# HVAC

## WINTER EDITION

CONSULTING - SPECIFYING engineer eBOOK

Air Solution COMPANY Cottonwood Filter Screens

GRUNDFOS

# Contents

**3** — Using louvers to prevent snow intake

**14** — Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

**15** — Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

**21** — Know when, how to specify a rooftop unit

**34** — Case study: Airport expansion includes rooftop units

**37** — Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

**38** — Pumping Control Methods and Their Impact on System Efficiency

**54** — Integrating a BAS into design

**68** — Sustaining indoor air quality

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# Using louvers to prevent snow intake

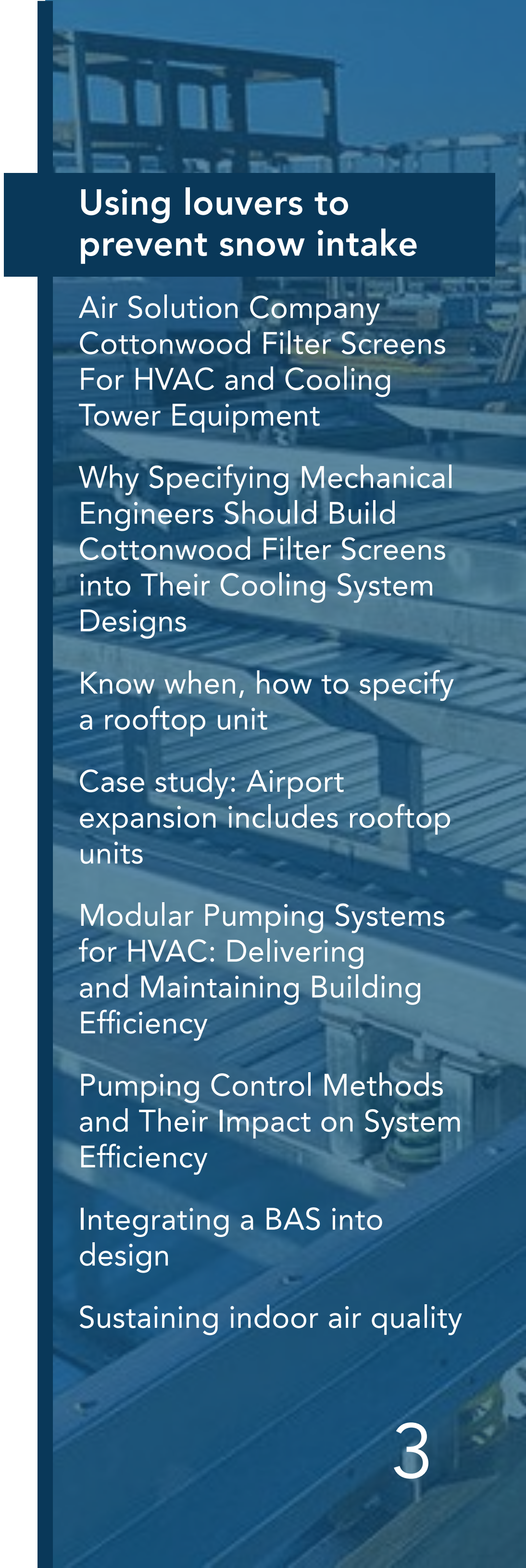
*Learn ways to minimize the amount of snow brought into the building via outdoor air louvers*

Northern climates, with the extreme temperature and precipitation conditions experienced, present many unique design challenges for the mechanical engineer involved in the design of heating, ventilation and air conditioning (HVAC) systems. One of these is ensuring perimeter surfaces are provided with heat to increase mean radiant temperature and improve comfort to satisfy ASHRAE 55: Thermal Environmental Conditions for Human Occupancy requirements.

Other HVAC design challenges include assuring good mixing of outdoor air with return air to prevent the tripping of freeze stats or the freezing of coils, and making sure that ceiling spaces above entrance vestibules do not drop below freezing to prevent fire suppression piping from bursting. There are many other cold weather challenges, some of which may have not yet been discovered.

Snow penetration of louvers and snow intake into air handling systems is a challenge that can cause many problems, including damage to filters; promotion of microbial growth as a result of repeated wetting of plenum, duct and air handling unit surfaces; leaks caused by melting snow in ducts and air handlers; and corrosion of AHUs and ductwork.

Air handling louvers are designed to protect air-intake openings from the infiltration of unwanted water while allowing air to pass into the system, with different louver models offering different levels of performance.  ANSI/AMCA Standard 500-L: Laboratory Methods of Testing Louvers for Rating defines test procedures for certifying louvers.



**Using louvers to prevent snow intake**

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

Most recently published in 2015, ANSI/AMCA Standard 500-L is the standard to which louvers are tested and its test protocols are what the AMCA certified rating program uses to certify a louver's performance.

