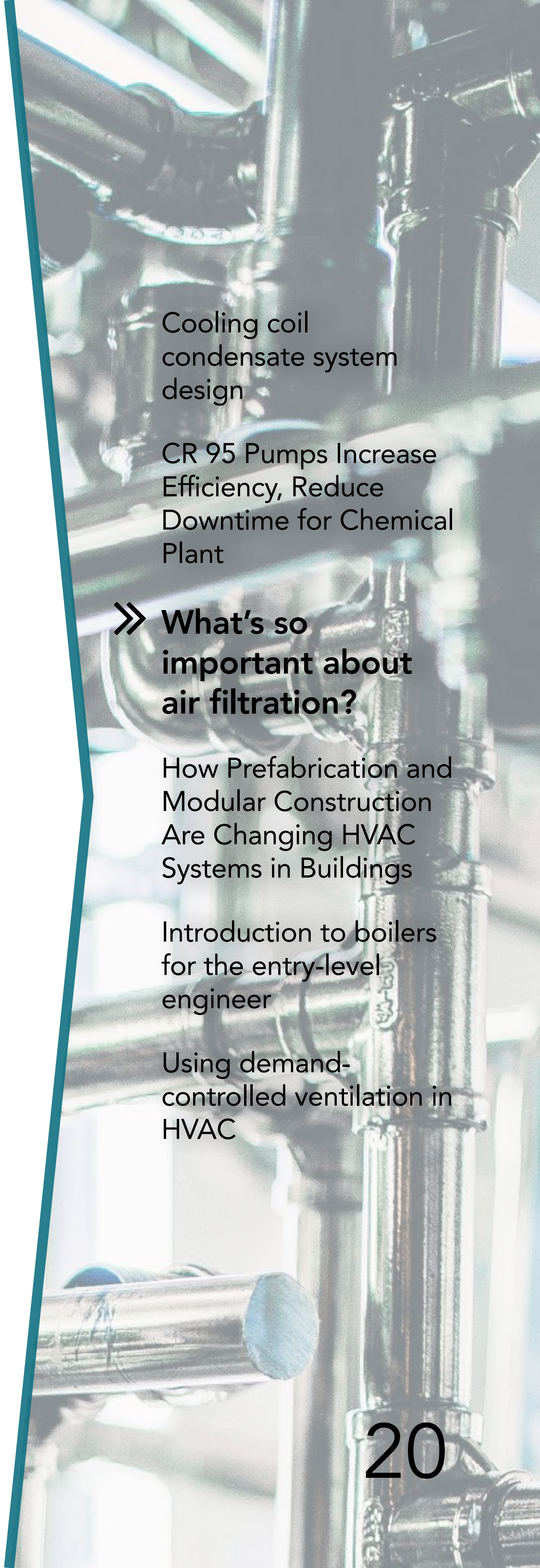
filter. In general, media air filters function by forcing air to flow through a fibrous media. As the air flows through this media, some of the particles in the air are captured by the media. As outlined in Chapter 29 of the 2016 ASHRAE Handbook: HVAC Systems and Equipment, the five main mechanisms by which particles are captured by the media are straining, inertial impingement, interception, diffusion and electrostatic effect.

**Straining** works by forcing an air particle through an opening that's smaller than the particle, trapping the particle. This mechanism is typically most effective on larger particles.

**Inertial impingement** works by forcing the air around filter fibers. As the airstream curves around filter fibers, the inertia of the airborne particle can force it into a filter fiber. Depending on the properties of the particle and the fiber surface, the particle may remain stuck to the filter. Inertial impingement is more common with higher velocity permanent media filters.

**Interception** works similarly to inertial impingement, but with some important differences. With interception, the airstream curves around filter fibers. The airborne particles get close enough to the fibers that they make contact and adhere through molecular interactions. The contact between the particle and filter fiber occurs more on the side than the front of the fiber, which differs from inertial impingement. Also, because interception requires close interaction between particles and filter media, it's more common with low-velocity extended media filters.

**The diffusion capture** mechanism is essentially an extension of the interception capture mechanism. Diffusion works through the normal erratic movement of very small particles. This erratic movement can bring particles close enough to filter fibers to be captured via



interception. The buildup of particles on filter media actually increases the effectiveness of diffusion capture. Diffusion is more effective at lower velocities and with smaller particle that move via diffusion.

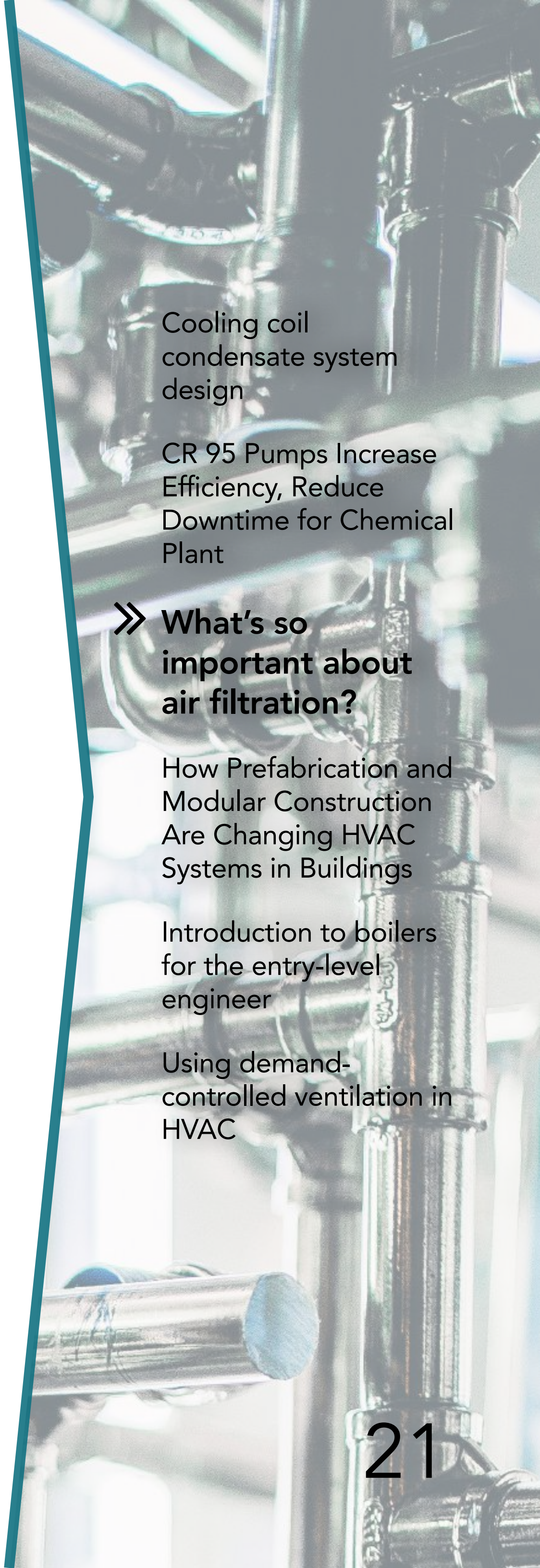
**Electrostatic effect** works by giving the filter media an electrostatic charge, which can attract and capture particles with the opposite charge. The filter’s electrostatic charge can be passive or active. A passive charge is added during the manufacturing of the filter or is generated in the filter media as air passes through it. On the other hand, an active charge is added to the filter with a power source.

## Filter styles

While the particle capture mechanisms of all media filters fall within the five categories laid out, filters can be constructed in many different ways. Depending on the application, several variables surrounding the design of a filter can be adjusted to achieve a balance between filtration efficiency, air resistance, particle holding capacity, leakage potential and cost.

As a filter holds onto more particles, its filtration efficiency actually increases due to smaller and smaller airways, but so does its air resistance. A filter with higher particle holding capacity allows it to trap more particles while minimizing the increase in air resistance. This increases the life of the filter, decreasing operating costs in the form of filter replacements.

Also, a filter usually has a maximum air resistance for which it’s designed. A pressure drop across the filter that is higher than this design value can result in damage to the



filter. Some filter design variables that can be adjusted include: media material, media assembly style, filter installation style, edge sealing style and filter size.

***Figure 1:*** *Custom health care air handling units are shown with filtration components as required by ASHRAE 170. These air handling units were installed as part of Advocate Good Shepherd Hospital's modernization project in Barrington, Ill. Courtesy: IMEG Corp.*

Fiberglass is the most common filter media material used in commercial HVAC systems. There are several properties of fiberglass media that can be adjusted based on the requirements of a filter. Some examples of these properties include average diameter and length of the glass fibers and the packing density of the glass fibers. In general, denser packing of the glass fibers can offer better filtration efficiency but will have a higher air resistance. Coarser fibers are used for lower filtration efficiencies while finer fibers are used for higher filtration efficiencies.

Fiberglass fibers used in HEPA and ULPA filters are especially fine and are often referred to as microglass. Some filters even contain different types and densities of fiberglass throughout the depth of the filter. These variations can allow for increased particle holding capacity.

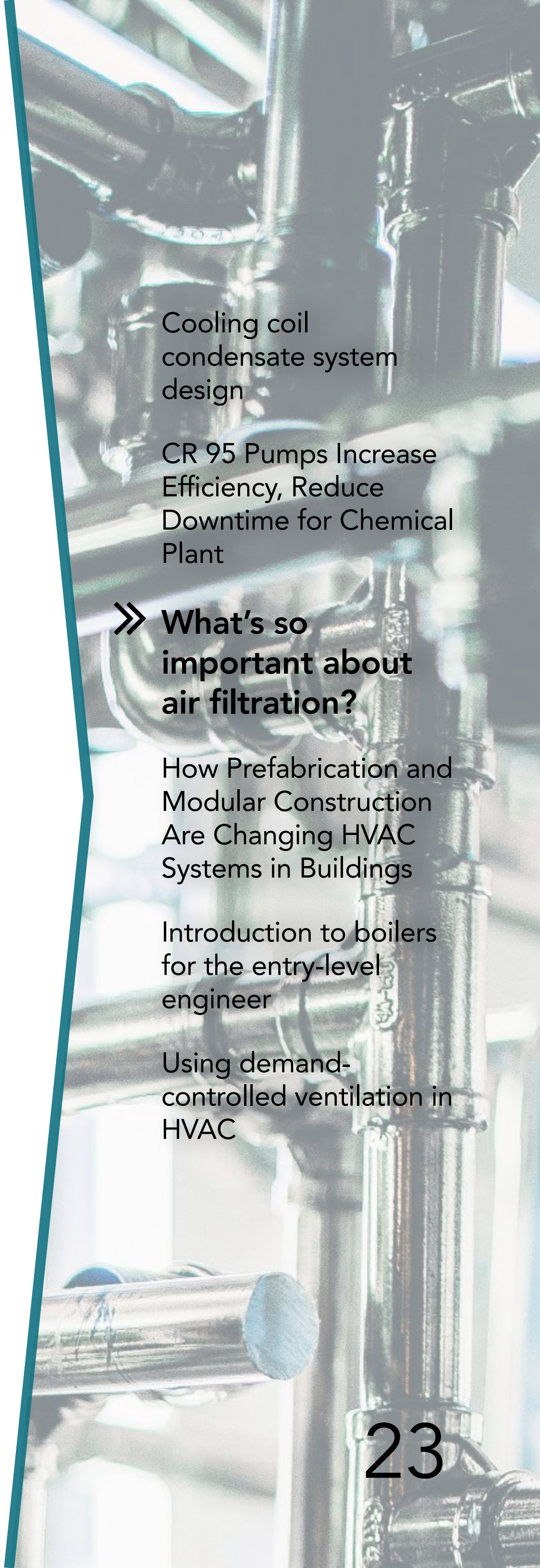
Note that there are also other filter media materials besides fiberglass. Permanent media filters, also referred to as washable filters, often have media consisting of metal and/or plastic filaments arranged in a weave. These filters typically have relatively low efficiencies, with MERV ratings between 1 and 4, but they are designed so they can be cleaned of captured particles and reinstalled.

HEPA and ULPA filters can be constructed of plastic fibers, such as polypropylene and expanded polytetrafluoroethylene (i.e., Teflon). Expanded PTFE offers some advantages over microglass filter media, such as more uniform fiber size distribution, smaller fiber size, increased media strength and more chemical resistance. These properties offer lower air resistance and less potential for filter damage at higher airflows and pressure drops. Additionally, some filter medias are embedded with antimicrobial materials to help maintain the integrity of the filter throughout its life.

In addition to the media material itself, there are many variations of media arrangement within a filter.

The simplest arrangement of filter media is a flat panel across the face of the filter, with or without a supporting material included to hold the media in place. The flat panel media arrangement is used with lower efficiency filters with minimal filter depth. This style of filter is not commonly seen in health care central air handling systems.

Perhaps the most common style for arranging media in a filter is to form the media into a series of pleats. This effectively increases the surface area of the filter, which helps to reduce air resistance and increase particle holding capacity. A supporting structure is



sometimes required to maintain the arrangement of the pleats. The style and material of the pleat support structure depends on the spacing of the pleats, the maximum resistance rating of the filter and the depth of the filter.

***Figure 2:*** *Modular health care air handling units with filtration components as required by ASHRAE 170 were installed as part of Genesis Hospital East Campus Integration Project in Davenport, Iowa. Courtesy: IMEG Corp.*

Thin filters (e.g., depths less than 4 inches) with efficiency ratings less than MERV 8 might have self-supported pleats or a cardboard pleat support structure. Deep filters (e.g., 6 or 12 inches deep) with higher efficiencies might have pleat supports/separators constructed of aluminum or plastic. Some deep filters are constructed of multiple v-banks of thin pleated media filters. The v-banks are supported by a rigid plastic or metal structure. This arrangement can achieve a higher amount of media area than a typical deep pleat filter, increasing dust holding capacity and decreasing air resistance.

Thin pleated filters are typically referred to as "pleated filters" whereas deep pleated filters are referred to as "box filters" or "cartridge filters." These types of filters are most commonly seen in health care central air handling systems.

Another filter media arrangement style is the bag filter. Bag filters consist of multiple media pockets supported by a frame on the front face of the filter. As air flows through the filter, it inflates the media pockets. This style of filter can accommodate relatively deep filters and high filter efficiencies, but not HEPA/ULPA ratings. These filters are susceptible to leakage and damage from impacts or moisture. They are seen in health care HVAC systems, but are not as common as pleated and cartridge filters.

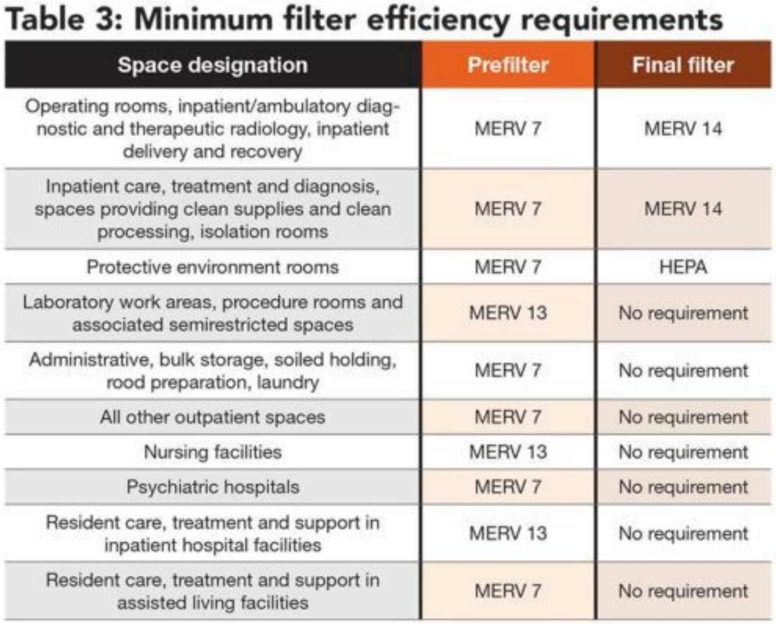


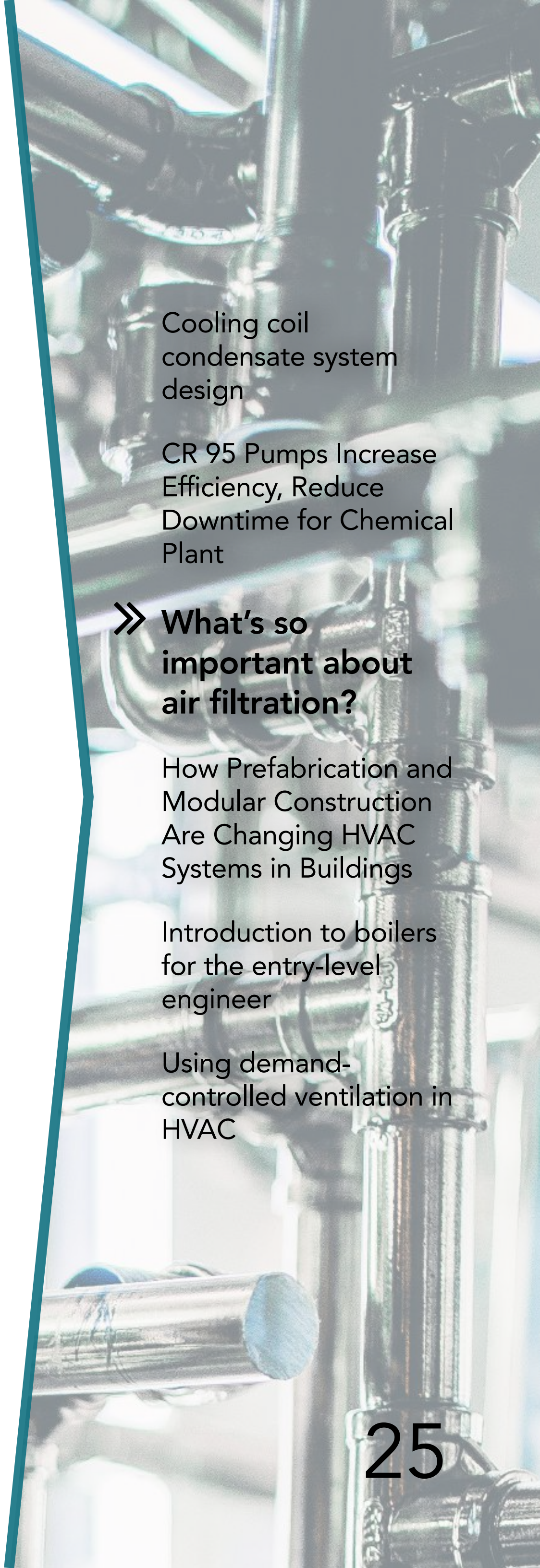
**Table 3: Minimum filter efficiency requirements**

| Space designation | Prefilter | Final filter |
|---|---|---|
| Operating rooms, inpatient/ambulatory diagnostic and therapeutic radiology, inpatient delivery and recovery | MERV 7 | MERV 14 |
| Inpatient care, treatment and diagnosis, spaces providing clean supplies and clean processing, isolation rooms | MERV 7 | MERV 14 |
| Protective environment rooms | MERV 7 | HEPA |
| Laboratory work areas, procedure rooms and associated semirestricted spaces | MERV 13 | No requirement |
| Administrative, bulk storage, soiled holding, rood preparation, laundry | MERV 7 | No requirement |
| All other outpatient spaces | MERV 7 | No requirement |
| Nursing facilities | MERV 13 | No requirement |
| Psychiatric hospitals | MERV 7 | No requirement |
| Resident care, treatment and support in inpatient hospital facilities | MERV 13 | No requirement |
| Resident care, treatment and support in assisted living facilities | MERV 7 | No requirement |

***Table 3:** Minimum filter efficiency requirements are from ASHRAE Standard 170-2017. Courtesy: IMEG Corp.*

Filters can be installed into air handling systems in two main ways: side-load and front-load. As implied by the name, side-load filters are loaded from the side of the air handling system. The filters are inserted in one side of the unit, with additional filters pushed into the side of previously loaded filters until they cover the entire width of the air tunnel.

This installation style in convenient from a maintenance standpoint, but it does have drawbacks. The seals between the filters are only achieved by the sides of the filter frames being pushed against each other. Ultimately, this does not achieve an airtight seal and will result in unfiltered air bypassing the filters. This is typically acceptable for low efficiency filters (i.e., MERV 8 or less) but is less acceptable for higher efficiency filters (i.e., MERV 13 and higher).