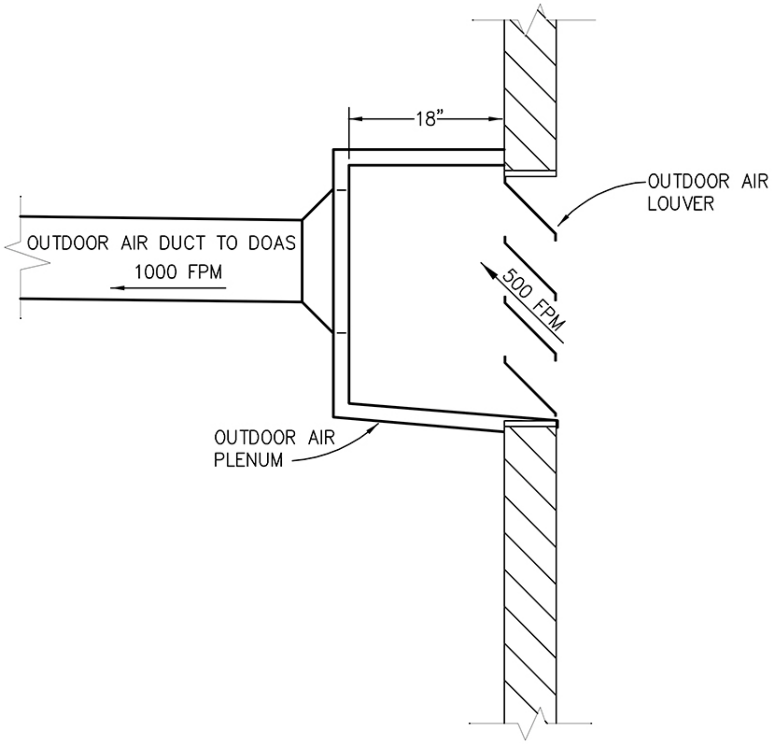


*Figure 1: Louver size is typically based on 500 fpm velocity through the free area to prevent rain penetration, however snow captured in the intake air will enter the outdoor air ductwork in approximately 0.18 seconds. Courtesy: Peter Basso Associates*

ANSI/AMCA Standard 500-L covers five testing protocols: pressure drop, airflow leakage, water penetration, wind-driven rain penetration and wind-driven sand penetration. These tests are conducted at an AMCA-accredited laboratory. Once a louver has been tested and the accuracy of its ratings proven, the manufacturer can display the test results, along with an image of the AMCA seal that corresponds to the testing in its literature.

Selection of louvers in the Midwest, for example, is usually based on preventing water penetration through the louver due to rain falling on its face. Louvers are typically selected at a maximum of 500 feet per minute airflow velocity through the louver free area. Looking at a typical water penetration rated stationary louver with drainable blades, it

**Using louvers to prevent snow intake**

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

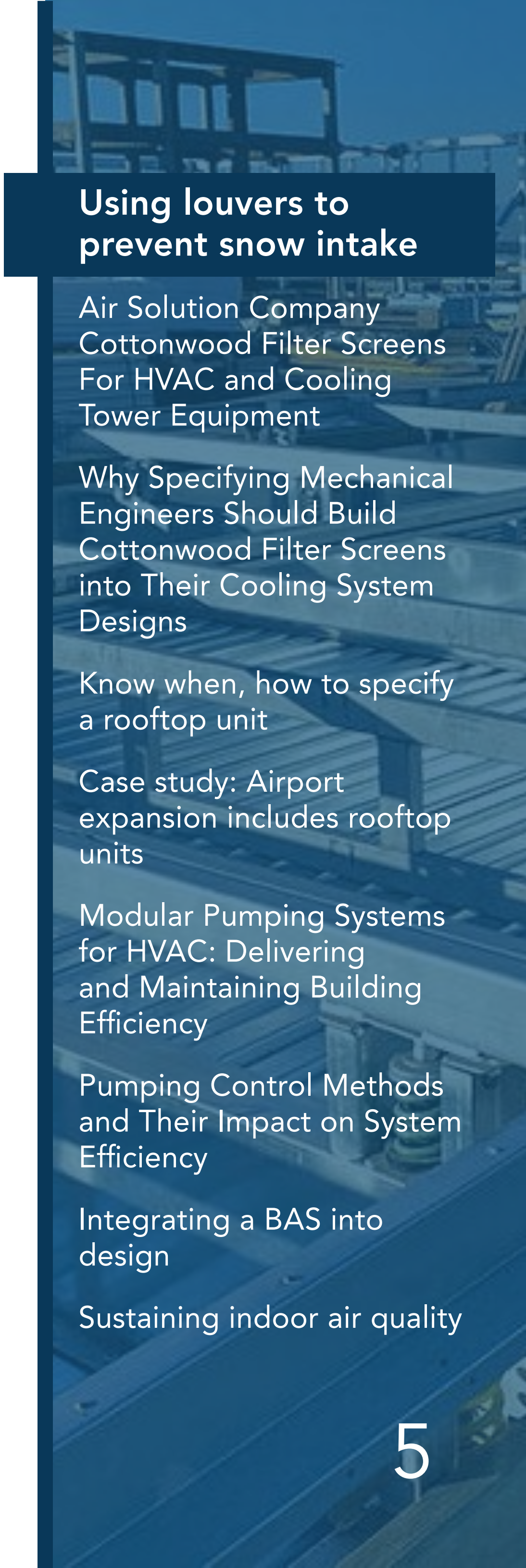
is found that the required air velocity for the beginning point of water penetration can typically be above 900 fpm through the free area, so a commonly used selection point of 500 fpm is relatively conservative with respect to water penetration.

The outdoor air plenum should be provided with a bottom sloping to the outdoors or provided with a drain to relieve any splashing water that makes its way through the louver. As an extra measure of precaution and good practice, the first 10 feet of outdoor air duct beyond the plenum should be sloped back toward the plenum and sealed watertight. With these considerations implemented in the design, rarely are there rain intrusion or water leakage problems in outdoor air intake systems.

Other parts of the country, especially throughout the South where hurricanes are common, may require hurricane louvers or wind-driven rain louvers. Hurricane louvers are designed to be used in locations subjected to extreme weather conditions from hurricanes or tropical storms where the louvers may be subjected to high-velocity debris. Wind-driven rain louvers are typically rated with a 29 mph wind directly at the louver face and with a simulated 3 inch per hour rainfall and are also rated at a 50 mph wind with a simulated 8-inch per hour rainfall, much higher than an AMCA water penetration louver.

## Preventing snow intake

Prevention of snow entry into an air handling system requires a different approach in louver selection and more importantly in plenum design. Snowflakes vary infinitely in density, shape and size — all of which influences snowflake fall velocity and wind/air entrainment. Numerous studies have been conducted using everything from optical instruments to radar modeling to determine the fall speed of hydrometeors and



**Using louvers to prevent snow intake**

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

snowflakes. Yet this information is not widely applied by many engineers to one of the most troubling aspects of air intake in a northern climate — snow entrainment.

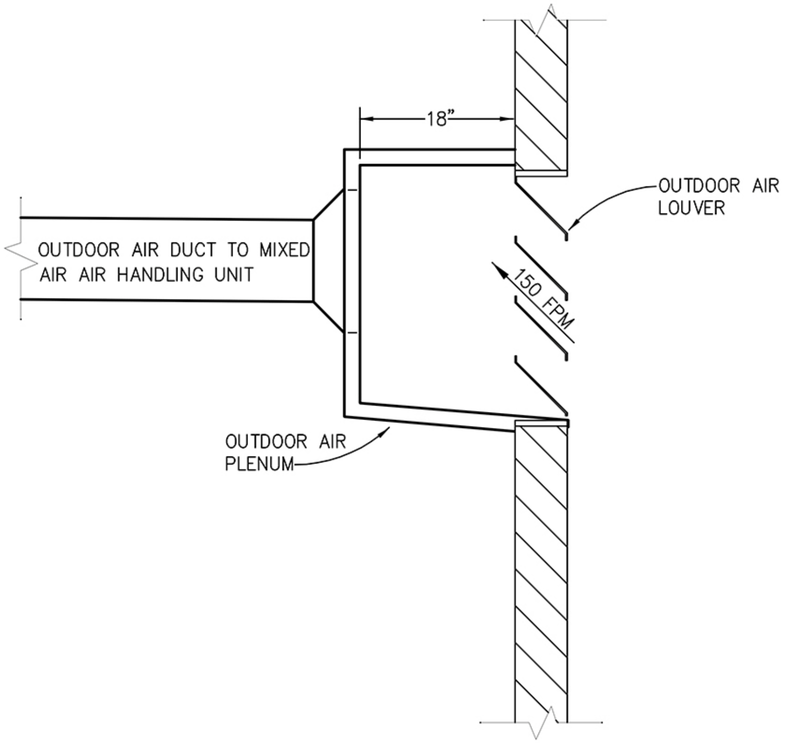


*Figure 2: Even with reduced intake velocity in winter economizer mode, snow captured in the intake air will enter the outdoor air ductwork in approximately 0.60 seconds. Courtesy: Peter Basso Associates*

Should you visit mechanical equipment rooms in the spring, at the end of the snowy season before filter changes have occurred, you will most likely find filters with obvious signs of water damage and signs of previous water ponding in intake plenums, intake ductwork and inside of AHUs. All of this causes damage to equipment and provides opportunities for microbial growth which could affect indoor air quality.

ASHRAE Fundamentals Handbook includes louver selection criteria based on cubic feet per minute and a face velocity of roughly 400 to 500 fpm through the louver free area is recommended. ASHRAE Systems and Equipment Handbook indicates “plenums in cold regions may require a snow baffle to direct fine snow to a low velocity area below the dampers.” ASHRAE Standard 62: Ventilation for Acceptable Indoor Air Quality states:

**Using louvers to prevent snow intake**

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

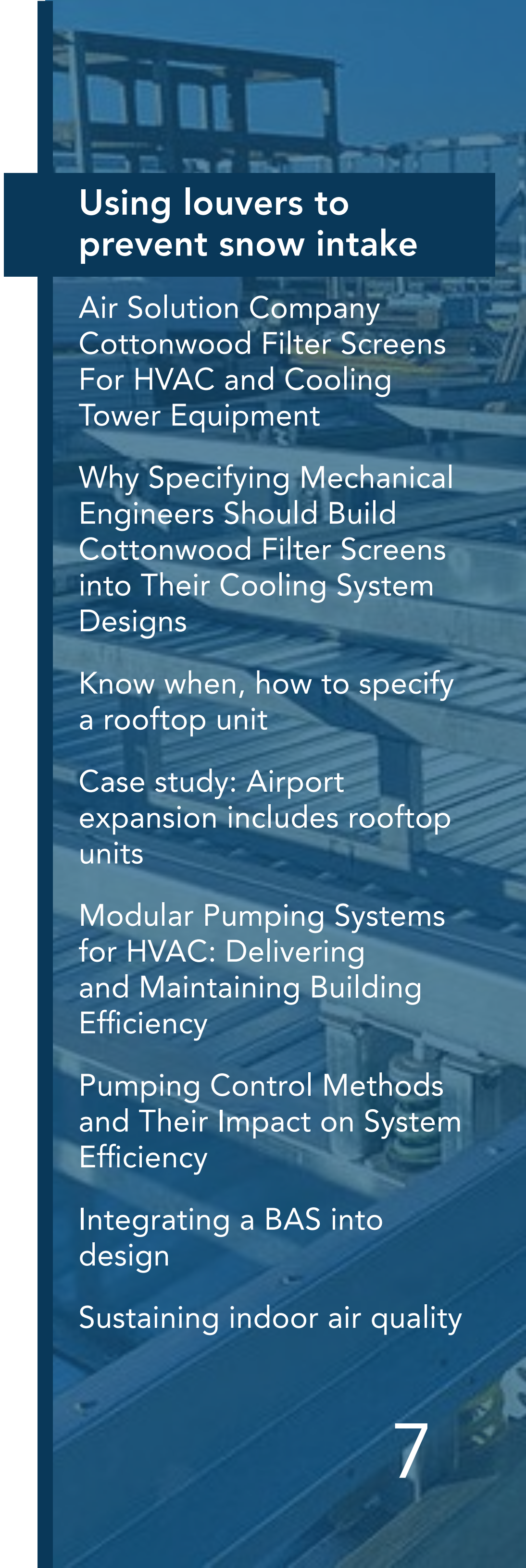
“Where climate dictates, outdoor air intakes that are part of the mechanical ventilation system shall be designed to manage water from snow, which is blown or drawn into the system.”