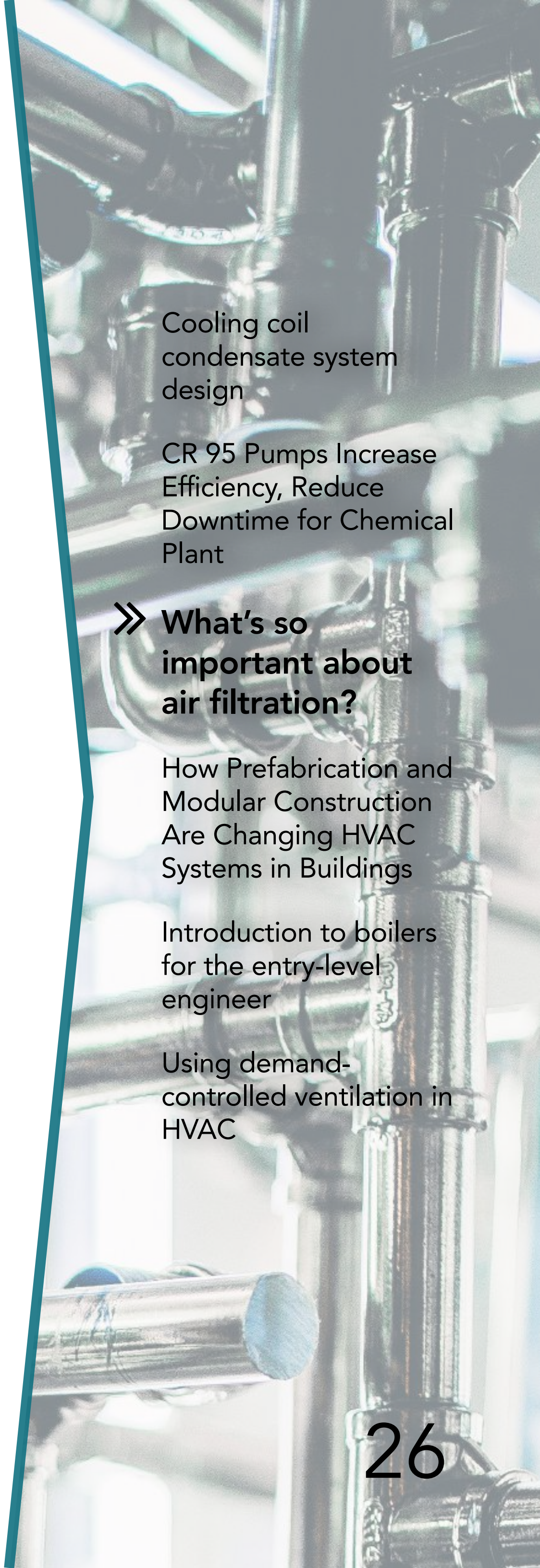


Front-load filters are installed into the air handling system from the front. Each filter is mounted into a grid-style frame that covers the face of the air tunnel. This requires more work to install the filter and requires a higher cost filter. However, this installation style offers much better sealing around the edges of the filter. Each filter is able to be sealed to the filter frame, minimizing the bypass of unfiltered air. Because of this feature, front-load filters are much preferred for high-efficiency filters.

There are also various options for the sealing mechanism around the edge of a filter. For low-efficiency side-load filters, there may not be any sealing mechanism, other than the flat frame of the filter. Front-load filters can be provided with a gasket material on the filter header, where the filter contacts the air handling system filter support frame. This gasket can be especially effective because the airflow against the front face of the filter pushes the gasket tighter against the support frame.

For HEPA/ULPA filters, a gel-seal with knife-edge design can be provided to seal around the filter. This sealing system includes a channel filled with gel. A knife-edge or thin metal protrusion is inserted into the gel when the filter is installed. This seal results in virtually no air leakage around the edges of the filter. A gel-seal with knife-edge system is basically required for any HEPA/ULPA filter that will be field tested for performance to HEPA/ULPA standards.

Experience has shown that a standard filter gasket will allow too much particle leakage for the filter to pass HEPA/ULPA performance requirements. This is especially applicable for pharmacy clean rooms within health care facilities. Per pharmaceutical regulations, the HEPA filters serving these spaces have to be tested biannually. Typically, it's difficult



to get a high-performing gel-seal with knife-edge system in a central air handling unit, so the HEPA filters perform best when installed in ceiling mounted laminar flow diffusers or fan filter units.

## Health care filtration requirements

The main code/standard governing required filtration levels in health care facilities is ASHRAE Standard 170: Ventilation of Health Care Facilities. ASHRAE 170 is adopted as code in numerous jurisdictions and compliance with the standard is required for Centers for Medicare and Medicaid Services reimbursements.

ASHRAE 170 lists required minimum filter efficiencies for systems serving various types of spaces within a health care facility. The minimum filter efficiencies are listed for two filter banks: the filter bank upstream of the main heating and cooling coils (normally referred to as the "pre-filter") and the filter bank downstream of all wet cooling coils (normally referred to as the "final filter"). In general, a minimum filter efficiency of MERV 7 is required for pre-filters and MERV 14 is required for final filters. Some spaces do not require final filters, while other spaces require higher filtration levels. Refer to Table 3 for a summary of the filter efficiency requirements included in the 2017 version of ASHRAE 170.

In addition to ASHRAE 170, there are additional standards that place filtration requirements on spaces within a health care facility. The most notable examples are USP General Chapter <797> Pharmaceutical Compounding – Sterile Preparations and USP General Chapter <800> Hazardous Drugs – Handling in Healthcare Settings, which govern the compounding of drugs in pharmacies. These regulations require HEPA filtration for most compounding clean rooms.

**Kevin Langan, PE, IMEG Corp., Rock Island, Ill.**

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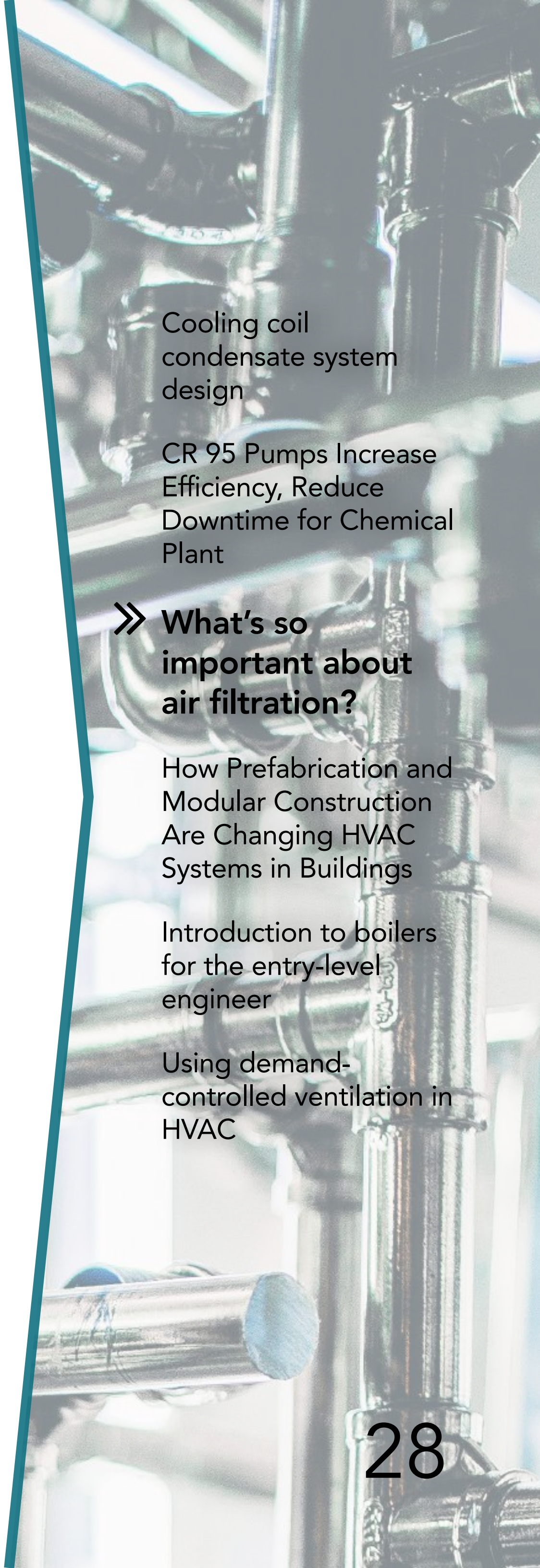


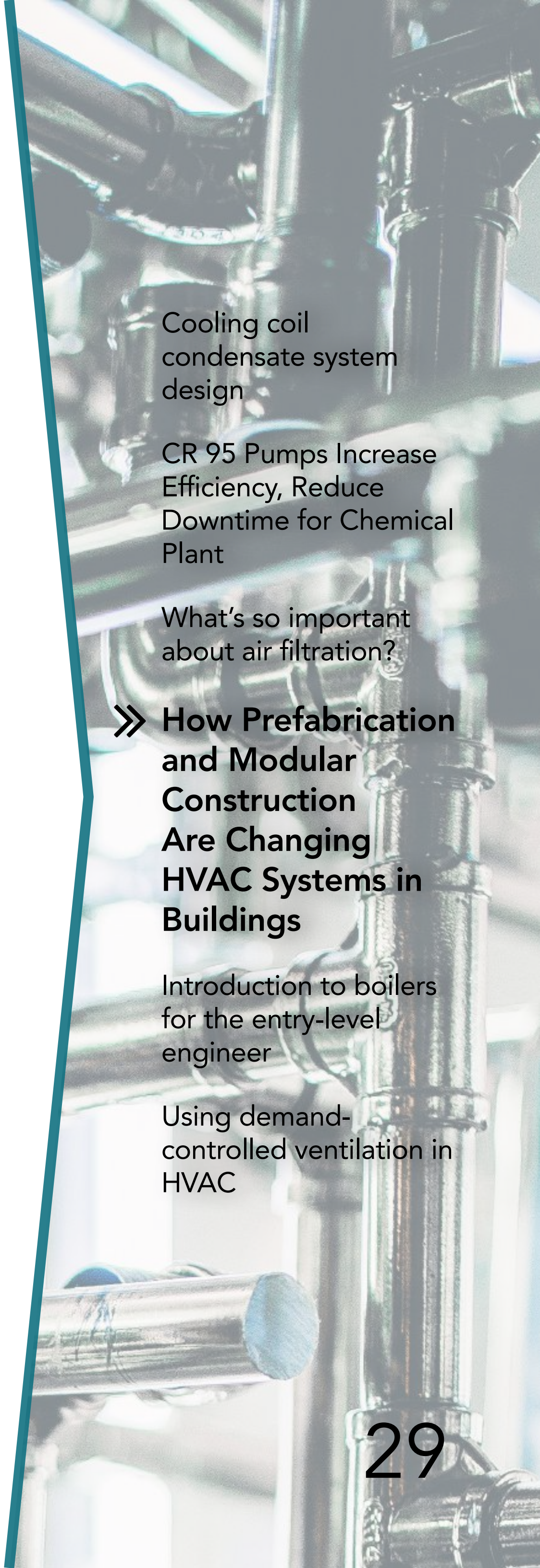
# How Prefabrication and Modular Construction Are Changing HVAC Systems in Buildings

*The positive impact on HVAC design, installation and overall efficiency*

Prefabrication and modular construction have grown over the last few years as a solution to the problem of trade workforce shortages. These building methods are almost universally agreed to be advantageous because they improve:

- Productivity
- Quality
- Schedule certainty
- Cost predictability
- Waste reduction
- Client satisfaction
- Safety performance

As a result, the use of these methods in all aspects of construction is only expected to increase. According to the Prefabrication and Modular Construction 2020 SmartMarket Report from Dodge Data & Analytics, contractors are looking for both architects and engineers to leverage prefabrication and modular construction in more of their designs, but most of them only have experience with traditional, on-site construction practices. Regarding projects with Electrical, Mechanical and Plumbing (EMP)-oriented trade assemblies for HVAC, plumbing and electrical racks, risers and other assemblies, 64 percent of general contractors/construction managers (GCs/CMs) and 77 percent of



trade contractors have used prefabricated systems — in stark contrast to just 39 percent of architects and engineers.[1]

In other words, prefabricated systems are well positioned to become the new industry standard, with demand driven by contractors and trades, but there is a lag in adopting these methods during project design. GCs/CMs forecast that 23 percent of projects over the next three years will include prefabricated systems for multi-trade assembly products — a 10-point increase from where we are today. Architects and engineers forecast prefabrication in only 19 percent of these upcoming projects — a 12-point increase from today's adoption.[2]

## Prefabrication and Modular Construction Trends

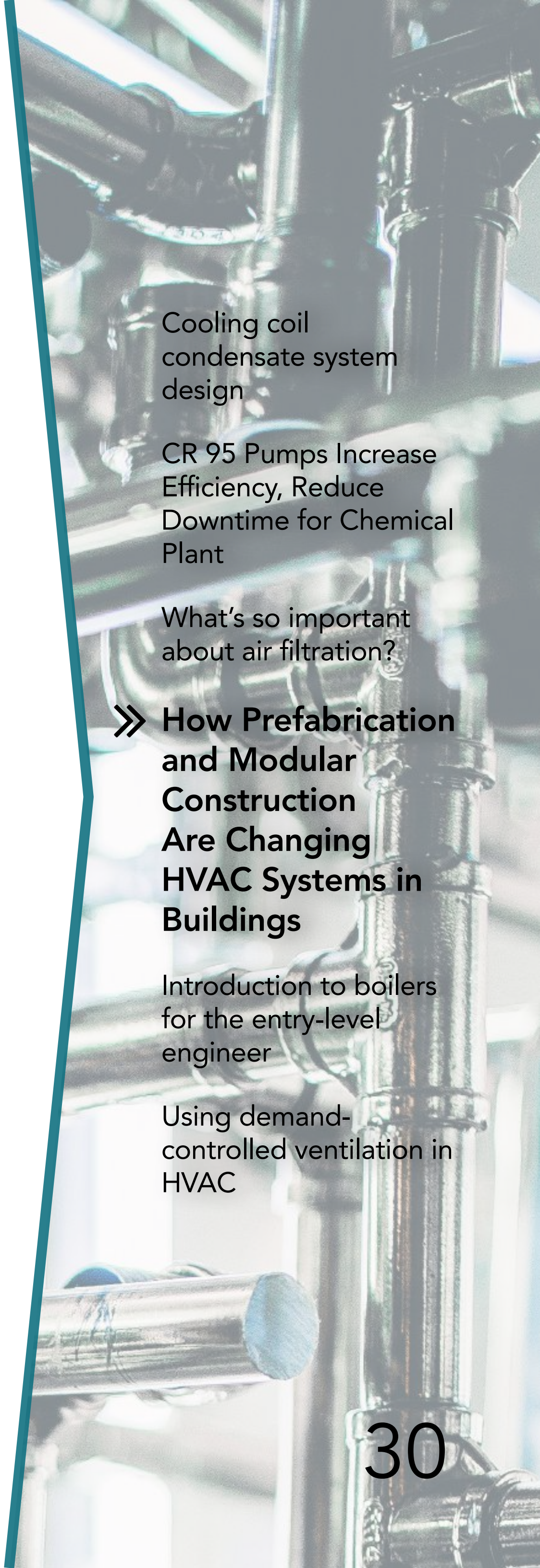
Prefabrication and modular construction are two ways of approaching off-site construction. The difference is what is built off-site.

## What Is Prefabrication?

"Construction World" magazine defines prefabrication as "the practice of assembling a variety of components of a structure at a manufacturing site and transporting those sub-assemblies to the location of the construction jobsite." [2] Prefabricated units range from wall and floor panels to stairwells and more. Projects that are considered "on-site construction" often utilize prefabrication.

## What Is Modular Construction?

In modular construction, the entire building is prefabricated. According to the Modular Building Institute:



> *Modular construction is a process in which a building is constructed off-site, under controlled plant conditions, using the same materials and designing to the same codes and standards as conventionally built facilities — but in about half the time. Buildings are produced in "modules" that when put together on site, reflect the identical design intent and specifications of the most sophisticated site-built facility — without compromise.* [4]

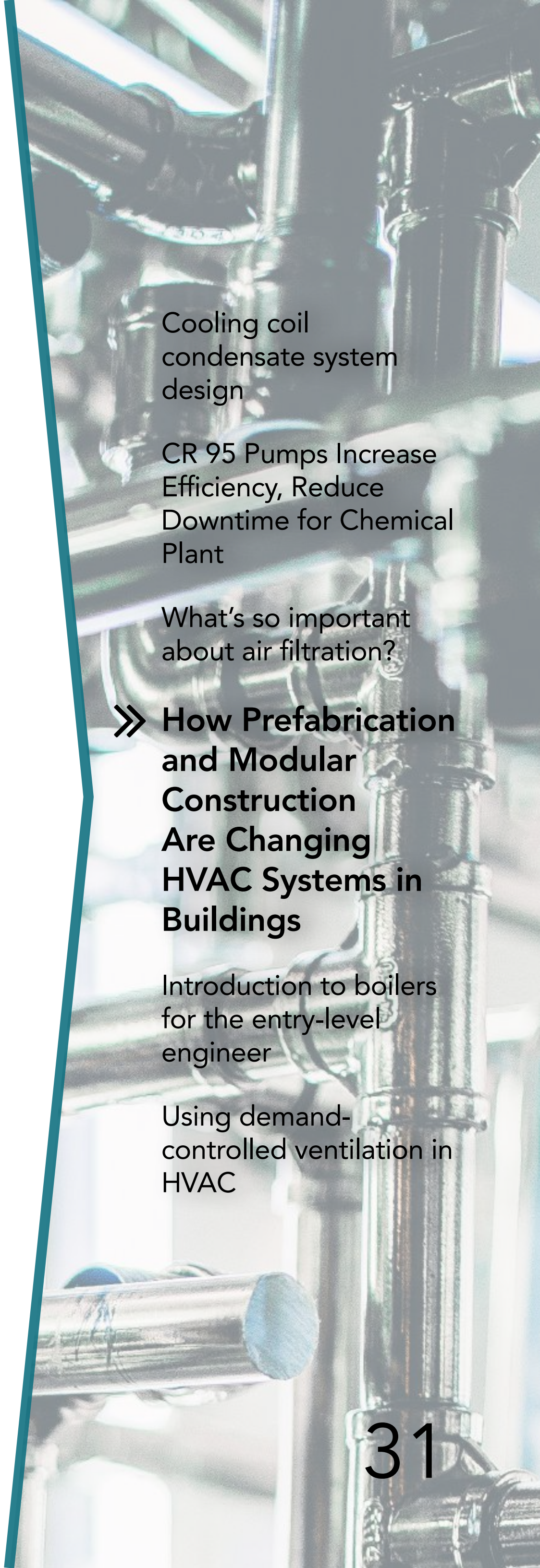
There are two types of modular construction: permanent modular construction and relocatable buildings.

**Permanent modular construction (PMC)** involves modules, or pods, that take the form of completed rooms or even complete hotel rooms with all the finishes. These modules are delivered to the job site and pieced together like building blocks.

**Relocatable buildings (RBs)** are what comes to mind for most people when they think of modular construction because examples are often seen traveling down the highway, bearing "wide load" signs. An RB is a partially or completely assembled building that complies with any applicable codes and/or regulations and is designed to be reused or repurposed multiple times. RBs are commonly seen at schools, medical clinics and construction sites.

## Market Adoption and Forecast

The survey on which the SmartMarket Report is based shows that the various forms of prefabrication and modular construction have reached different levels of adoption in the United States. Among the survey respondents: [1]



- 94% have used prefabrication in the last three years
- 38% have used permanent modular construction
- 28% have used relocatable modular construction

GCs/CMs agreed that the top obstacle to using prefabrication in more projects is its lack of inclusion in designs.