It is not possible to prevent every snowflake from passing through the louvers. Even with the air handling equipment off, the wind can blow accumulating snow through the louver and deposit it in the plenum. The goal of outdoor air intake design in northern climates should be to:

- Limit the amount of snow brought in through the louvers
- Not allow the snow to penetrate beyond the intake plenum
- Allow for proper draining of water within the plenum once the snow melts
- Allow access to the plenum for regular cleaning.

For most mixed air system AHUs operating in a northern climate, the intake louver selection is based upon 100% outdoor air economizer operation for when the outdoor air temperature is approximately 55°F to 60°F and cooling of spaces is required. The louver would be selected based on a 500 fpm velocity through the louver free area. Note that when it is 55°F to 60°F outside, snow intake is not an issue and the system typically would not be operating at full fan capacity with a variable air volume system. So, the louver selection at 500 fpm through the free area would be considered conservative.

With more emphasis placed on building operating costs, modern HVAC systems are



**Using louvers to prevent snow intake**

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

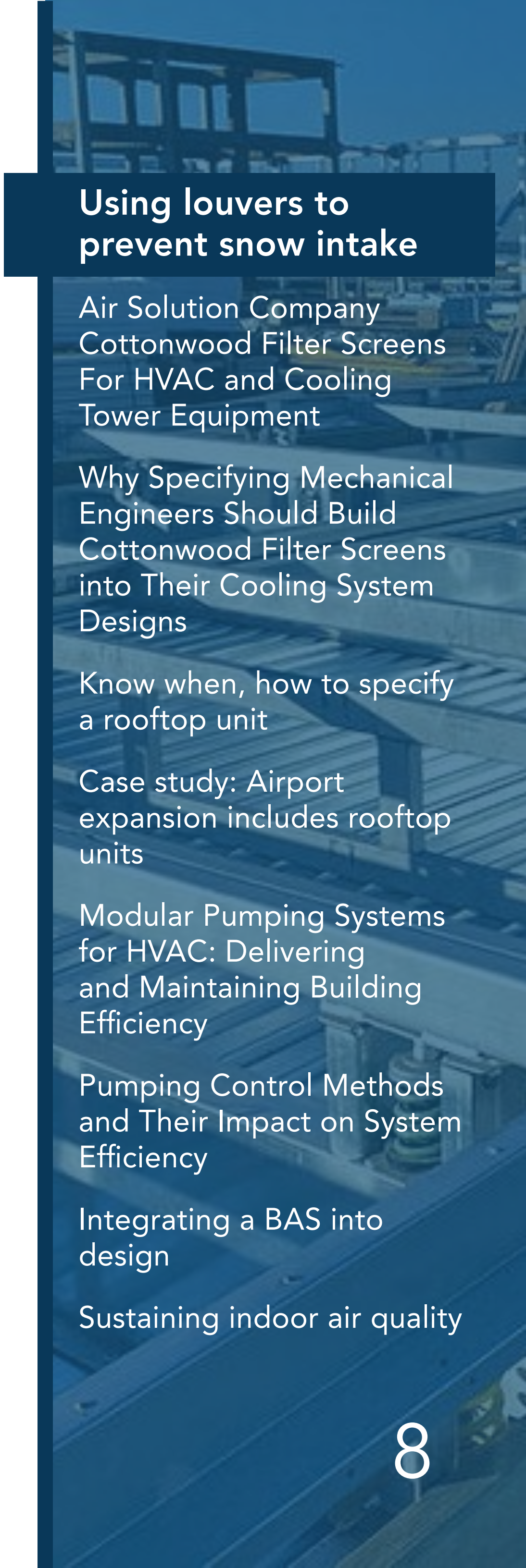
being optimized by looking at the heating and cooling function and at the ventilation function of HVAC systems separately. This allows each to be handled in the most efficient manner possible. Terminal equipment such as active chilled beams or induction units provide the heating and cooling, while dedicated outdoor air systems with energy recovery devices provide the ventilation.

Other systems are designed to provide the outdoor air directly to the spaces by way of a DOAS and use other forms of heating-only equipment or passive chilled beams. Any such use of a DOAS will typically significantly reduce the cost to heat and cool the incoming ventilation air and the use of these system types is increasing. These dedicated outdoor air systems supply 100% outdoor air.

Louver selection at 500 fpm will prevent water penetration during a typical rainstorm, but the potential for snow intake will be increased significantly as the supply air volume in a DOAS may not be reduced as it may be in a mixed air economizer system in economizer mode.

## Louver sizing to prevent snow entrainment

Snowfall typically occurs at 32°F and below — much above that and it would be rain or a heavier rain/snow mixture. Considering a mixed air system of 72°F return air and 32°F outdoor air, the designer can calculate that roughly 30% outdoor air is needed to make a 60°F mixed air condition. Using a louver sized for 500 fpm velocity with 100% outdoor air flow in the economizer mode, the system would have roughly 150 fpm velocity through the louver free area at 30% outdoor air flow through the louver. At this velocity, there is no concern for rain intake, but snow will still enter the plenum and, therefore, the plenum design must consider that.



**Using louvers to prevent snow intake**

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

Snowflake size, shape and density vary considerably based on temperature and myriad other factors that occur during the formation and life of a snowflake. This size, shape and density will affect a snowflake's terminal or fall velocity. Various studies have shown vertical fall velocities of between 1 and 8 feet per second. For this example, we will assume that it is 20°F and the snowflake's vertical fall velocity is 1 meter per second or roughly 200 fpm.

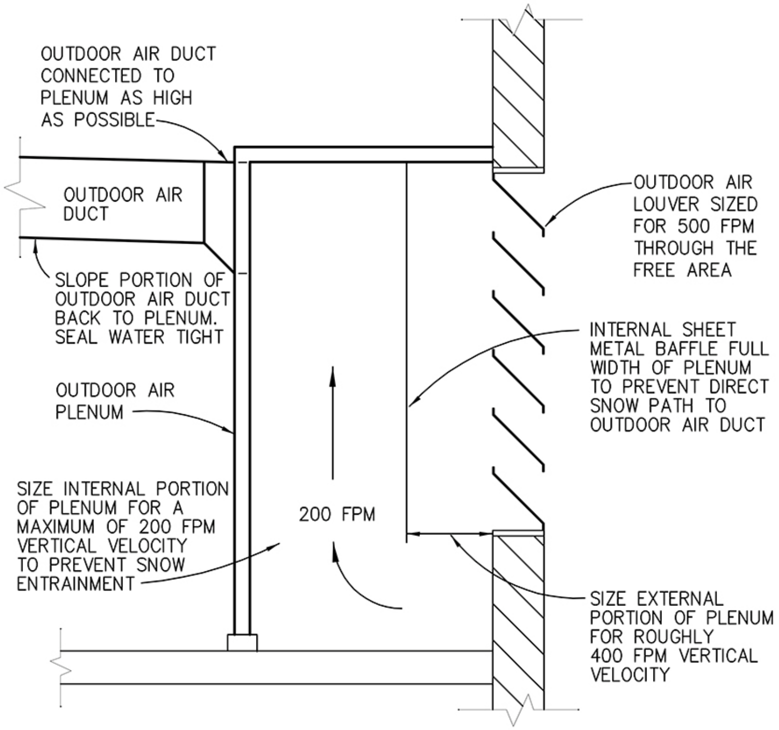


*Figure 3: This shows a typical condition where snow is entrained in the incoming air and travels into the outdoor air ductwork. Courtesy: Peter Basso Associates*

Assume the system has a DOAS and the louver has been sized for 500 fpm through the free area to prevent rain penetration (see Figure 1). Snow captured by the suction pressure at the louver face and entrained in the airstream would travel from the louver, where it is sent on an upward trajectory at 500 fpm to the outdoor air ductwork in 0.18 seconds.

Looking at a mixed air system, the louver would be sized at 500 fpm through the free area at full supply air volume to prevent rain entrainment while in the economizer mode. In the winter, the system may be operating at a minimum outdoor air position

**Using louvers to prevent snow intake**

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

of approximately 30%, with a resulting velocity of 150 fpm through the free area (see Figure 2). Snow captured by the suction pressure at the louver face and entrained in the airstream would travel from the louver, where it is sent on an upward trajectory at 150 fpm to the outdoor air ductwork in 0.60 seconds.

From these illustrations, it is easy to see how snow accumulations inside the plenum, outdoor air ductwork and most likely the AHU and filter bank are likely to occur. Figure 3 shows snow accumulation in the outdoor air ductwork with the louver and plenum visible in the background. Figure 4 shows snow making it all the way into the AHU. This accumulation of snow when melted will wet the filters, cause corrosion of the ductwork and AHU, allow bacterial growth within the air handling system and possibly leak onto the floor and into building areas below.

How do we resolve this problem of snow entrainment? There is one potential solution to this problem: heated snow melting louvers. These louvers melt snow as it passes by the louver and prevent accumulation inside the system. They are available both with electric and with hot water heating coils or screens and include the required sensors, controls, drains, etc. as required for proper operation. Note that they consume energy, add complexity, required maintenance and allow for potential future failures requiring repair or replacement. These devices, however, have proven successful where certain constraints would not allow for other options.

One such example of an application was in Sault Ste Marie, Mich., where a historic building was being renovated. Winter in the Sault Ste Marie sees a significant snow fall that typically begins in November and doesn't stop until mid-April. Due to the historic nature of this building, adding visible louvers to the exterior was not an option. The

**Using louvers to prevent snow intake**
Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment
Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs
Know when, how to specify a rooftop unit
Case study: Airport expansion includes rooftop units
Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency
Pumping Control Methods and Their Impact on System Efficiency
Integrating a BAS into design
Sustaining indoor air quality

AHU — a 100% DOAS — was located in the basement. An areaway was provided and an outdoor air intake louver was installed in the basement wall.

Based on the louver location in an areaway and an extremely tight mechanical room, the only possible solution was to provide a heated louver assembly to melt the incoming snow. In addition, the snow melt system that served the building's exterior walkways and stairs was extended to the base of the areaway to melt the snow, which continuously blows into it and would quickly fill it.

*Figure 4: Snow entrained in the outdoor air flow can travel all the way into the air handling unit where it can plug filters and melt and cause damage to the AHU. Courtesy: Peter Basso Associates*

Although in the above application the heated louver assembly worked well, there could be a simpler, less expensive, lower energy consuming and relatively maintenance-free method of handling snow intake, especially in new construction where proper planning will allow for inclusion of details to handle this problem. One such successful example was in Marquette, Mich. (see Figure 5). The average snowfall velocity is roughly 200 fpm or greater. In this case, the designer provided a chamber in the outdoor air plenum where the vertical air velocity was less than 200 fpm. As a result, the snow was unable to travel up and into the outdoor air ductwork.