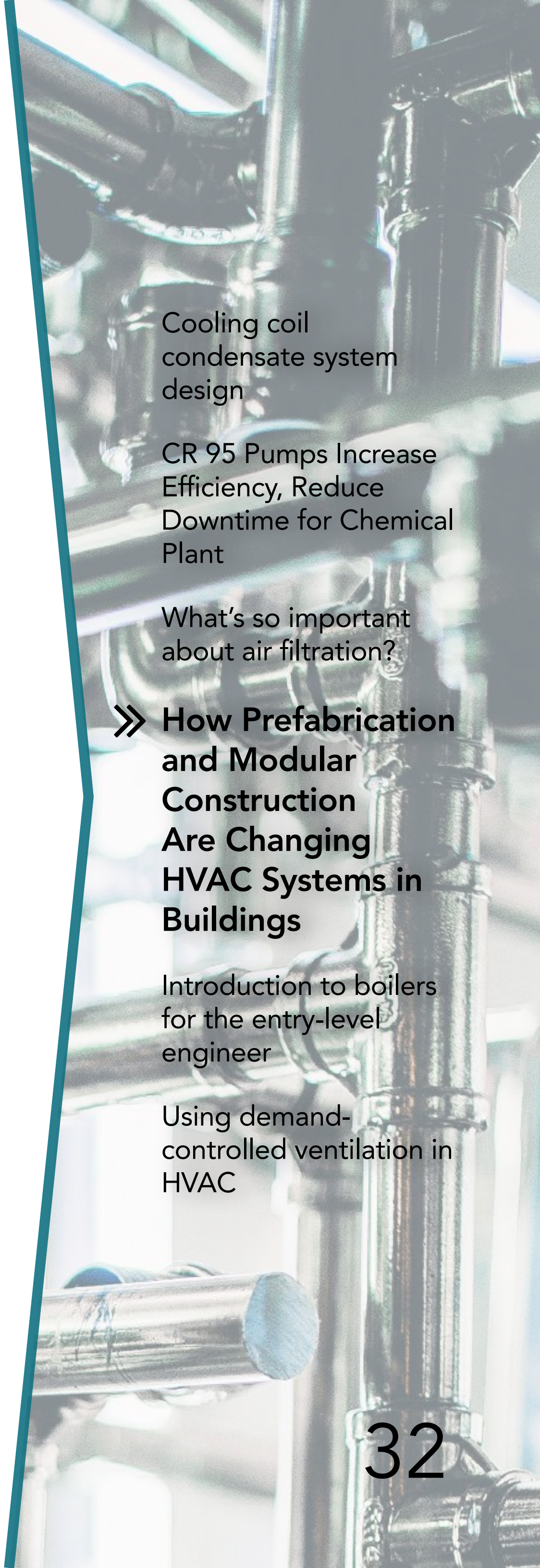
Survey respondents said that over the next three years, they expect to see more prefabrication and modular construction used in these building types:

- Health care facilities
- Hotels and motels
- Multifamily
- College buildings and dormitories
- Low-rise offices (1–4 stories)
- K–12 schools

## Prefabrication in HVAC Systems

HVAC systems are vital for buildings. They must be reliable, efficient and designed to help the facility team optimize system performance, because HVAC impacts far more than human comfort. The optimal indoor climate raises people's productivity by up to 10 percent. A five- to eight-degree variance from the optimal temperature can decrease productivity by five to 10 percent.

A building's HVAC system is made up of many components. The most important pieces



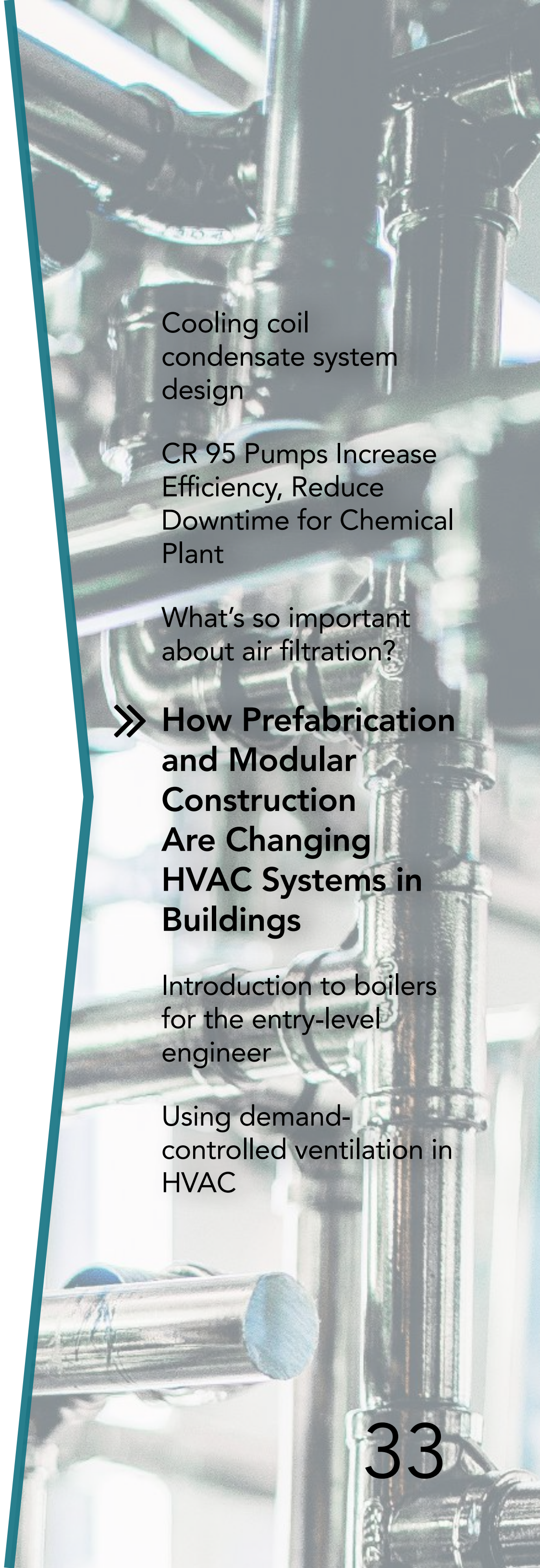
are the chiller and the air handling unit (AHU), which circulates air throughout a building to provide heating and cooling — both of which comprise many parts.

The HVAC industry has used prefabrication to overcome installation and commissioning challenges for many years. For example, when chillers were first introduced to the market, all the components were supplied individually: compressors, condensers, evaporators, expansion valves, power and controls units and other ancillary items. But now, chillers are sold as complete packaged systems. Likewise, AHUs are now sold as packaged systems made of many integrated components: filters, heating and/or cooling coils, humidifier, mixing chamber, blower/fan, balancing, heat recovery device, controls, vibration isolators, sound attenuators and more. The industry depends on chiller and AHU manufacturers to apply their expertise and design skills to build these important systems in factories for optimal efficiency and performance, rather than expecting contractors to do this work on-site. If the assemblies aren't sized, selected and built correctly, the building has problems.

But, for some reason, this logic doesn't extend to most HVAC pumping systems. The pump is the heart of the HVAC system, moving valuable and expensive chilled water throughout a building to maintain comfort for all. It serves as a water handling unit (WHU) for the entire building. Yet most pumping systems are still stick-built, requiring contractors to source and assemble multiple parts at the construction site. As an industry, it's time to recognize the value of prefabricated HVAC pumping systems.

## The Value of Prefabricated Pumping Systems

Prefabrication offers the HVAC industry some of the same benefits of modular con-



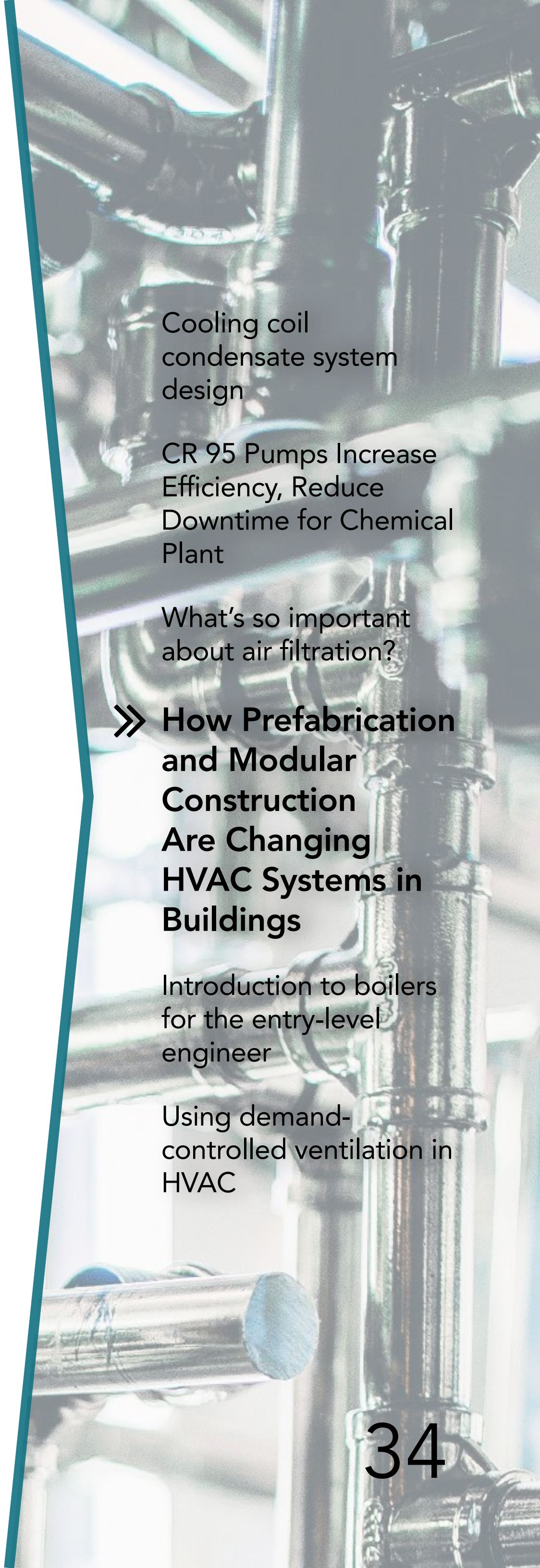
struction overall: the quality of a factory-controlled construction environment, and faster project completion.

### *The Quality of the Factory-controlled Environment*

In the modular construction industry, factory-controlled builds allow for tighter construction, due to fewer site disturbances and less waste generation. Prefabrication and modular construction are considered green building approaches because materials can easily be recycled within the factory. In addition, manufacturers are able to control inventory and protect materials. An added safety benefit for the workers is improved air quality, and materials stay dry — nearly eliminating the chance of moisture being trapped inside the new building.

The same benefits can be achieved in the HVAC industry by using prefabricated pumping systems. The pumps, motors, drives and controls can be installed on a base frame, along with all the isolation valves, check valves, gauges and sensors. Everything can be pre-wired, -programmed and -commissioned to job-site requirements within the factory. This approach saves many hours of job-site labor, both mechanically and electrically, allowing for repeatability and ensuring the highest quality of work.

When assembling systems on-site with pumps, drives and controls from different manufacturers, it’s not always easy to achieve optimum controls curves. And connecting two or more pumps in parallel, which is often required to maximize efficiency in the building, adds another level of difficulty, as the controls need to be set up for redundancy and/or cascade operation. But with an experienced single-source pumping system manufacturer, the assembly and design are optimized, and control programming maximizes operation efficiency.



Additionally, packaged pumping systems can come with sensors on the inlet and outlet manifolds (or differential pressure sensors) and can be programmed to provide either proportional or quadratic pressure control. Any setpoint changes can be made on a single pump controller either at the control panel or through the building management system (BMS) for easy use.

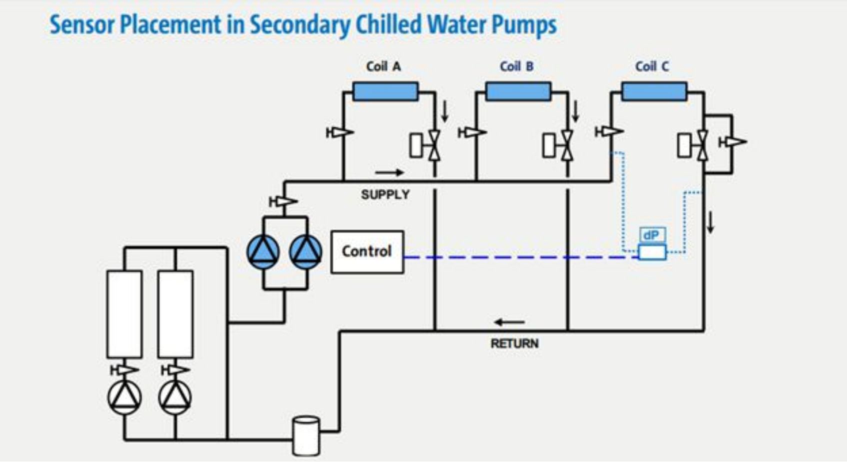
## *Faster Project Completion*

In modular construction, module assembly and site foundation work happen simultaneously, allowing projects to be completed 30 to 50 percent faster than with traditional construction methods. Since 60 to 90 percent of the construction is completed inside a factory, weather does not impact the construction timeline. Buildings can be occupied sooner, creating a faster return on investment.

The Modular Building Institute shared an example timeline illustrating these potential savings: [5]

Using prefabricated equipment helps drive efficiencies in the permits & approvals stage by simplifying design and streamlining the submittal process between the MEP and mechanical contractors. Additionally, in the install & site restoration stage, time is saved because the systems can be sourced more easily and simply dropped in at the site, ready to go with a flip of the switch.

Figure 1

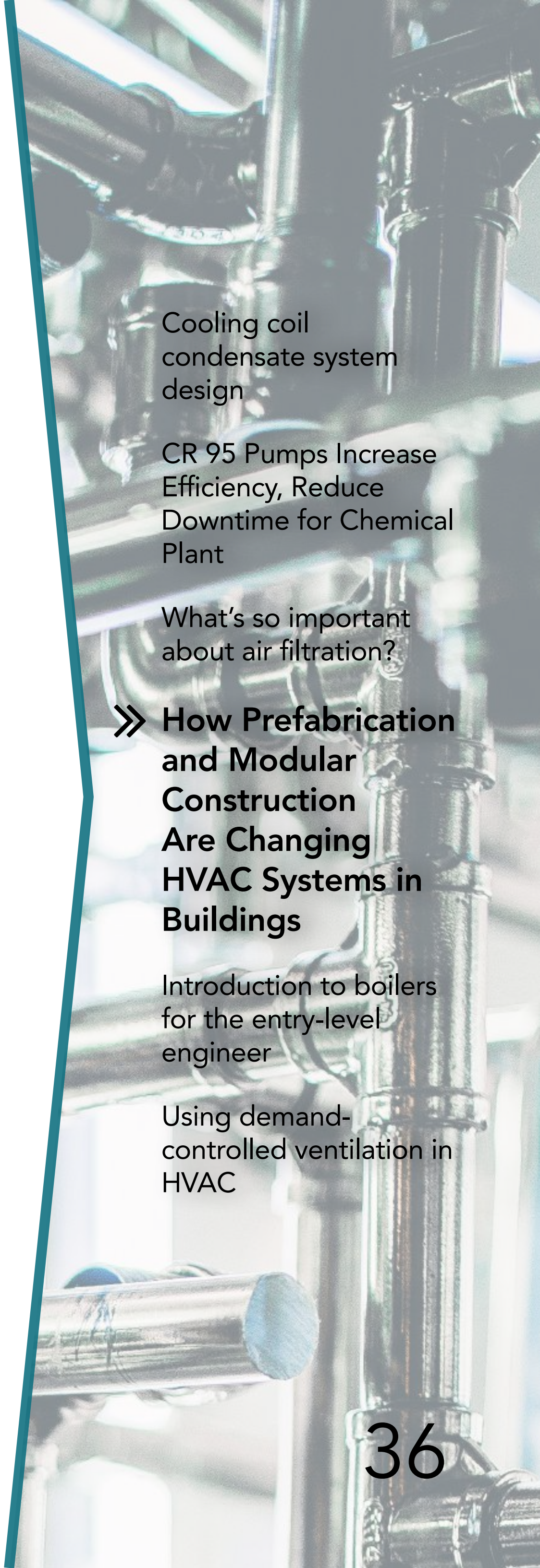


In the HVAC industry, when using off-the-shelf or configured prefabricated pumping systems, the manufacturer can source, build, pre-wire, pre-test and pre-commission the system while other building construction tasks happen. Once the system is delivered, contractors just have to make the piping connections and plug it in. The pre-testing and pre-commissioning ensure there are no surprises or delays.

Additionally, built-in, pre-programmed sensors and control equipment allow for data- and performance-driven system control.

## Sensors for More Accurate Pump Control

The most common best practice in HVAC pump control is also the most intrusive and expensive: remote-mounted differential pressure sensors. Sensors allow the pumping system to react efficiently to changes in system flow requirements. Illustrated in Figure 1 is a remote-mounted, differential pressure sensor system that measures the pressure

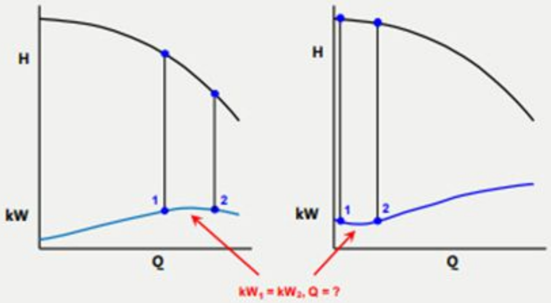


loss through the coil, control valve and balancing valve.

**Figure 2**

Power-based Control and Relation to Pump Performance Curve

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



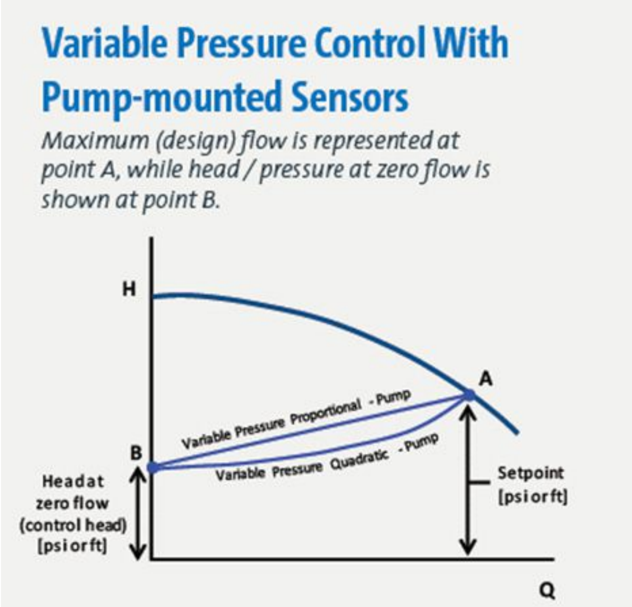
But the difficulty in locating and installing this sensor (or sensors) leads to questionable decisions when the system is commissioned. This difficulty has led to many systems operating far below their intended efficiency. When there is indecision around correct sensor placement, sensors get mounted improperly in the system, in the mechanical room or across from the pump system itself. Utilizing normal control methodologies, none of these alternate locations are ideal, and they will not deliver the pumping efficiency that was intended when the system was designed. Some have suggested removing the sensor altogether and letting the pump, motor and drive figure out where to run. This type of power-based pump control can work for a system with a constant load, but it struggles to perform when system conditions aren't actually as designed or there is a dynamic variable load. Advancements in pump system control allow for a pump system–mounted sensor, but this must be planned for. Let's evaluate the effect of each control strategy on overall system efficiency.

## Control Strategies: With & Without Sensors

### *Power-based Pump Control: No Sensor Used*

Power-based pump control, in which controls operate without sensors or any direct feedback (data) from the system, has gained in popularity over the last 10 years. In this method, pump performance curves are loaded into the pump control, and both pressure and flow are estimated using the power consumed by the motor and drive. Caution must be taken when using power-based control, as this method does not work for all pump types. Since the only thing being measured is motor input power (via the variable frequency drive), there may be two points on the pump curve that require the same power. An example is shown below in Figure 2.

***Figure 3***



### *Proportional Pressure: Pump-mounted Sensors*

There's a common misconception that if a pump-mounted sensor is used, the pump can only operate in constant pressure mode. This is incorrect, as current pump technology allows proportional and/or quadratic pressure control, even in systems with pump-mounted sensors.

When pump-mounted sensors or power-based control are used (see Figure 3), there must be two setpoints: head/pressure at design (or maximum) flow (A), and head/pressure at zero flow (B). These two settings define the control curve characteristics. To properly set these parameters during commissioning, the head at zero flow (i.e., fixed head or control head) needs to be determined. For a hydronic circulation system, like the example illustrated in Figure 1, the fixed head would also represent the control head required if a remote-mounted differential pressure sensor were used.