**Using louvers to prevent snow intake**

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

When possible, it is important to leave the bottom of the plenum uninsulated and exposed to the heated mechanical room so the snow accumulation will melt. In one recently designed project, the plenum was installed on a slab on grade. The site walkway snow melt system was extended to this concrete plenum floor to allow for melting of the snow accumulation within the plenum.

In all cases, the plenum must be accessible for cleaning or, if required, for snow removal.

Problems with snow entrainment can be extremely difficult to resolve after construction is complete and the building is occupied. A survey of air handling system filters in the springtime in northern climates will often show water damage to the filters as a result of previous snow event accumulations. If the snow accumulation is large enough, it can result in filters being pulled through the filter racks, allowing unfiltered air to penetrate to the coils and be recirculated to the spaces. Slowly over time, corrosion of ductwork and air handling equipment will occur.

*Figure 5: Designing the outdoor air plenum with a vertical chamber with an upward airflow velocity of less than 200 fpm will prevent snow from rising up and into the outdoor air ductwork. Courtesy: Peter Basso Associates*

In the worst case scenario, melting of the snow will result in dripping and damage to

**Using louvers to prevent snow intake**

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

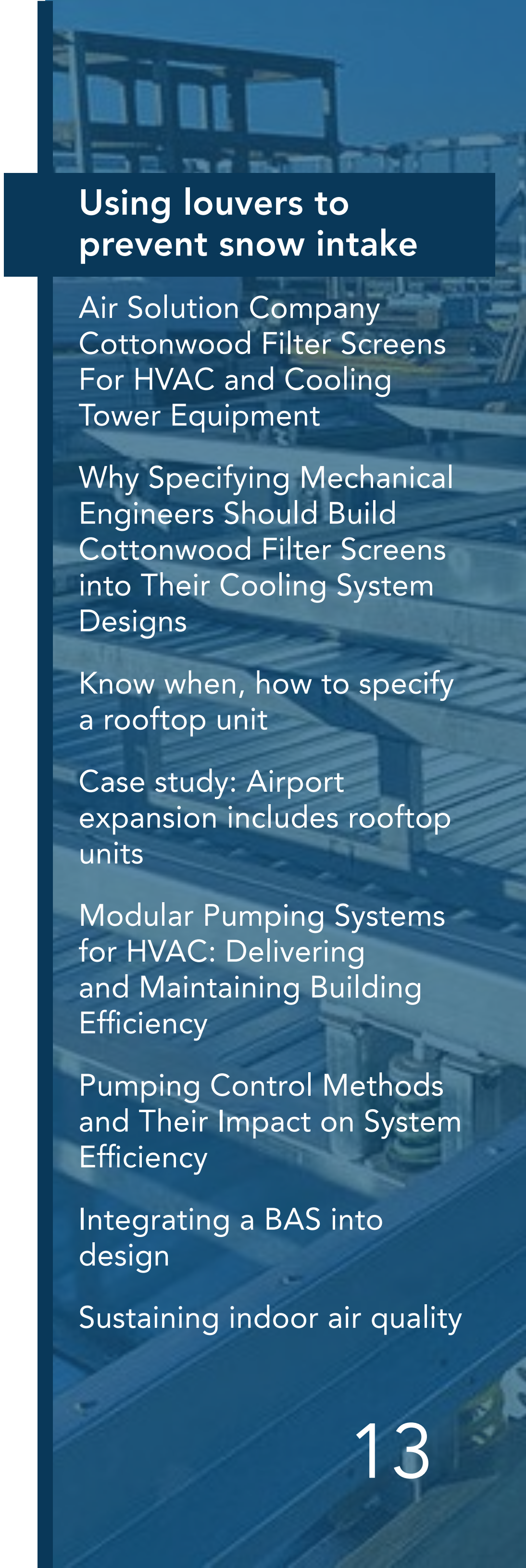
Sustaining indoor air quality

building contents and finishes, leading to dissatisfied occupants. Correction of these problems can often require significant rework or replacement of the intake plenums or portions of the air handling systems.

Thoughtful analysis of air intake system design will reduce the likelihood of this occurring, preserve filters, extend the life of ductwork and equipment, improve the quality of the air being supplied to the occupied spaces and will allow the owner and engineer to go outdoors to enjoy the snow, rather than spending time indoors figuring out how to resolve a snow intake problem.

**Brian M. Runde**

***Brian Runde*** *is a vice president with Peter Basso Associates Inc. He has more than 40 years of practical, design and engineering management experience on complex building systems projects.*



**Using louvers to prevent snow intake**

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

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## Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

*Air Intake Filter Screens For HVAC Equipment (commonly called Cottonwood Filter Screens). Stops airborne debris from entering air intake openings on rooftop units, condensers, chillers, dry coolers, air handling units, intake louvers and cooling towers.*

Using louvers to prevent snow intake

**Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment**

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

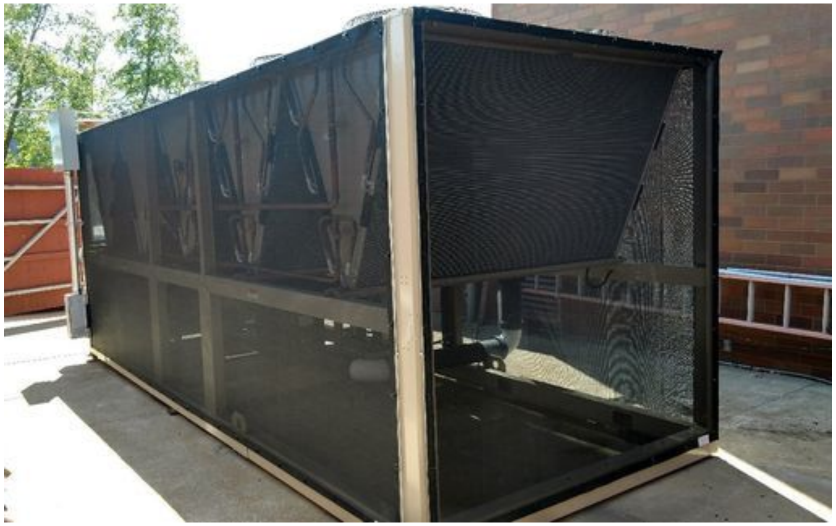
Sustaining indoor air quality

# Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

**RANDY SIMMONS**
President and Co-owner
Air Solution Company

When mechanical design engineers are tasked with designing cooling systems, it typically starts with understanding the cooling needs then determining what budget is available for development - That's when the work begins. Engineers set out to develop the most efficient system within the constraints of the allocated money and when approved and built, the project typically comes to an end when the system is eventually taken over by the building owner. But it doesn't always end there.

Out of the blue comes a phone call from the customer whose system was turned over 2 yrs., ago, complaining



about the system not performing properly - Commonly it's too hot or too humid inside the building or, process equipment is overheating - Suddenly, the engineering firm and associated OEM are in motion putting current projects aside and frequently allocating un-billable engineering resources to investigate the problem only to find that the system has not been properly maintained - this is called "Project Bounce-Back". All too often, coils haven't been cleaned or have been improperly cleaned or, belts haven't been changed, cooling tower strainers are plugged, or solenoid blow-down valves are getting wedged open due to debris build-up in the sump and not clearing the valve resulting in make-up water running sometimes for days as it tries to replenish water supply - and the list goes on and on - Bottom line is - lack of proper maintenance is typically the culprit. Why? you might ask, would maintenance not be performed on brand new equipment - well the list of potential reasons is as long as your arm but to the engineering company and OEM tasked with identifying the problem -

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

**Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs**

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

they are the losing parties because they not only take a hit to their bottom line when they are called into action but can't bill for their time - but they run the risk of delaying current projects on the drawing board.

How can engineering firms help prevent this from happening - It's simple, integrate Cottonwood Filter Screens into the overall design so airborne debris is stopped at its point of entry where it can be seen and easily cleaned using a broom, brush, shop vacuum, sidewalk blower or garden hose - even rain can help rinse them clean - In other words, you simplify the maintenance to a point where there is no excuse for not keeping the unit clean - no water or chemicals are needed nor is it necessary to remove the cottonwood filter screens for cleaning. In other words, they help protect the integrity of the mechanical designs.

With an ever-increasing emphasis on high efficiency equipment and in particular micro-channel condenser coils, more engineering firms are recommending them, and more customers are willing to pay the higher up-front investment cost on the premise that they will save significantly more money on energy over the life of the unit. Well

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

**Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs**

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

that all sounds good and makes logical sense - if in a laboratory environment; In real life practice however, it is rare that customers capture the energy savings promised by the high efficiency micro-channel coils - Why? The answer is simple - In North America, good PM practice is considered to be quarterly rather than "as needed" hence, when you consider that compared to standard efficiency condenser coils that may have 10 fins per inch while the micro-channel coils may have 20 fins per inch in the same footprint - the high efficiency micro-channel coil is a better filter than the standard efficiency coils because it captures more debris - which means it fouls out sooner between scheduled maintenance. The irony of this is that because it fouls out sooner, it runs longer in a fouled condition between quarterly cleaning - hence the very machine that can deliver an energy cost savings can actually become an "Energy Hog". How do you solve the problem? there are only three ways:

1. Don't specify micro-channel coils unless they are in a clean operating environment, or the client is willing to have them cleaned "as needed"

2. Clean them more frequently - most won't do that because of the fragile nature of the coils and the damaging effect of traditional cleaning methods and the increased labor cost.

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

**Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs**

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

3. Protect them with Cottonwood Filter Screens which relocates the debris load away from the coils stopping it where it is easy to clean without removal and without physical contact with the condenser coil.

In short, building in basic maintenance solutions in the mechanical design and specifying process will enable your designed system to run cleaner longer, while increasing customer satisfaction and reducing / eliminating "Project Bounce Back".

To learn more about how Cottonwood Filter Screens can help improve operational efficiency of cooling systems (rooftop units, dry coolers, chillers, cooling towers etc.) while reducing maintenance and energy cost, visit Air Solution Company at **www.airsolutioncompany.com** or, call 1-800-819-2869.

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

**Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs**

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

# Snow Stopper™ Screens

## Reduce the snow intrusion that can build up inside rooftop air intake units and louvered air handling units, damaging expensive internal filters.

### THE PROBLEM

### THE SOLUTION

**Winter season snow build-up inside air intake chambers and plenums can damage expensive internal air filters and lead to snow melt damage to ceilings and walls! The end-result is a drain on maintenance time and budgets due to ceiling and wall repairs, unplanned filter replacements, and problems related to unfiltered air entering the building.**

- Constructed of heavy-duty weather-resistant materials and feature quick-release mounting fasteners.
- Black screens absorb UV rays from the sun, are flexible and non-conductive to cold temperatures; help prevent flash-freezing and unabated snow entry into system.
- Also highly-effective at filtering airborne debris during the spring, summer and fall; provide measurable savings in energy and maintenance costs.

***Snow Stopper™ Screens Mount inside or outside louvers and on rooftop air handling units for a snow barrier at point of entry.***

**› CLICK HERE ‹ TO LEARN MORE, OR CALL AIR SOLUTION COMPANY AT 800-819-2869**

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# Know when, how to specify a rooftop unit

*There are some key components to recognize when designing air-cooled rooftop units*

Rooftop units have long been used to satisfy building heating, ventilation and air conditioning requirements. Some of the benefits of rooftop units include lower first cost, ease of installation and reduction of area inside the building for mechanical equipment.