## Conclusion

Prefabrication and modular construction are growing trends with staying power, well-positioned to transform the building industry. These methods can be implemented for nearly any aspect of construction, based on the needs of the building. Prefabricated HVAC pumping systems offer benefits not only for the HVAC system itself, but also for the overall building, depending on the application and building needs.

## References

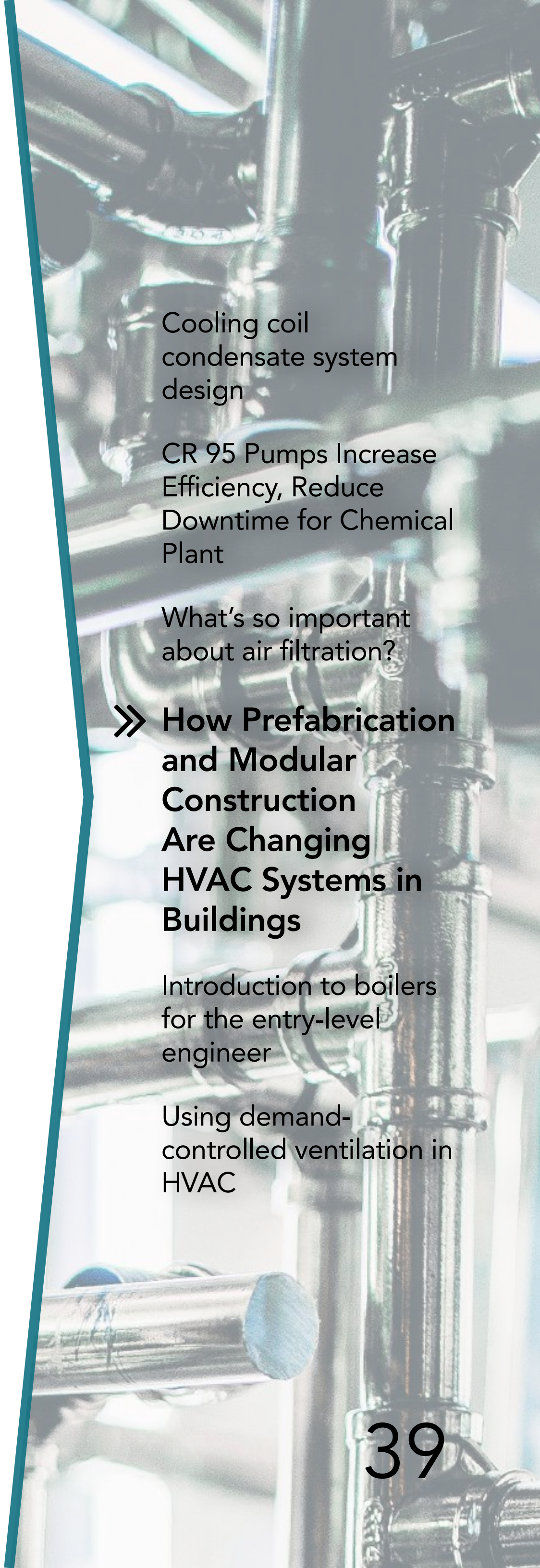
1. Jones, S. A., & D.A. Laquidara-Carr, eds. "SmartMarket Report: Prefabrication and Modular Constriction 2020." Dodge & Data Analytics, 2020. https://www.construction.com/toolkit/reports/prefabrication-modular-construction-2020

2. Construction World. "7 Benefits of Prefabricated Construction." http://www.constructionworld.org/7-benefits-prefabricated-construction/

3. Modular Building Institute, "What is Modular Construction?" https://www.modular.org/HtmlPage.aspx?name=why_modular

4. Jones and Laquidara-Carr.

5. Modular Building Institute.



Cooling coil condensate system design

CR 95 Pumps Increase Efficiency, Reduce Downtime for Chemical Plant

What's so important about air filtration?

» **How Prefabrication and Modular Construction Are Changing HVAC Systems in Buildings**

Introduction to boilers for the entry-level engineer

Using demand-controlled ventilation in HVAC

# Introduction to boilers for the entry-level engineer

*Entry-level consulting engineers should understand the definition and applications of a commercial hydronic boiler*

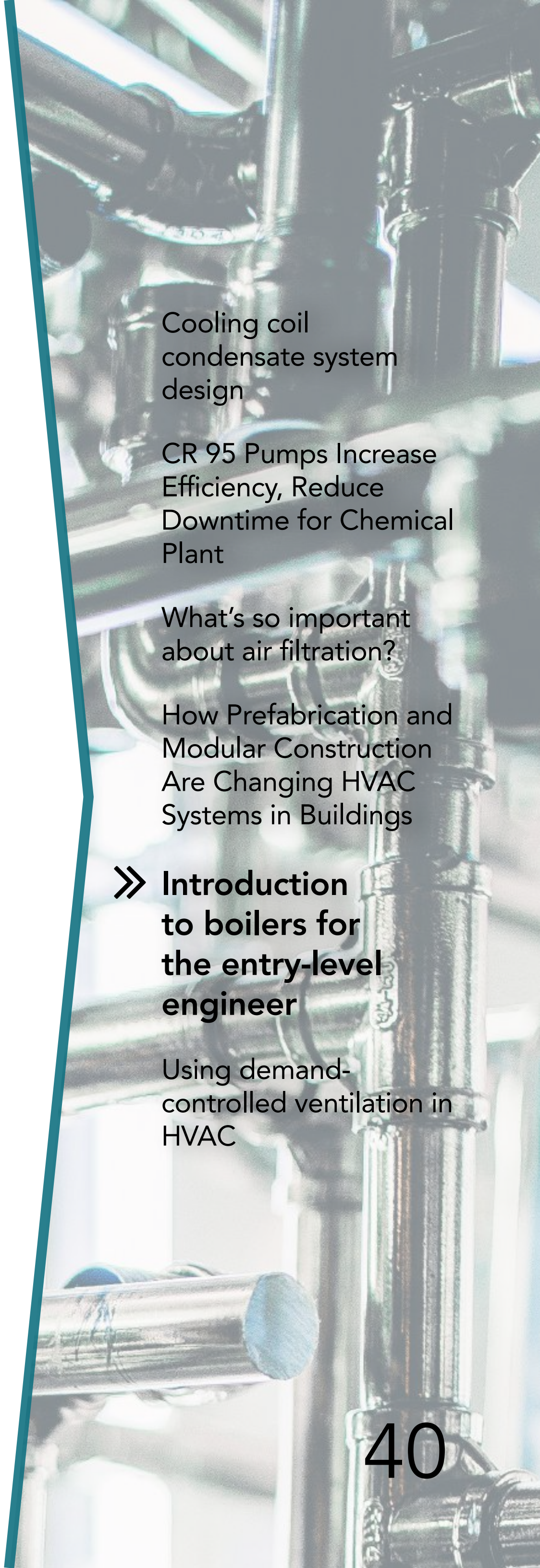
When beginning a career in consulting mechanical engineering, there is a lot to learn. Specifications can seem like a foreign language and the details of mechanical equipment can overwhelm the young engineer. With regards to hydronic heating systems, the beginning of this navigation starts with the commercial hydronic boiler.

The hydronic boiler is the heart of the hydronic heating system. The heating system consists of many parts including the boiler itself, the piping distribution, pumps, central and terminal devices that deliver the hot water to where it's needed and building automation systems to control how much heat is being delivered. The boiler is a pressurized vessel that burns combustible fuel to heat water that is used to heat a commercial building.

## What defines a hydronic boiler?

A hydronic boiler can be either a condensing or noncondensing boiler. Both types of boilers can be either a fire– or a water-tube boiler. When selecting a fire-tube boiler, it can be categorized either as a wetback or a dryback boiler.

Since we will use the term Btu/hour frequently throughout this article, a definition is in order. The Btu is the heat required to raise the temperature of 1 pound of water by 1 F. The heating capacity of boilers is rated in Btu/hour; 1,000 Btu/hour is referred to as MBH.



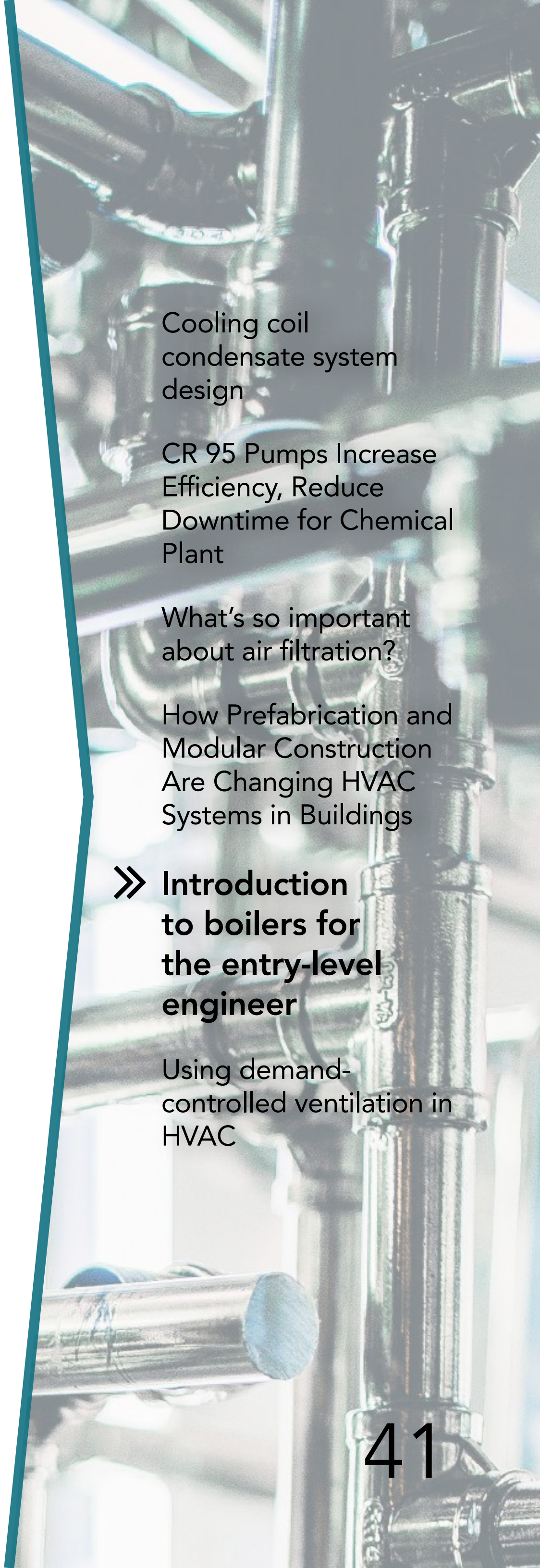
A condensing boiler typically ranges from 400 MBH up to 3 million Btu/hour and a noncondensing boiler typically ranges from 400 MBH up to 6 million Btu. A condensing boiler has two heat exchangers and a lower temperature of combustion products (around 130 F).

Efficiencies of condensing boilers reach up to 98%. This is accomplished by condensing water vapor and other components in the exhaust gases to recover latent heat of vaporization while preheating the entering water stream. The condensate is acidic, with a pH between 3 and 4. The majority of condensing boiler combustion chambers are stainless steel construction to withstand the acidic condensate.

In comparison, a noncondensing boiler has a single combustion chamber and a single heat exchanger with higher temperature products of combustion (around 350 F). Their combustion chambers are not required to be acid corrosion resistant because the flue gases don't condense and acidify. Also, the heat of the flue gases is wasted when the products of combustion are discharged straight out the exhaust flue.

In short, a condensing boiler has a higher initial cost due to the corrosion–resistant construction and multiple heat exchangers and it is more cost–efficient to operate. Where budget is a concern, engineers should choose noncondensing boilers.

A commercial hydronic boiler can be either a fire- or water-tube boiler. Water-tube boilers consist of water flowing through tubes that are encased by hot combustion gases. Conversely, fire-tube boilers consist of hot combustion gases passing through tubes surrounded by water. Fire-tube boilers are further classified by the type of reversal chamber between passes (see Figure 1) through which flue gases travel through the



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furnace. If the reversal chamber is surrounded by water, it is defined as a wetback boiler and if the reversal chamber contains a lined rear wall, it is a dryback boiler.

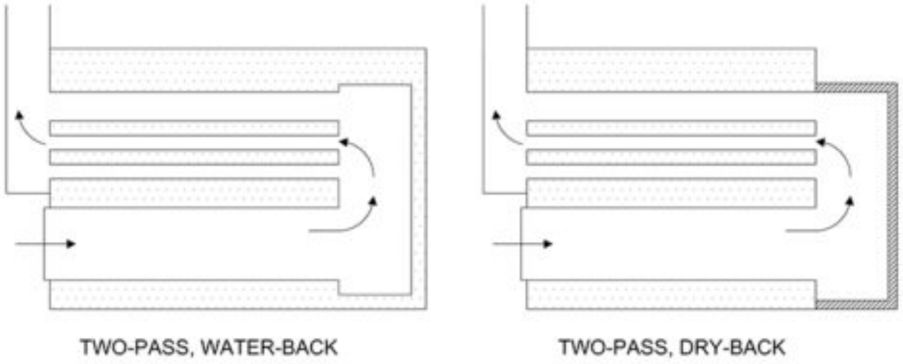


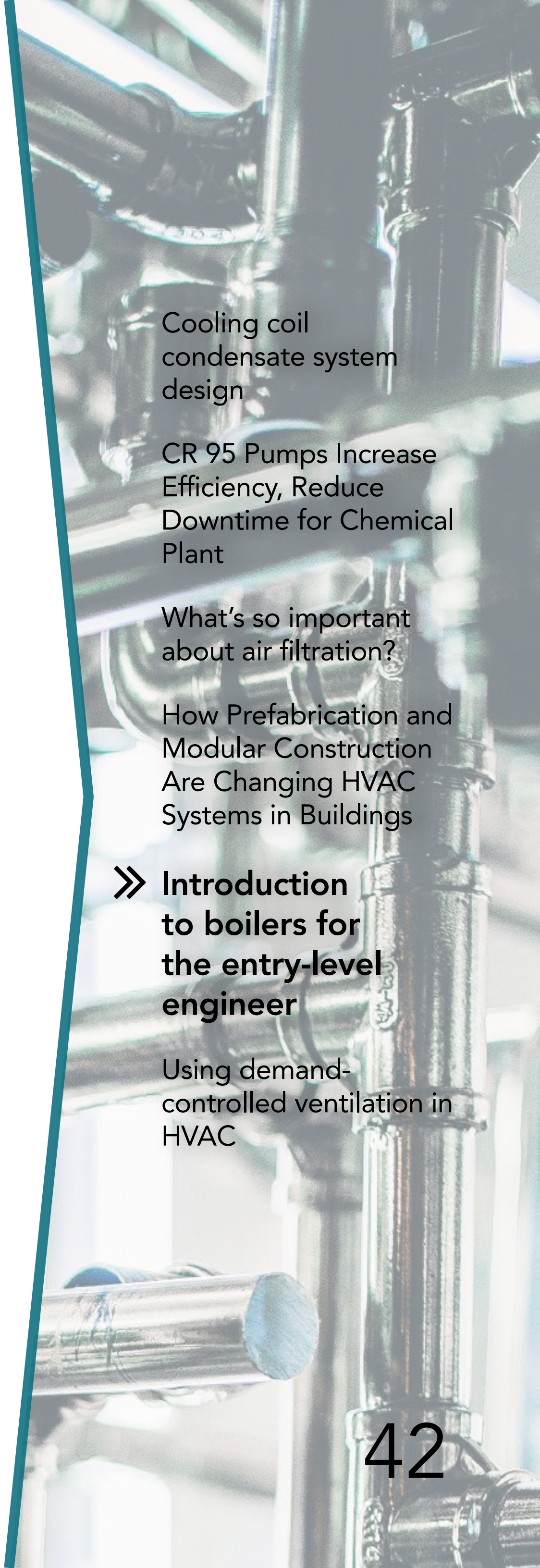
***Figure 1:*** *This boiler diagram shows the difference between dryback and wetback boilers. Courtesy: CCJM Engineers*

Fire-tube boilers also have much longer fire-up times and require longer adaptation periods to altering demands due to their high thermal mass (high volume of water in the boiler). These types of boilers also require regular and difficult maintenance periods. Water-tube boilers have relatively fast fire-up times and respond easily to frequently changing demands due to their small thermal mass (low overall water volume) compared to equivalent fire-tube boilers.

## Boiler definitions and classifications

After navigating which type of commercial hydronic boiler will best serves the needs of a particular project, one must then dive into the specifications that will define and describe the boiler for the project.

A specification for a boiler can have confusing verbiage that is difficult to navigate. Key components include its burner, combustion chamber, heat exchanger, controls and exhaust stack. The burner of a boiler provides the flames that heat the water in the boil-



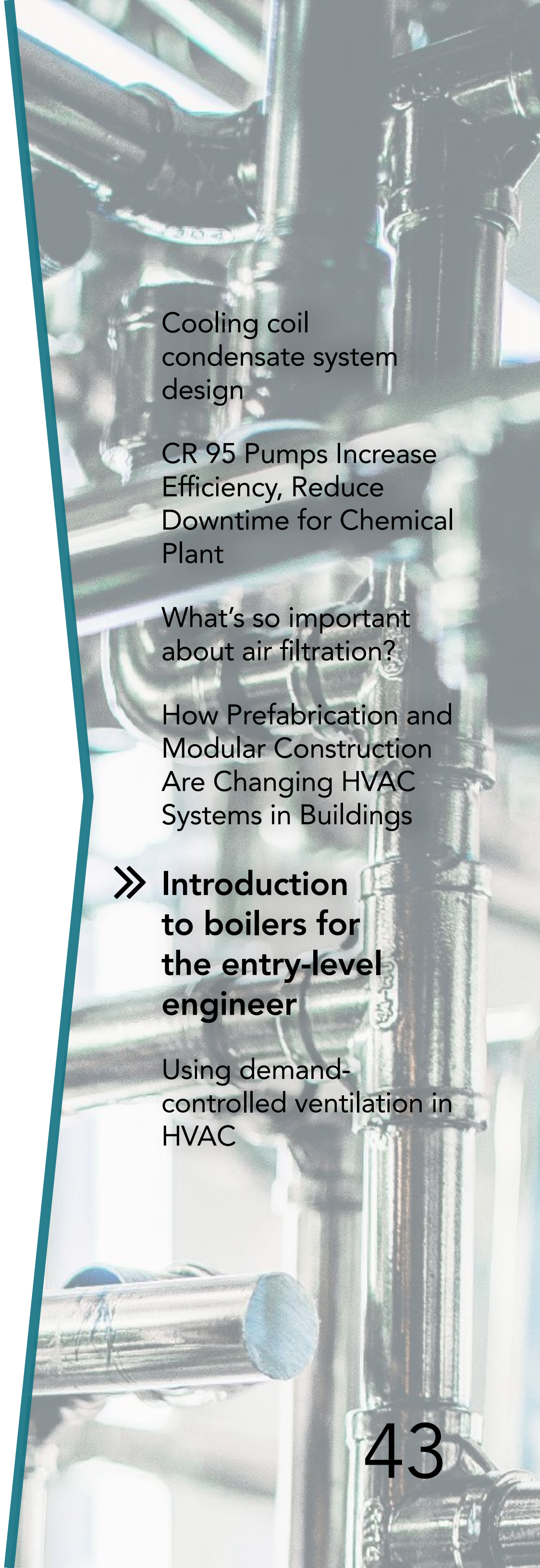
er, while the combustion chamber is the area within the boiler where fuel is burned to heat the water. This chamber holds the burner and is usually made of cast iron or steel. The heat exchanger of a boiler allows the transfer of the heat produced by the burners to the water in the boiler. To set the water temperature, ignition, air and fuel supply mixtures and internal pressure, every boiler will have systems controls.

These systems controls also contain a safety control to ensure that the internal pressures in the boiler don't get too high. These safety controls ensure that the water temperature stays within a safe range and the system is running as designed.

The final component of a boiler is the exhaust stack. The exhaust stack contains all of the pipes used to carry exhaust gases from the boiler to the outside of the building. This component is crucial to the safety of the system because of the toxicity of carbon monoxide in any building.

When choosing a hydronic boiler, another key term to look at is its turndown ratio. The turndown ratio of a boiler is the ratio between full boiler output and the boiler output when operating at low fire. Typical boiler turndown is 4:1 meaning a 400-horespower boiler with a turndown of 4:1 will modulate down to 100 horsepower before cycling off.

When an engineer needs to develop a boiler specification for a specific project, they typically look in their company's custom master specification library or one of the model master specifications like the American Institute of Architect's MasterSpec library to look for the applicable master specification under Division 23. Specifically, they would look for section 23 52 16 condensing boilers, section 23 52 33 water-tube boilers or section 23 52 39 fire-tube boilers, depending on the specific type of boiler the project



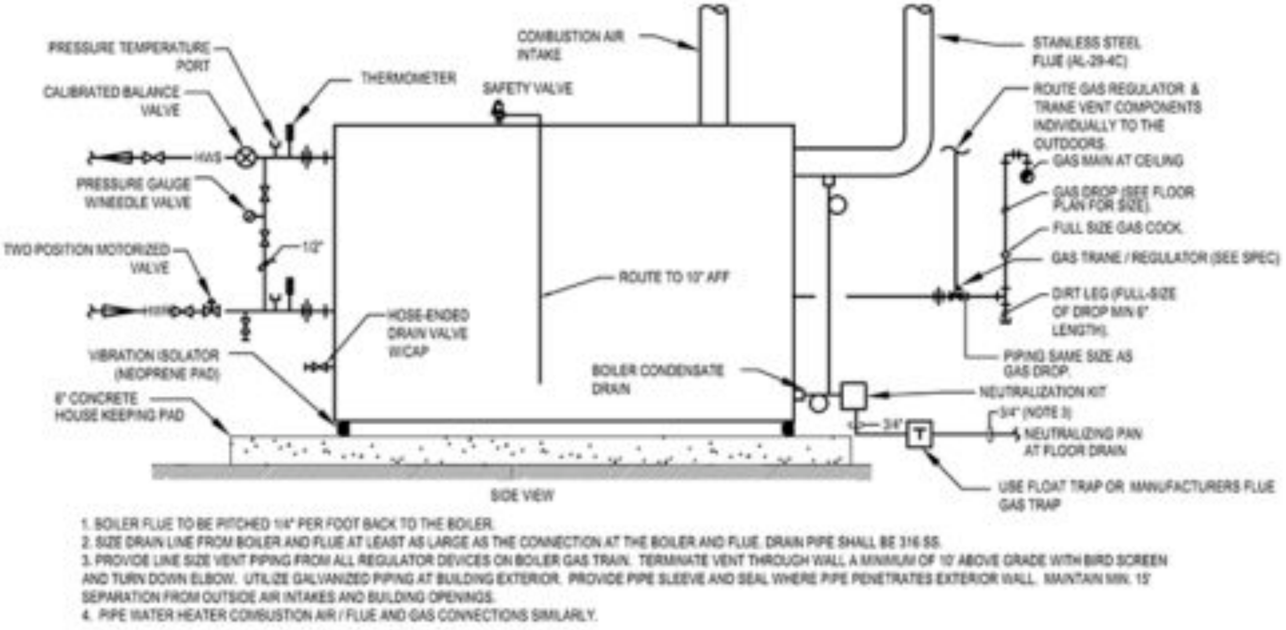


***Figure 2:*** *This sample condensing boiler installation detail shows all the components typically in a condensing boiler installation. The main components that distinguish a condensing boiler are the neutralization kit and stainless steel AL-29-4C flue. Courtesy: CCJM Engineers*

engineer for the project has selected in the basis of design. One of these specifications would be selected and edited for the project.

To demonstrate how a master specification is edited for a particular project, we will use specification section 23 52 16 condensing boilers for a boiler being implemented in a local public school district.

Part 1 of the condensing boiler specification will the general description what type of condensing boiler is being described in the section of this article titled “What defines a hot water boiler?”

## Part 1: General

1.1 Related documents

Retain or delete this article in all Sections of Project Manual.

A. Drawings and general provisions of the contract, including general and supplementary conditions and Division 01 specification sections, apply to this section.

1.2 Summary

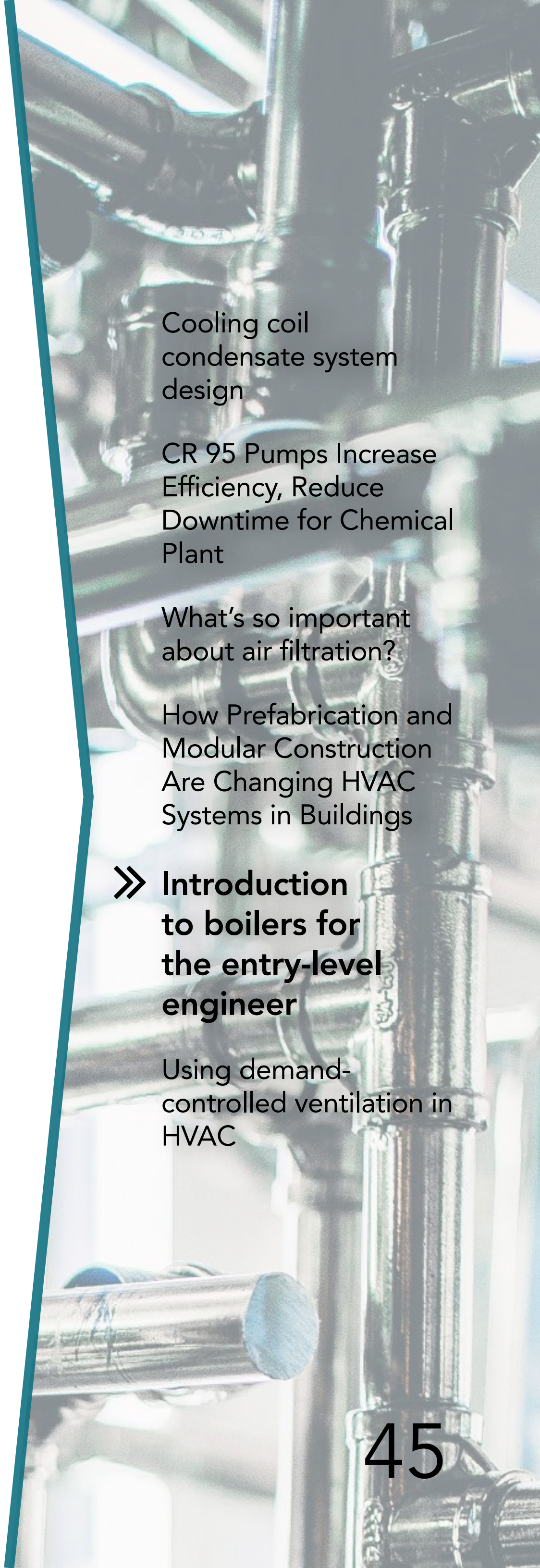
A. Section includes gas-fired, [~~pulse-combustion~~] [fire-tube] [~~water-tube~~] [water-jacketed] condensing boilers, trim and accessories for generating [hot water] [~~and~~] [~~steam~~].

To follow the type of boiler illustrated in Figure 1, we would edit the following raw specification sections as shown below while confirming the features with the basis of design condensing boiler:

## Part 2: Products

2.1 Forced-draft, fire-tube, condensing boilers

B. Manufacturer: Design note: Select manufacturers from owner's approved list, if applicable or based on engineer preference and local engineering and maintenance support.



C. Description: Factory-fabricated, -assembled and -tested, fire-tube condensing boiler with heat exchanger sealed pressure tight, built on a steel base, including insulated jacket; flue-gas vent; combustion-air intake connections; water supply, return and condensate drain connections; and controls. Water-heating service only.

D. Heat exchanger: Nonferrous, corrosion-resistant combustion chamber.

E. Pressure vessel: Carbon steel with welded heads and tube connections.

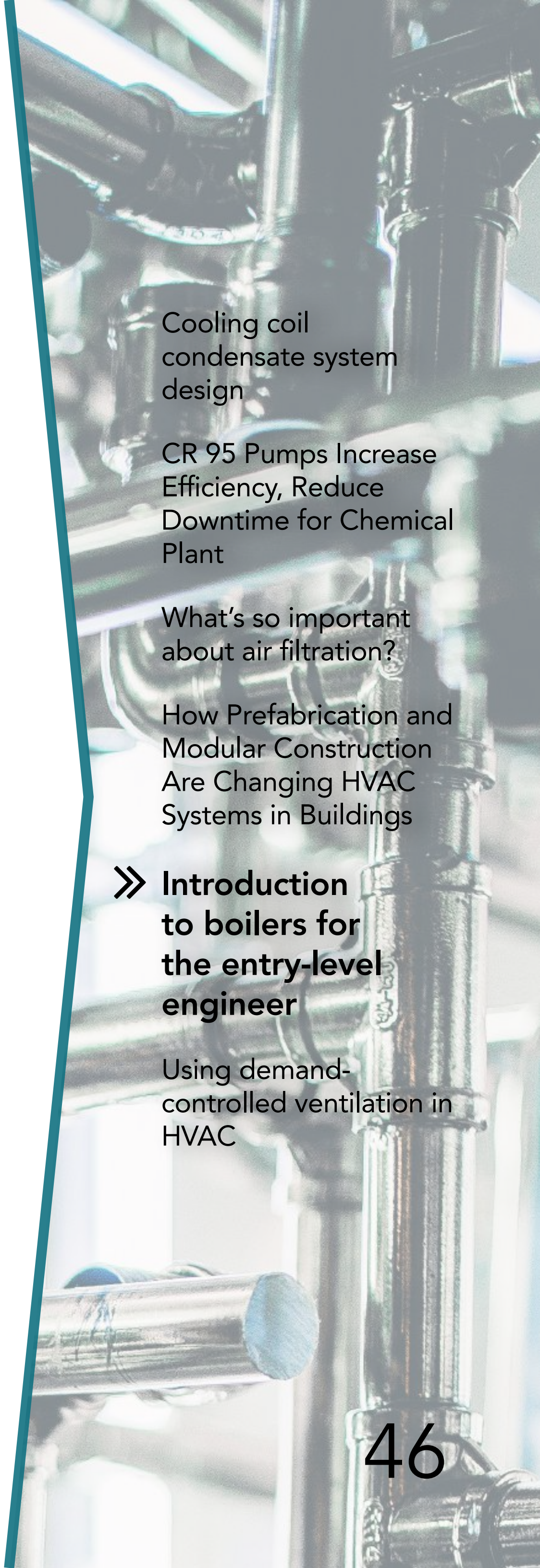
F. Burner: [Natural] [~~Propane~~] gas, forced draft. Design note: Pick whichever is common for the region.

G. Blower: Centrifugal fan to operate during each burner firing sequence and to prepurge and postpurge the combustion chamber.

Default motor characteristics are specified in Section 230513 “Common Motor Requirements for HVAC Equipment.”

1. Motors: Comply with National Electrical Manufacturers Association designation, temperature rating, service factor and efficiency requirements for motors specified in Section 230513 “Common Motor Requirements for HVAC Equipment.”

    a. Motor sizes: Minimum size as indicated; if not indicated, large enough so driven load will not require motor to operate in service factor range above 1.0.



H. Gas train: Combination gas valve with manual shut-off and pressure regulator.

I. Ignition: Spark ignition with 100% main-valve shut-off with electronic flame supervision.

J. Casing:

1. Jacket: [Sheet metal] [Plastic], with snap-in or interlocking closures.
2. Control compartment enclosures: NEMA 250, Type 1A.

If retaining second option in “Jacket” Subparagraph above, delete “Finish” Subparagraph below.

3. Finish: [Baked-enamel] [Powder-coated] protective finish.

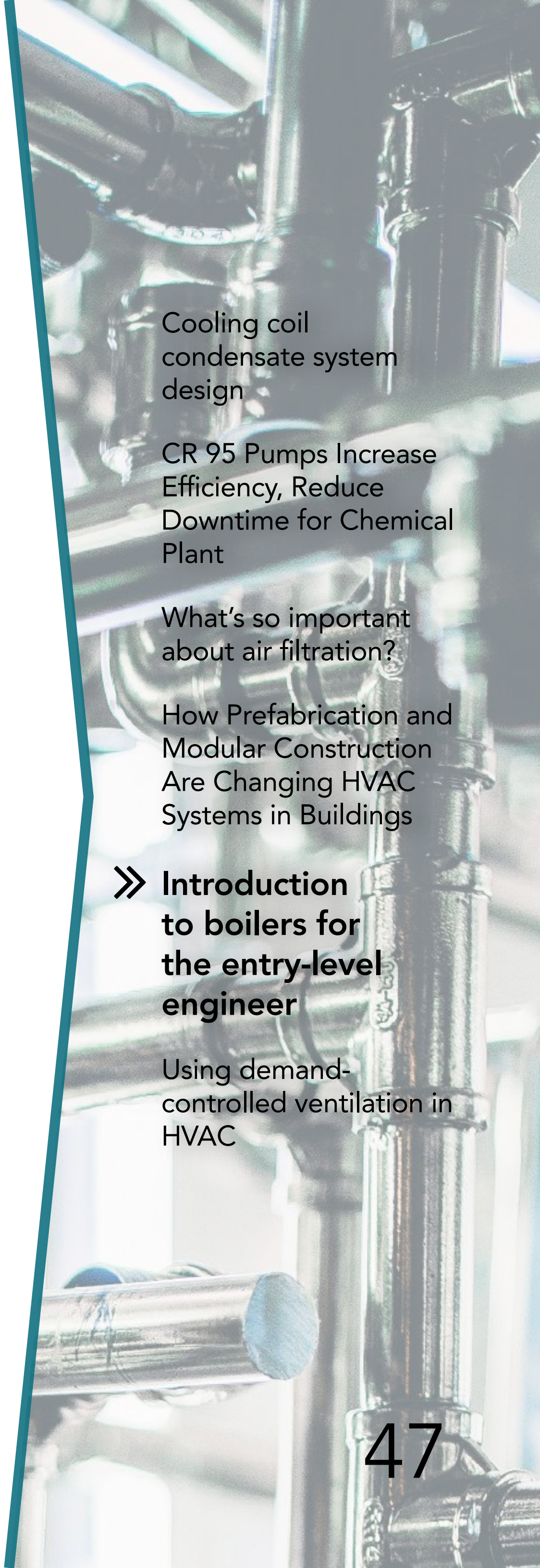
4. Insulation: Minimum 2-inch–thick, [mineral-fiber] [polyurethane-foam] insulation surrounding the heat exchanger.

5. Combustion-air connections: Inlet and vent duct collars.

If Project has more than one type or configuration of boiler, delete “Capacities and Characteristics” Paragraph below and schedule boilers on Drawings.

K. Capacities and characteristics:

1. Heating medium: Hot water.



2. Design water–pressure rating: [160 pounds/square inch gage] Design note: This is the standard working pressure for American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section IV Heating Boilers Class.

3. Safety relief valve setting: Design note: Value ranges from 30 psig up to the design water-pressure rating and is selected by the consulting engineer based on the highest pressure point in the system, in psig.

4. Entering-water temperature: Design note: Value is based on the project design requirement, in degrees F.

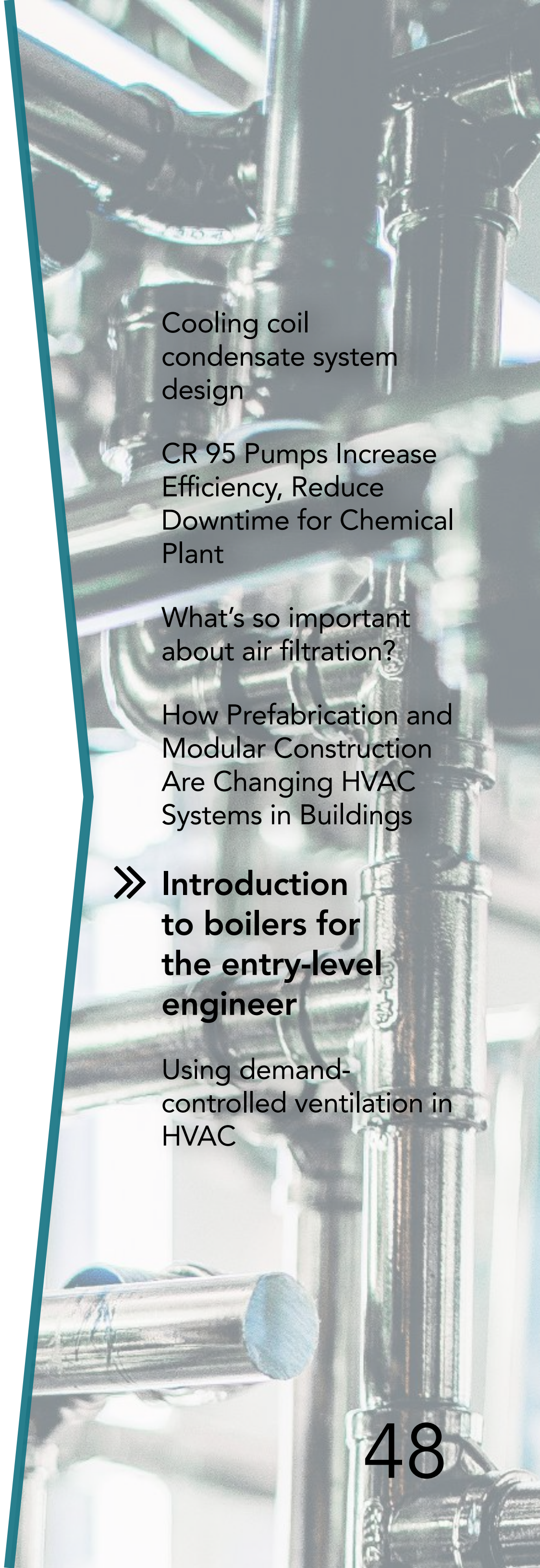
5. Leaving-water temperature: Design note: Value is based on the project design requirement, in degrees F.

6. Design water flow rate: Design note: Value is based on the project design requirement, in gallons/minute.

7. Minimum water flow rate: Design note: This value is based on the basis of design boiler's stated minimum flow requirement, in gpm.

8. Design pressure drop: Design note: Value is based on the basis of design boiler listed pressure drop, in psig.

Retain "Minimum Efficiency AFUE," "Minimum Thermal Efficiency," or "Minimum Combustion Efficiency" Subparagraph below. Specify standing or intermittent pilot with



minimum AFUE. Sustainable design systems require compliance with ASHRAE/IES 90.1 and may require efficiency in excess of minimum efficiency required by ASHRAE/IES 90.1.

9. Minimum efficiency annual fuel utilization efficiency: Design note: Value is based on the basis of design boiler listed efficiency in percentage.

10. Minimum thermal efficiency: Design note: Value is based on the basis of design boiler listed thermal efficiency in percentage.

11. Minimum combustion efficiency: Design note: Value is based on the basis of design boiler listed combustion efficiency in percentage.

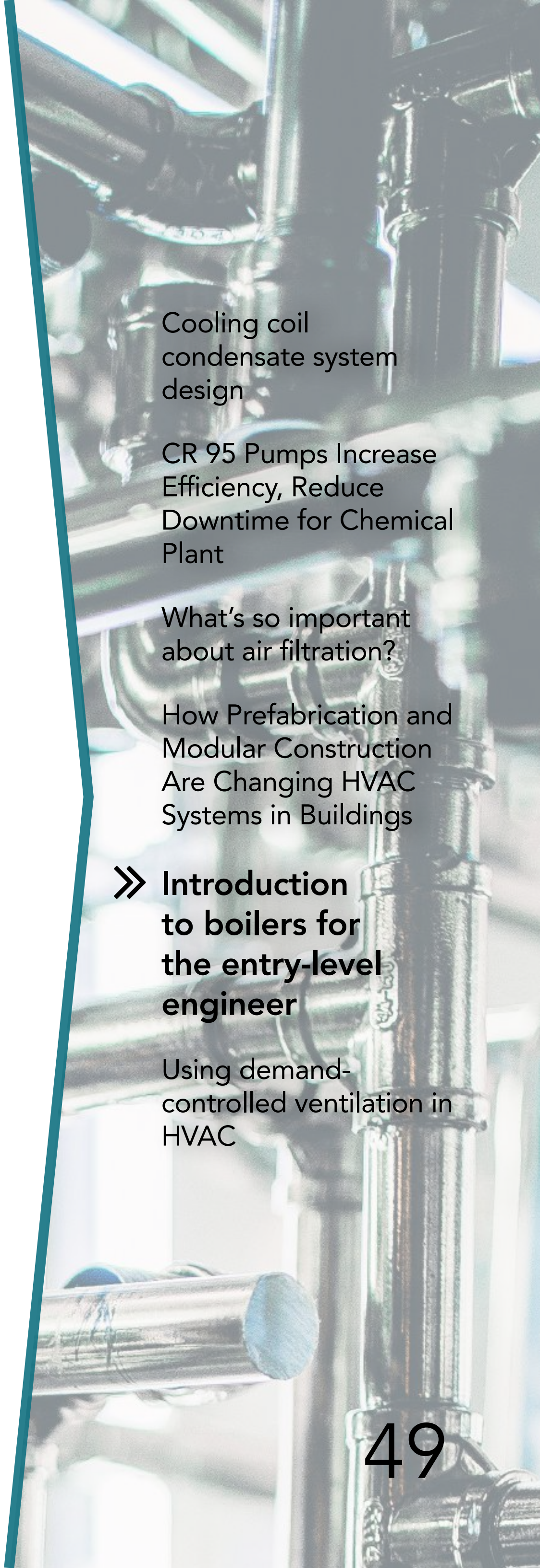
Retain “AGA Input” or “Gas Input” Subparagraph below.

12. American Gas Association input: Design note: Value is based on the basis of design boiler listed data, in MBH.

Consider actual Btu content of fuel source if retaining “Gas Input” Subparagraph below. Contact fuel supplier and boiler manufacturers to determine impact. Add text indicating Btu content of fuel if applicable.

13. Gas input: Design note: Value is based on the basis of design boiler listed data, in cubic feet per hour.

Retain “AGA Output Capacity,” “DOE Output Capacity,” or “Equivalent Direct Radia-



tion" Subparagraph below for rating methods.

14. AGA output capacity: Design note: Value is based on the basis of design boiler listed data, in MBH.

15. Department of Energy output capacity: Design note: Optional value is based on the basis of design boiler listed data, in MBH.

16. Equivalent direct radiation: Design note: Value is based on the basis of design boiler, listed data as EDR.

Consider impact of site altitude on fan and motor.

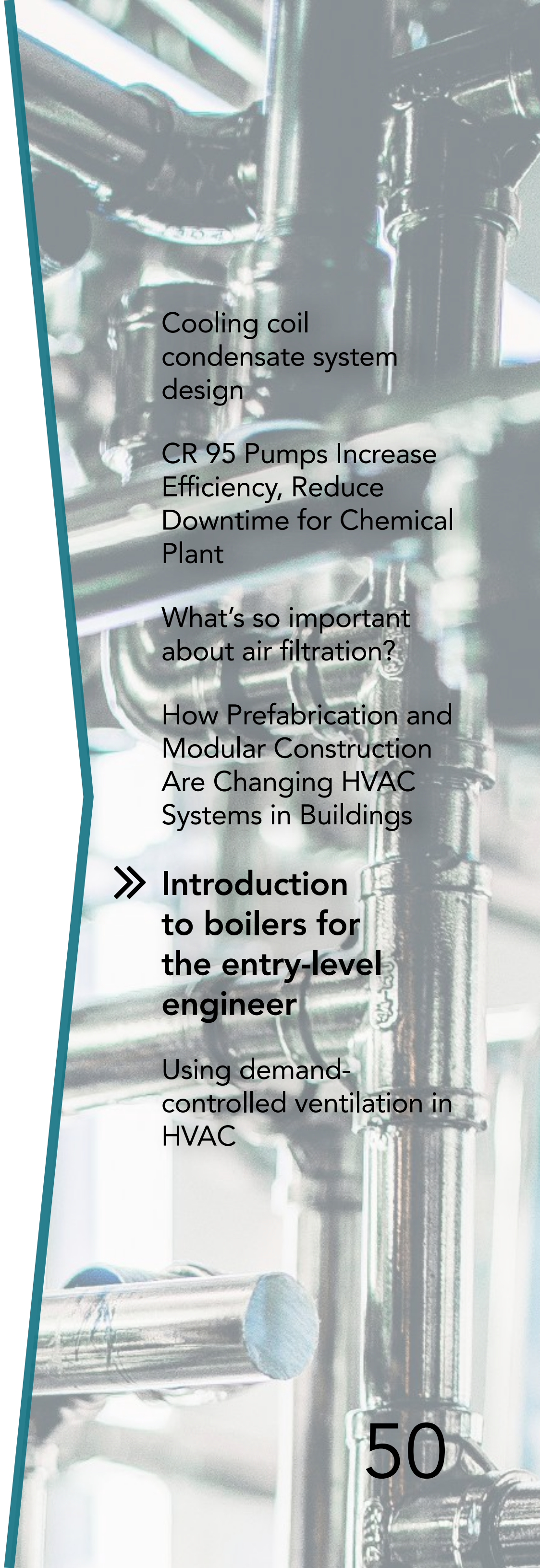
17. Blower:

    a. Motor horsepower: Design note: Value is based on the basis of design boiler listed data.

    b. Revolutions/minute: Design note: Value is based on the basis of design boiler listed data.

18. Electrical characteristics:

    a. Volts: [115] [208] [230] [460] Design note: Value is based on the basis of design boiler listed data and project conditions.



b. Phase: [Single] [Three] Design note: Value is based on the basis of design boiler listed data and project conditions.

c. Hertz: [~~50~~] [60] Design note: 60 hertz is the standard in the U.S.

d. Full-load amperes: Design note: Value is based on the basis of design boiler listed data.

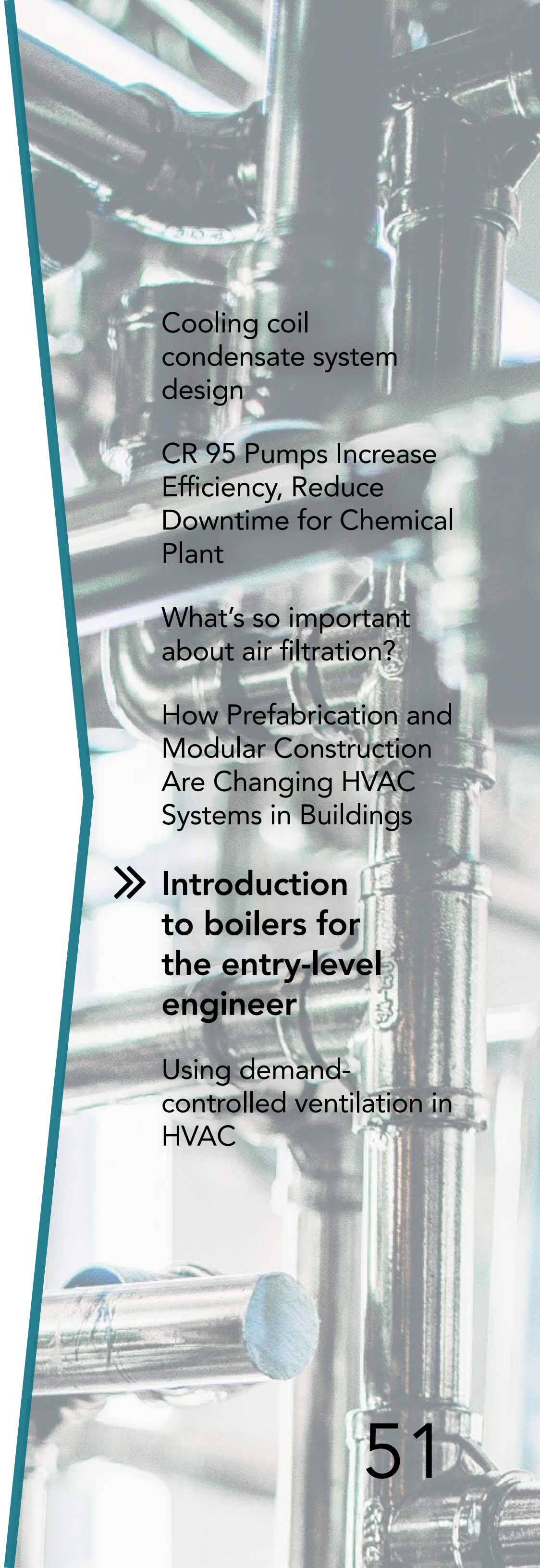
e. Minimum circuit ampacity: Design note: Value is based on the basis of design boiler listed data, for wire sizing.

f. Maximum overcurrent protection: Design note: Value is based on the basis of design boiler listed data, for power circuit breaker sizing.

Note that this specification's edits are for a standard condensing boiler project in the U.S. For a given project, the young engineer should request more guidance from the project engineer and customize the options and construction to match owner requirements, local code requirements and project budget. Once the verbiage and classification are defined for a commercial hydronic boiler, the specifications can then reflect the boiler being used for the project. To properly specify the boiler, the consulting engineer needs to understand the application considerations of the boiler chosen.

## Commercial application considerations

Commercial boilers are used typically in hospitals, offices, hotels and schools. These



boilers typically work with heat output from 6,000 MBH to as low as 400 MBH. Commercial condensing boilers are available in fire– and water–tube designs. They typically use propane or natural gas to provide hot water. These systems in a condensing mode operation can have fuel efficiency as high as 98%, depending on the extent of condensing to capture the latent heat of the flue gas by the return water.


**Figure 3:** *An elementary school heating plant has two condensing boilers and hot water distribution pumps. Courtesy: CCJM Engineers*

Most architectural projects with large amount of glazing will favor the hydronic boiler because it is an efficient and cost-effective boiler to be used for heating schools, offices and other commercial buildings. Overhead air heating doesn't work well with tall glazing higher than 5 feet, so some type of local perimeter heating, whether baseboard or radiant ceiling panels, provides an effective solution. For most applications and regions in the U.S., hydronic heating generally provides a more cost-effective solution than electric heating.

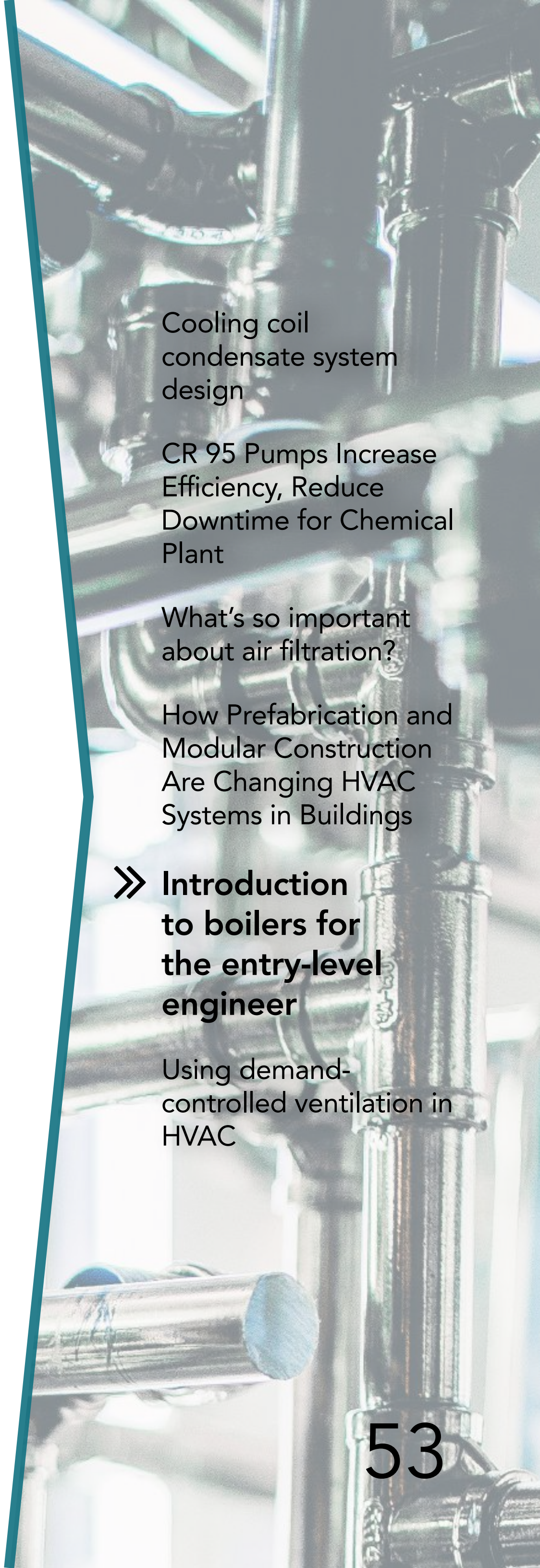
Although gas boilers are typical 10% to 25% higher in price than their oil-fired counterparts — the quick payback due to lower natural gas prices per gallons/minute of heated water compared to oil boilers makes it worth the investment. Natural gas-fired boilers also boast approximately 10% higher AFUE than oil-fired boilers, a measure for a boiler's combustion efficiency.

Fuel oil also frequently lacks the pipeline infrastructure, which means certain means of resupply and storage have to be taken into consideration. Oil has its advantages in terms of providing maximum heat; the boilers are capable of supplying the amount of heat required to reach a certain setpoint two times faster than natural gas boilers due to the higher temperatures oil burns at. The higher burning temperatures also ensure lower amounts of condensation, which leads to a longer life span of the boiler if the boiler construction isn't corrosion resistant.

Condensing boilers are the most popular commercial water boiler due to the high combustion energy efficiency levels they are able to achieve. However, multiple important factors should be taken into consideration when deciding whether the initial price increase, typically in the 30% cost premium range, is worth it for the system, whether it be a new or retrofit project. Beyond first cost, system operation also plays a significant role in their selection.

Generally, condensing boilers operate at lower supply and return water temperatures, typically 160 F supply and 130 F return, to achieve their optimal energy savings. Systems in northern climates that require a higher supply temperature during peak heating season tend to operate outside the condensing return water temperature for much of the heating season. They do provide high energy efficiency during the shoulder months when only lower–quality heat is adequate.

Condensing boilers achieve their highest efficiencies around 98% when the return



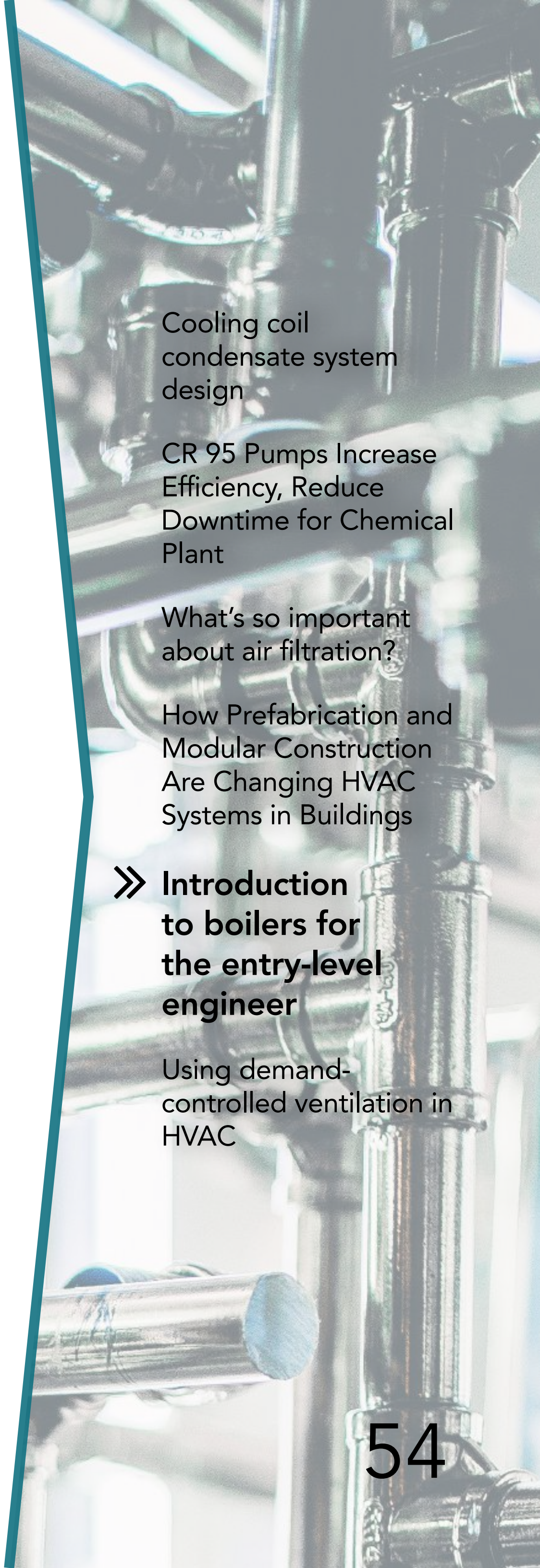
water temperature is as low as possible, typically around 80 F. However, typical return water temperatures for conventional hydronic systems is around 130 F, which yields overall boiler efficiency around 90%. The lower hot water return temperature aids in condensing the flue gases produced from the combustion of natural gas, which in turn causes a release of energy that heats the return water before entering the combustion chamber of the boiler and thus raising the overall efficiency of the boiler.

They are available in fire– and water–tube configurations. If the system is expected to be running at high supply and return temperatures for most of its operating hours, a condensing boiler system will not be the optimal system selection because the hot water return temperature will always be too high for condensing operation. The equipment that is being served by the boilers also should be one of the deciding factors for the boiler type.

Some terminal heating equipment require higher temperature heating fluid to ensure proper operation. Radiant ceiling panels are a good example of such equipment that perform most optimally at supply temperatures around 180 F. For systems with a large number of these devices, a condensing boiler may not the optimal choice. Conversely, applications such as underfloor heating and variable air volume box reheats and installations in milder winter climates (Department of Energy and International Code Council climate zones 2, 3 and 4) are excellent for taking advantage of the benefits of condensing boilers with lower supply water temperatures around 150 F to 160 F.

## Hybrid systems

Combining condensing and noncondensing boilers in the same system, also called a



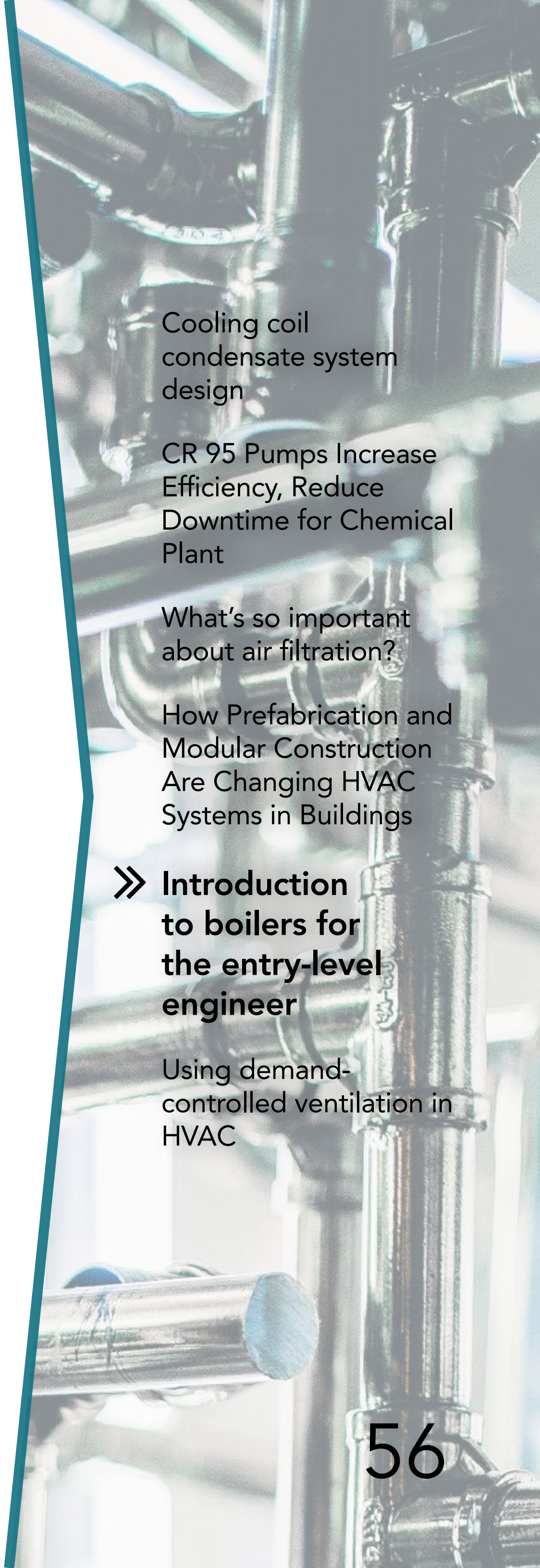
hybrid system, can help improve overall system efficiency. As discussed above, the return water to the boiler has to be a low enough temperature for the flue gases to condense. Usually, this happens when the weather conditions do not require the boiler system to be firing at high combustion, which usually happens around the shoulder seasons of fall and spring. This is where hybrid systems are optimal by selecting just enough condensing boilers to pick up the load for the shoulder months along with lower water temperature loops such as reheats and underfloor heating, if they are part of the project. By doing so, the system minimizes capital investment in condensing boilers and at the same time takes advantage of the higher efficiencies condensing boilers are capable of for a significant portion of the year.

***Figure 4:*** *This photo shows one of the existing 75,000 MBH boilers under maintenance at an international airport. Courtesy: CCJM Engineers*

After selecting the suitable condensing boiler for the application, special precautions have to be taken into consideration when designing the flue exhaust stack and condensate drainage. Both the gaseous exhaust and condensate from a condensing boiler are moderately acidic. Therefore, the flue for condensing boilers is typically fabricated with AL-29-4C stainless steel to resist corrosion.

A neutralization kit containing calcium carbonate (limestone chips) on the boiler's drain line is required to neutralize the acid before releasing into the sanitary drain system. The condensate that drains to the neutralizing basin has to be corrosion–resistant while complying with local plumbing code–acceptable materials. Sizing and routing of the exhaust and drainage is usually specified per the boiler manufacturer's recommendations.

**Jacob Haddadin, EIT and Stephanie Khouri, CCJM Engineers Ltd., Chicago**
***Jacob Haddadin*** *is a mechanical engineer at CCJM Engineers and a recent graduate from the Illinois Institute of Technology, with hands-on commercial building mechanical design experience covering multifamily residential, educational and laboratory facilities and commissioning. Stephanie Khouri is a mechanical engineer at CCJM Engineers and a recent graduate of Marquette University developing her mechanical design experience with commercial and educational facilities.*



# Using demand-controlled ventilation in HVAC

*Mechanical engineers should consider the many factors that go into designing buildings for indoor air quality and indoor environmental quality*

A recent article published in The Washington Post by Christopher Ingraham clearly explained "Why crowded meetings and conference rooms make you so, so tired." It had a concise description of carbon dioxide levels and their effect on occupant comfort and performance.

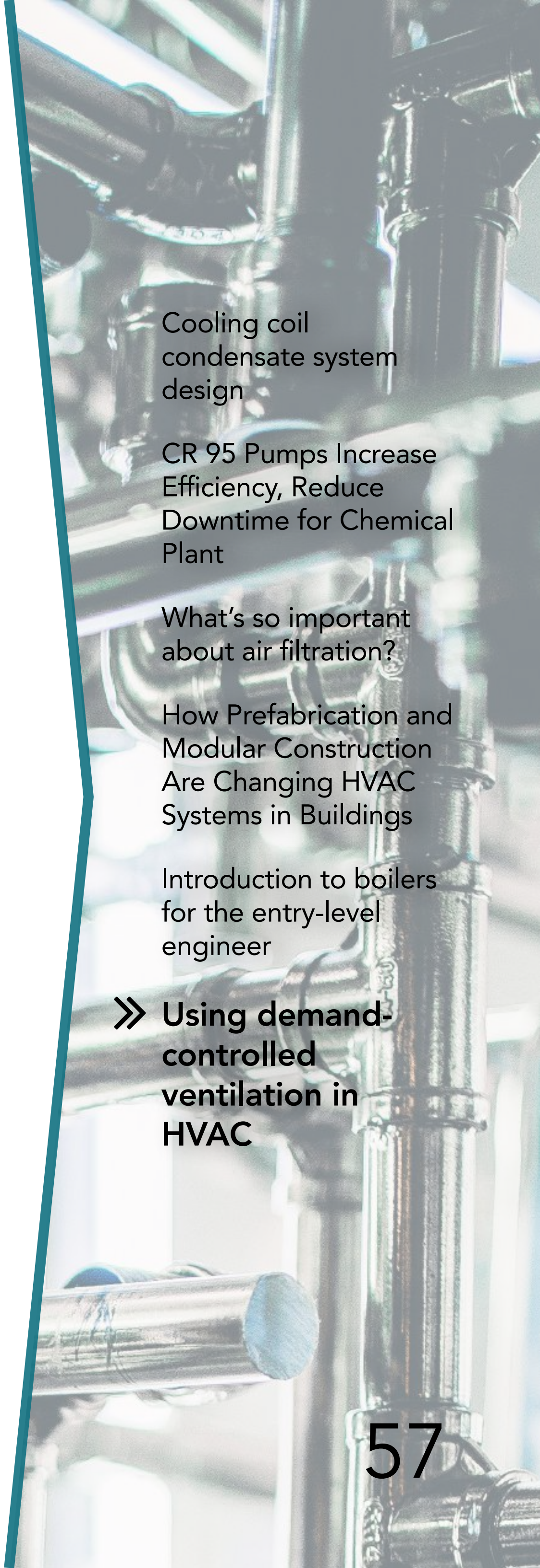
A graph of a live meeting showed how quickly the CO2 in a crowded conference room went from 800 to 1,000 parts per million, the threshold at which ASHRAE Standard 62.1-2016: Ventilation for Acceptable Indoor Air Quality states occupants first start to feel stuffy and sleepy.

## Indoor environmental quality

IEQ includes everything from room color and ergonomic layout, to how well the pest control is done. For many, it is defined by the U.S. Green Building Council's LEED rating system and comes down to a few main topics:

- Thermal comfort.
- Lighting.
- Acoustics/sound.
- Ventilation.

For the heating, ventilation and air conditioning engineer, there are two ASHRAE com-



pliance standards: ASHRAE Standard 55: Thermal Environmental Conditions for Human Occupancy, and ASHRAE Standard 62.1.

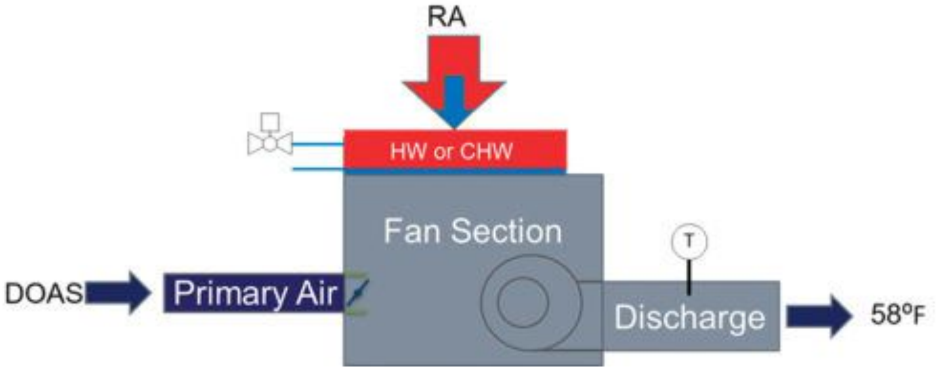


***Figure 1:*** *The schematic shows a series terminal box using dedicated outside air that can be directly measured and controlled. Courtesy: Envise*

## What is a high-performance building?

According to Title IV – Energy Savings in Buildings and Industry in the Energy Independence and Security Act of 2007, a high-performance building is "a building that integrates and optimizes on a life cycle basis all major high-performance attributes, including energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality and operational considerations."

The convergence of making a building both comfortable and energy–efficient has been a challenge for several years. As designers are discovering, traditional HVAC designs don't make it easy in many parts of the country, especially those with higher levels of cooling requirements, as traditional HVAC designs are developed based on an average of climate conditions across the country.

## Demand-controlled ventilation

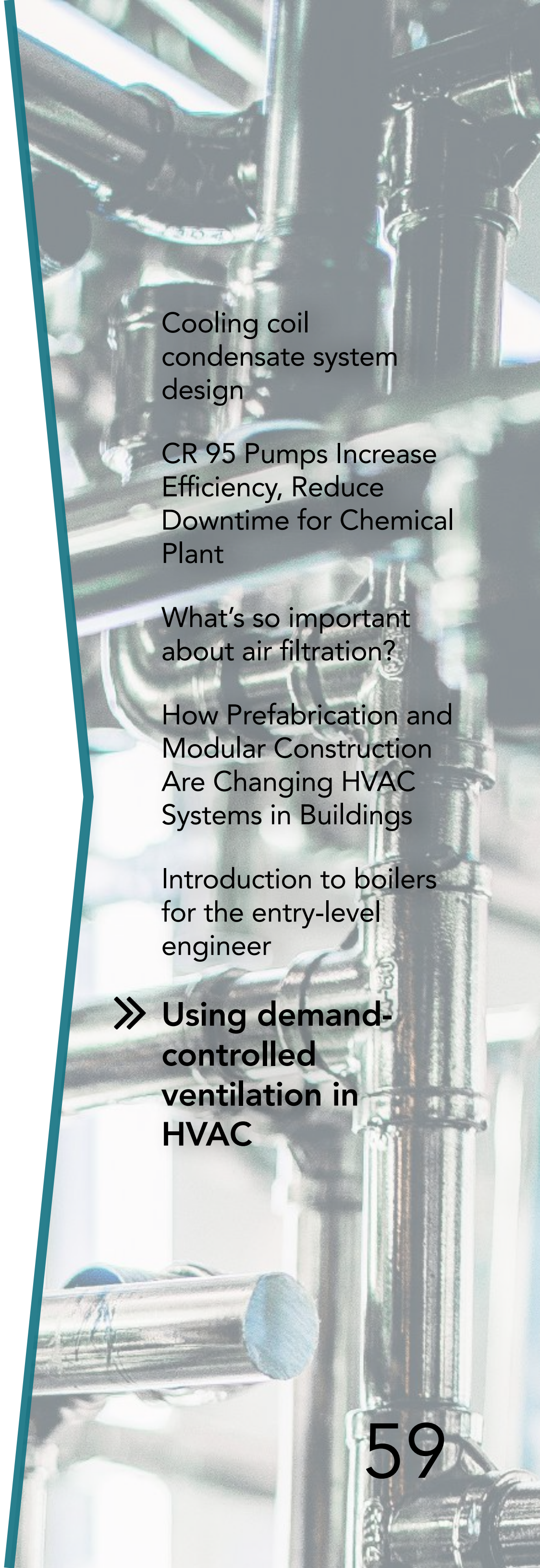
One of the most popular ways to meet ASHRAE 62.1 requirements and conserve energy is through DCV. This method allows the engineer to decrease the amount of ventilation in a space if it can be demonstrated there are either no people in the space or not enough people to justify the "cubic feet per minute rate per person." The intent of this method is to match the provided ventilation rate with actual occupancy (demand), maintaining indoor air quality without overventilating.

The ASHRAE 62.1-2016 rules for implementing DCV are found in section 6.2.7:

> 6.2.7.1. DCV shall be permitted as an optional means of dynamic reset. Exception: CO2-based DCV shall not be applied in zones with indoor sources of CO2 other than occupants or with CO2 removal mechanisms, such as gaseous air cleaners.
>
> 6.2.7.1.1 For DVC zones in the occupied mode, breathing zone outdoor airflow (Vbz) shall be reset in response to current population.
>
> 6.2.7.1.2 For DVC zones in the occupied mode, breathing zone outdoor airflow (Vbz) shall be no less than the building component (Ra x Az) of the DCV zone. Note: Examples of reset methods or devices include population counters, carbon dioxide sensors, timers, occupancy schedules or occupancy sensors.

With this in mind, how do we determine the number of individuals in the breathing zones? While there are many different ways to accomplish DCV sequences, here are two basic examples:

$CO_2$ control for:
- Open offices.



- Meeting rooms.
- Other transient spaces.

Occupancy sensor control for:

- Private offices.
- Enclosed limited purpose rooms.

Both start on the premise that if the schedule is "occupied," but no one is in the space, primary air is reduced to the minimum square foot requirement.

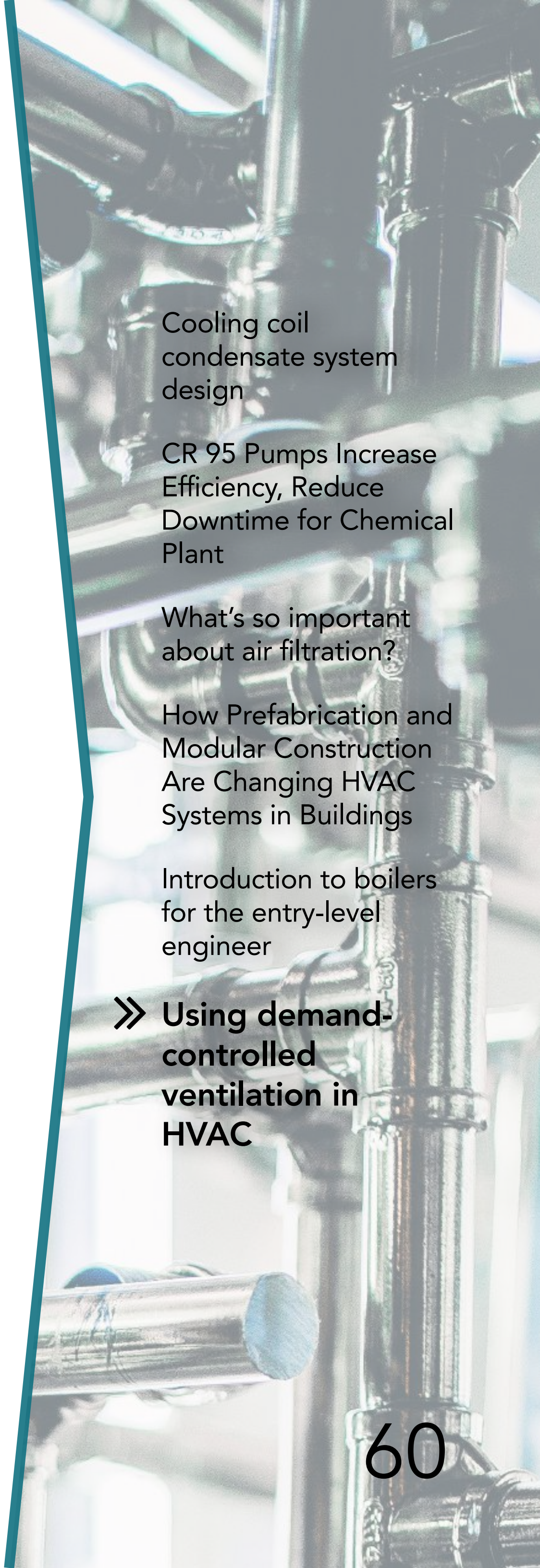
## Using outside air

The most precise way to control outside air is by having a dedicated source, such as a dedicated outside air unit, feeding only outside air to the terminal zones. The terminal zones are sequenced as follows:

1. Primary air is reduced to a "minimum setpoint." This is the ASHRAE 62.1 cubic feet per minute per square foot value only (0.06 cfm/square foot) for the office space category.

2. If $CO_2$ increases above the outside air $CO_2$ level by a differential, primary air is incrementally increased back to the design airflow rate.

3. If the occupancy sensor is activated, primary air is returned back to the design airflow rate.



As an option in private offices, primary air can be shut off completely until the occupancy sensor is activated.

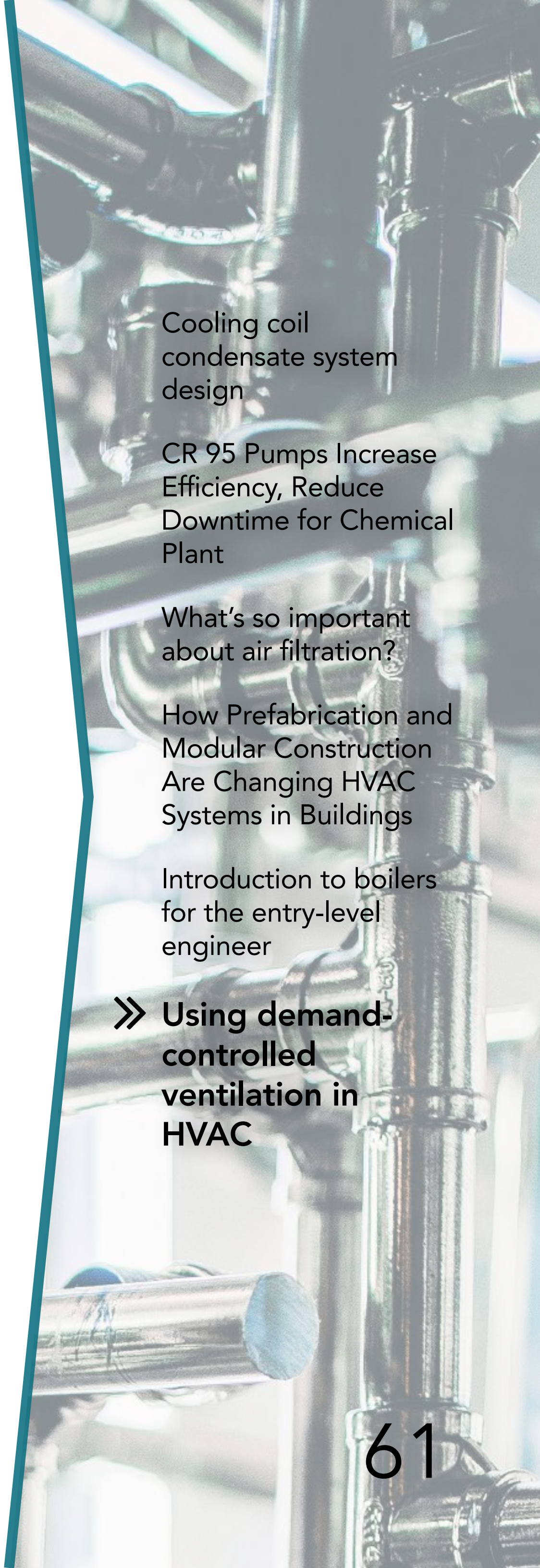
Two examples of when you may need additional primary air include temperature override and dewpoint override. In temperature override, you must stop the DCV reset and return to normal design airflow if the cooling setpoint cannot be maintained with the sensible coil. In the case of dewpoint override, you can stop the DCV reset and return to normal design airflow if the space dewpoint approaches the sensible chilled water temperature (58°F), if using a sensible chilled water coil.

There are a few factors to consider when controlling outside air. First, you should be aware if there are very low airflow rates on the primary air and whether they can be controlled accurately below 20% of box rated flow. Secondly, one needs to consider the availability and cost of points for occupancy sensor, $CO_2$ or dewpoint calculation.

When considering DCV at the air handler with a single-zone air handling unit, outside air can be measured and controlled directly at the outside air inlet (see Figure 3). $CO_2$ can be measured for the zone in the return air duct. Outside air is controlled to the minimum zone cubic feet per minute per square foot ventilation rate. If return air $CO_2$ increases above the outside air $CO_2$ by a differential of 700 ppm (or 1,100 ppm for outdoor air with acceptable $CO_2$ concentrations), outside air is increased back to the design airflow rate $V_{bz}$ ($R_a + R_p$).

## Variable air volume systems

Multiple-zone VAV systems with direct digital controls of individual zone boxes reporting to a central control panel may include means to automatically reduce outdoor air



intake flow below design rates in response to changes in system ventilation efficiency as defined by Appendix A of ASHRAE Standard 62.1-2016.

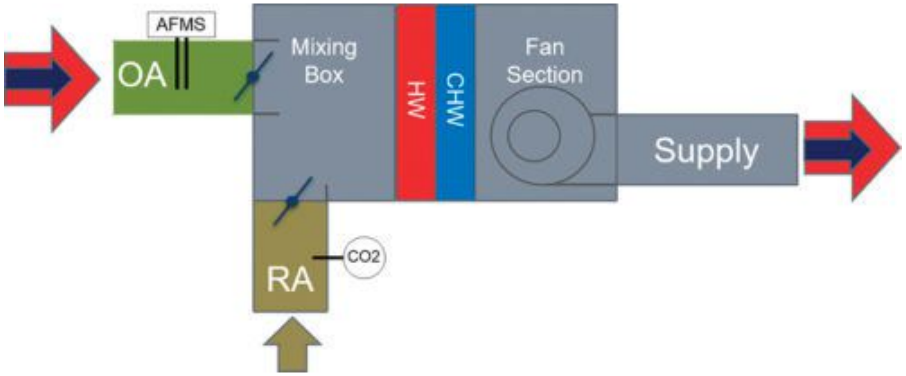


*Figure 2: A terminal box schedule shows that the minimum calculated cubic feet per minute per square foot is less than the primary airflow minimum scheduled cubic feet per minute, which may create controllability issues. Courtesy: Envise*

A few things to note about this scenario:

- Outside air can be measured and controlled directly at the outside air inlet.
- $CO_2$ and occupancy are measured for each zone at the zone.
- Zones send their occupied status to the AHU based on $CO_2$ differential.
- There are two outside air cubic feet per minute flow setpoints.
- Outside air is controlled to the measured minimum zone cubic feet per minute per square foot ventilation rate Ra.
- Outside air is increased back up to the design airflow rate Vbz (Ra + Rp) measured maximum.

Typical sequence of operations for this AHU/VAV system scenario:

1. The ventilation outside air damper will modulate to maintain the minimum outside air design setpoint value once the unit is enabled to run.

2. The minimum outside air cubic feet per minute will be increased on a trim and

respond setpoint optimization sequence: each zone associated with the AHU will be capable of registering a vote for more ventilation air. Upon a demand for one or more $CO_2$ monitored zones, the minimum outside air cubic feet per minute will be allowed to gradually increase up to the "design maximum" ventilation rate.

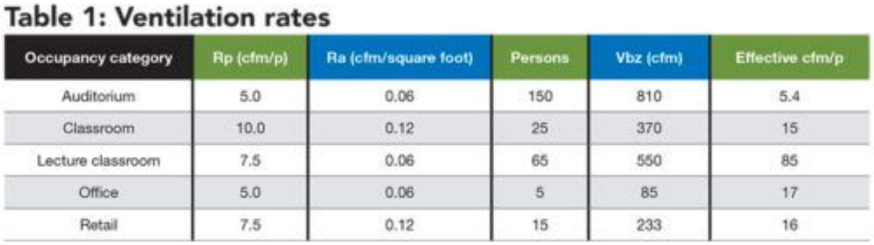


**Table 1: Ventilation rates**

| Occupancy category | Rp (cfm/p) | Ra (cfm/square foot) | Persons | Vbz (cfm) | Effective cfm/p |
|---|---|---|---|---|---|
| Auditorium | 5.0 | 0.06 | 150 | 810 | 5.4 |
| Classroom | 10.0 | 0.12 | 25 | 370 | 15 |
| Lecture classroom | 7.5 | 0.06 | 65 | 550 | 85 |
| Office | 5.0 | 0.06 | 5 | 85 | 17 |
| Retail | 7.5 | 0.12 | 15 | 233 | 16 |

***Table 1:*** *This shows the rate per person (Rp) and rate per area (Ra), resulting in the total ventilation rate for the space — called the ventilation breathing zone (Vbz) cfm. Actual values adapted from ASHRAE Standard 62.1-2016 Table 6.2.2.1. Courtesy: Envise*

3. As the $CO_2$ in the monitored zones decreases, minimum outside air cubic feet per minute will be decreased back to the scheduled "minimum" ventilation rate.

The following represents the trim and respond formula to be calculated once every five minutes (adj.):

*OA cfm = [(max cfm stpt – min cfm stpt)/20] * (votes)] + last cfm value*

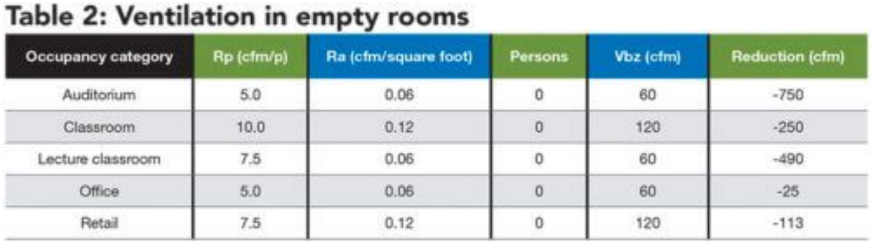
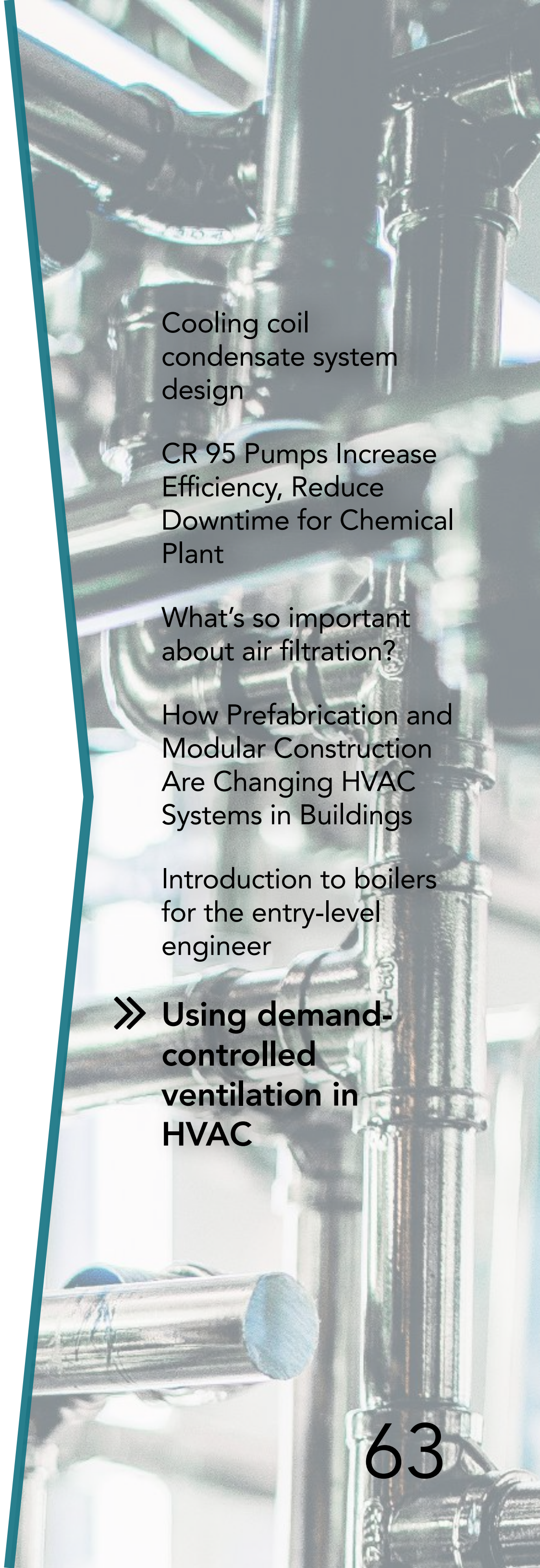


**Table 2: Ventilation in empty rooms**

| Occupancy category | Rp (cfm/p) | Ra (cfm/square foot) | Persons | Vbz (cfm) | Reduction (cfm) |
|---|---|---|---|---|---|
| Auditorium | 5.0 | 0.06 | 0 | 60 | -750 |
| Classroom | 10.0 | 0.12 | 0 | 120 | -250 |
| Lecture classroom | 7.5 | 0.06 | 0 | 60 | -490 |
| Office | 5.0 | 0.06 | 0 | 60 | -25 |
| Retail | 7.5 | 0.12 | 0 | 120 | -113 |

***Table 2:*** *This shows the cubic feet per minute reduction if there are no persons in the room, based on ASHRAE information. Courtesy: Envise*

When the votes go to zero, then the cubic feet per minute will be trimmed back to minimum once every five minutes (adj.):



$$\text{OA cfm} = \text{last cfm value} - (\text{max cfm value} - \text{min cfm stpt})/*20$$

For engineers concerned about a ventilation increase that is too gradual, this factor in the default formula can be changed and lowered to produce a faster and more dramatic response to $CO_2$ changes. This is best determined in the field during system commissioning.

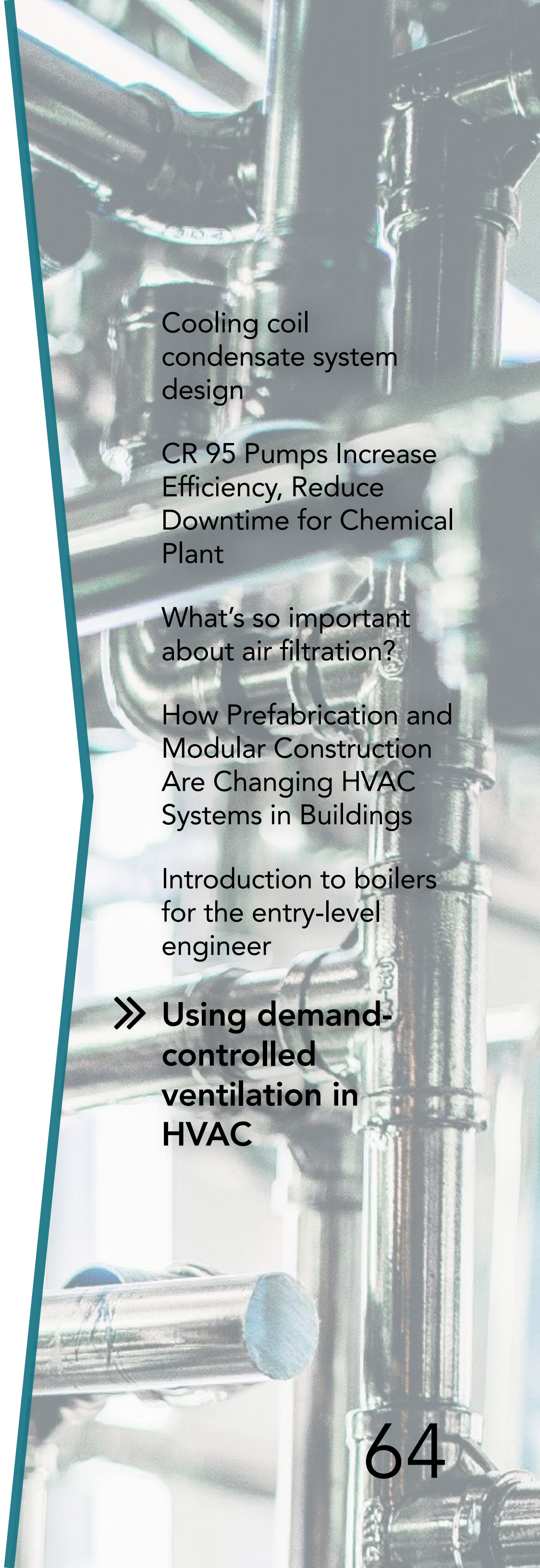
Mechanical engineers should consider the cost of $CO_2$ sensors, aesthetics and reliability/calibration of these sensors. When considering $CO_2$ sensors, know that:

- Most control system manufacturers have $CO_2$ options built into their zone sensors, which helps bring the cost down and improve the "look."

- $CO_2$ sensors are easy to maintain and calibrate if you understand how they self-calibrate.
- Physical destruction is the most common problem.

- Building automation system service agreements are highly recommended.

The use of a separate outside air $CO_2$ sensor is not recommended for a few reasons. First, if the sensor does need to be calibrated or otherwise fails, you not only cause problems with a zone but with your entire building. Second and most importantly, it is simply not needed. Ambient $CO_2$ levels in the atmosphere are currently at 414 to 430 ppm worldwide.



## Dewpoint monitoring and control

You may notice that several of these methods use sensible chilled–water coils. As a result, condensation at the zone may not be desired, and if you are in a situation where you may be condensing at the zone, you might find the zone outside the ASHRAE 55 standard for thermal comfort as well. For both of these reasons, controlling to a dewpoint is more desirable than basic relative humidity control.

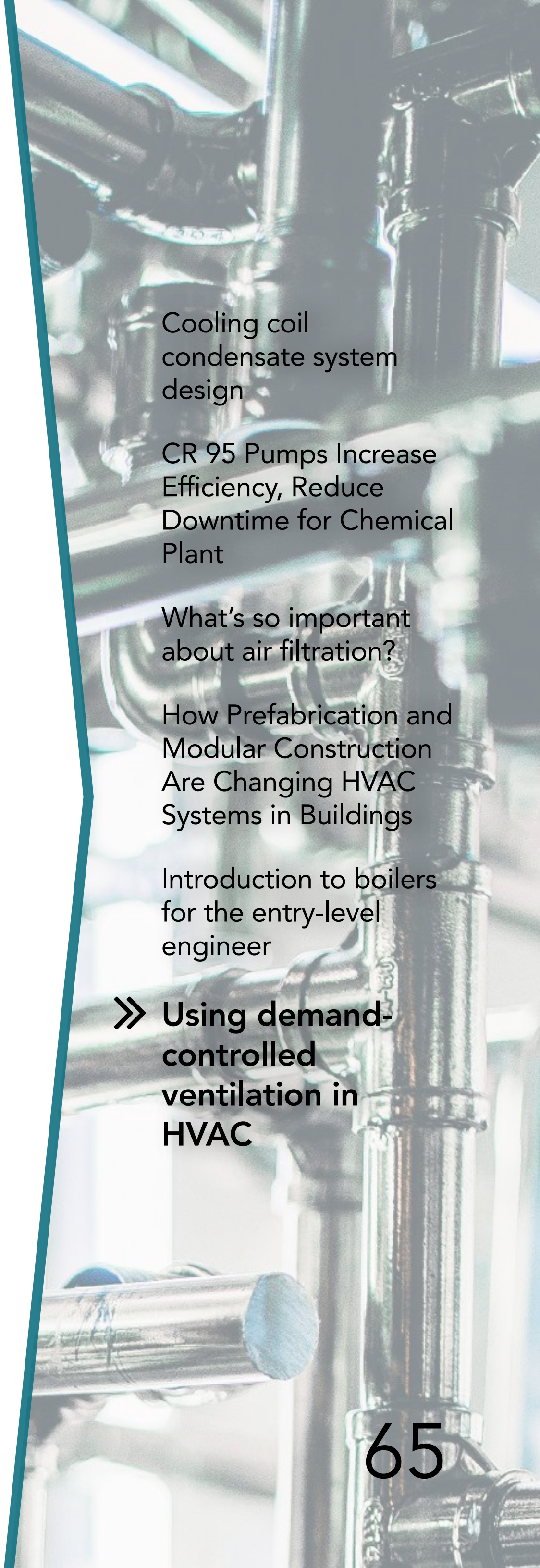
The general ASHRAE 55 requirement is to maintain humidity that corresponds to a dewpoint temperature at or below 62.2°F. Because sensible chilled water systems run at temperatures of 58°F, monitoring and maintaining a dewpoint control at 54°F (at a zone air temperature of 74°F) for the space will meet both requirements.

It is recommended to space dewpoint sensors throughout the floorplate, approximately one per 10,000 square feet. If a section of floor has a separate environmental system or is shut off tightly from other spaces, the area should have a separate monitoring point.

## Thermal comfort of occupants

The requirements of ASHRAE Standard 55-2017 are various and include:

- Temperature.
- Thermal radiation.
- Humidity.
- Air speed.



There are many personal factors as well that need to be taken into account when designing spaces. The standard does not cover other nonthermal environmental factors such as air quality, lighting or acoustics. While the standard is complex and beyond the scope of this article, in the context of the high–performance building, occupant control over their comfort settings should be more accessible. The sophisticated technologies that allow us to perform algorithms like the DCV sequences also allow the designer and facility owner to allow occupants to customize their environmental experience.

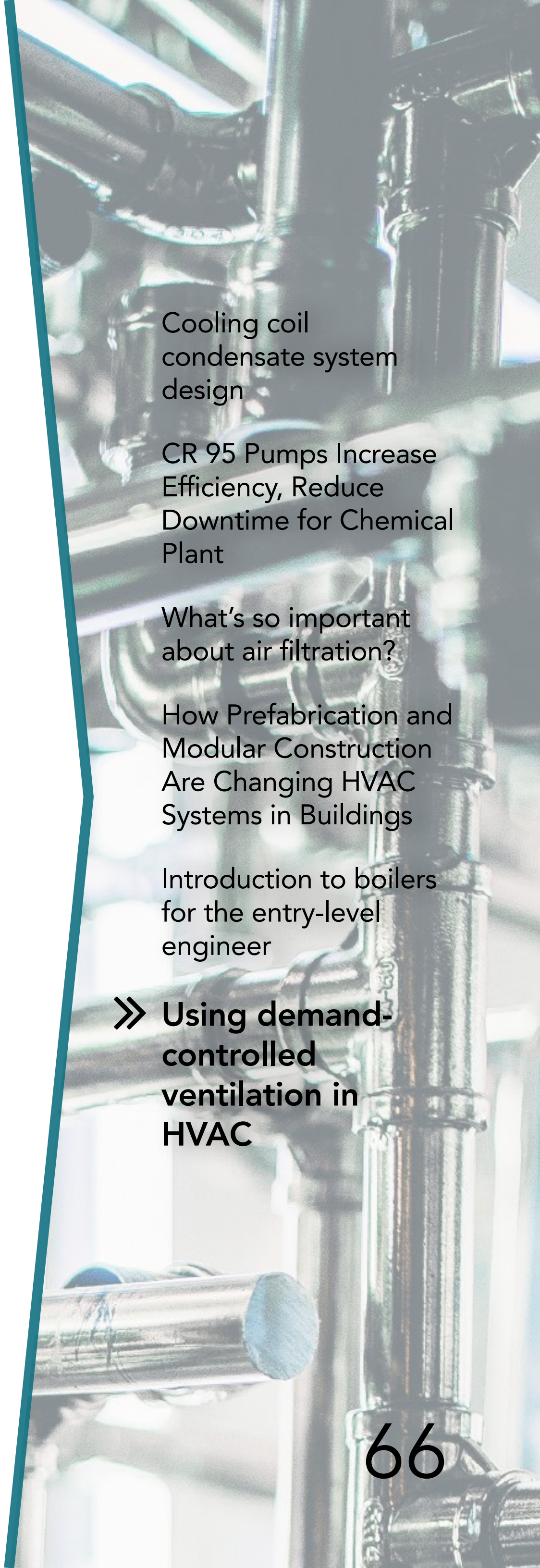
## Occupant interface experience

Attention needs to be paid to the occupant interface experience. How can an occupant adjust not only the temperature setpoints, but other factors in the environment such as lighting? This is done through unified room controls.

Unified room controls can:

- Sense thermal comfort at the person, not the corner of the room.
- Get rid of the wall warts.
- Control lighting with the HVAC.
- Allow an occupant a single point of control.

When it comes to indoor comfort, sensing temperature and the control of HVAC in general, the traditional methods have limitations that can be overcome. Sensing temperature at the wall with a traditional thermostat or electronic sensor is no longer required. Proper occupant comfort is sensed at the occupant, not at the wall. Many modern ceiling devices, even lighting fixtures, are available that can measure the temperature in the middle of the room, where the occupants spend most of their time.



This is just one convergence of lighting technology with HVAC control technology.

Smartphone apps are the second convergence of lighting technology and HVAC control technology; they are unified room controls.

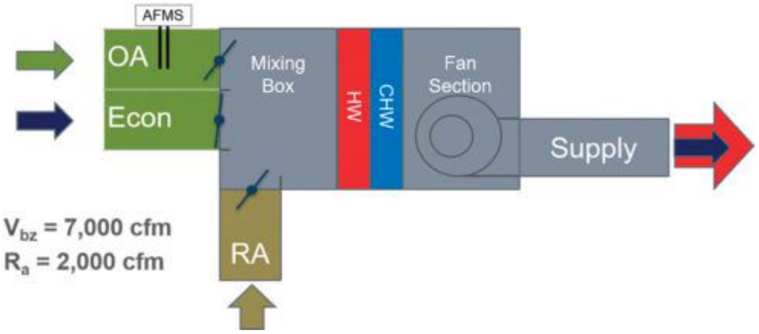


***Figure 3:*** *A schematic of a single zone air handler indicates where outside air can be measured and controlled directly. Carbon dioxide can be measured for this sequence from the return air duct or plenum. Courtesy: Envise*

## Key takeaways

DCV is a key component in achieving both ASHRAE 62.1 requirements and saving energy. In many cases, it can improve energy efficiency or gain points in a rating system like LEED.

Additionally, new technologies are replacing the traditional concept of room controls with light switches and thermostats on the wall. Designers and consultants can embrace unified room controls, which give the occupant an enhanced interface experience.

**Michael Phillips, Envise, Sterling, Virginia**

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