The maintenance of rooftop units also can be a benefit if proper roof access is available. All of the components are in one location to be worked on and maintenance personnel do not have to go throughout a building to find various units such as with a water-source heat pump system.

## Rooftop unit efficiencies

Rooftop units are rated for different efficiencies based on the tonnage. Units rated for less than 65,000 Btu/hour are rated to a seasonal energy efficiency ratio, which "measures the total cooling of a central air conditioner or heat pump (in Btu) during the normal cooling season as compared to the total electric energy input (in watt-hours) consumed during the same period."

Units rated for 65,000 Btu/hour and higher are rated to energy efficiency ratio, which "measures of how efficiently a cooling system will operate when the outdoor temperature is at a specific level." The energy efficiency ratio value is the efficiency at the peak cooling condition.

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

**Know when, how to specify a rooftop unit**

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

The integrated energy efficiency ratio is used on the larger tonnage units as a measure of efficiency at part load conditions. Table C403.3.2 in the International Energy Conservation Code outlines the minimum efficiencies required for different types of rooftop units, such as cooling only units or heat pumps and minimum efficiencies required based on the tonnage of the units.


Figure 1: A total enthalpy wheel installed rooftop unit can provide additional energy savings. Courtesy: SmithGroup

## Derating equipment

There are some general design parameters that apply to both package rooftop units and applied rooftop units. The ambient temperature will affect the performance of air-cooled equipment. All unitary air conditioners and heat pumps are tested and rated to AHRI Standards. AHRI Standard 210/240 is applicable for equipment less than 65,000 Btu/hour and AHRI Standard 340/360 is applicable for equipment from 65,000 Btu/hour to less than 250,000 Btu/hour.

The latest version of these standards is 2019 and 2017, respectively, which rate air-cooled equipment at 95°F dry bulb and 75°F wet bulb in the cooling condition, and 47°F dry bulb or 17°F dry bulb in the heating condition. These have long been the ambient temperatures air cooled equipment has been rated at.

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

**Know when, how to specify a rooftop unit**

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

These conditions apply to vast parts of the United States, but if a project is located in the Pacific Northwest, Southwest desert or upper Midwest, for example, the design ambient temperatures will be different from the standard testing temperatures.

Rooftop units that are installed in high-temperature locations, such as Phoenix, need to be derated due to ambient dry bulb temperatures that can reach 115°F. The daytime high temperatures can be 115°F with temperatures on a roof being near or exceeding 125°F. The rooftop unit is not able to reject as much heat to the atmosphere when the dry bulb is higher outside, so the total capacity and sensible capacity will be less than what is listed in a manufacturer’s catalog.

Many locations in the United States have a design heating temperature lower than 17°F. The building can still have a call for cooling, depending on the building use type. This can cause an issue with head pressure in the condenser and cause the refrigeration system to short cycle or have other problems. Manufacturers offer low ambient controls or kits that will enable the refrigeration system to operate properly at low ambient conditions. These are accessories and need to be specified by the design engineer. Engineers should be cognizant of the design ambient conditions and how they can affect the capacities of package rooftop units.

The entering air temperature is also a key component when designing air-cooled rooftop units. AHRI Standard 340/360 also defines the entering air temperature as 80°F dry bulb and 67°F wet bulb. This condition can be different depending on what climate a building is located in.

For example, in hot, dry climates a typical entering air temperature could be 78°F dry

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

**Know when, how to specify a rooftop unit**

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

bulb and 63°F wet bulb. This will reduce the capacities of the rooftop unit from the listed catalog data. Air-cooled rooftop units are commonly used for office buildings and light commercial spaces. These spaces typically are 15% to 20% outside air and the entering dry bulb temperature is below 90°F.

It is important to keep the entering dry bulb temperature below 90°F to this type of equipment so the refrigerant system can operate properly. Most manufacturers rate this type of equipment to 90°F in their catalogs. This is due to not have the refrigeration circuit fail on high head pressure and to limit the compressor from cycling too often.

There is a limit to the temperature difference across the cooling coil that air-cooled equipment can produce because of the refrigeration cycle. These types of units can typically produce a 20°F to 25°F delta T in the cooling condition. An engineer should always calculate the entering air temperature to the equipment and ensure that the equipment will properly condition the space in both the cooling mode and the dehumidification mode. A rooftop unit will not dehumidify to below the standard room condition of 75°F and 50% relative humidity if the entering air temperature is too high. This will cause humidity to build up in the space and become uncomfortable to the occupants.

An engineer should look at different duct layouts associated with the rooftop units and shift rooms to adjoining rooftop units to lower the entering air temperature or using specialty package rooftop units if an entering air temperature approaches 90°F dry bulb.

Using louvers to prevent snow intake
Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment
Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs
**Know when, how to specify a rooftop unit**
Case study: Airport expansion includes rooftop units
Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency
Pumping Control Methods and Their Impact on System Efficiency
Integrating a BAS into design
Sustaining indoor air quality

Figure 2: An applied rooftop unit has multiple coils and airside economizer. Courtesy: SmithGroup/Liam Fredrick

## Equipment improvements

A common problem with air-cooled rooftop equipment is oversizing. Most engineers are conservative in nature and want to ensure that there is enough cooling and heating capacity. Engineers dread the phone call saying the space is too hot or too cold or that the controls aren’t working properly or that there are operations and maintenance issues. This can lead to several issues with package rooftop equipment.

Calculated peak load will occur for a few hours during the year, depending on which design criteria the engineer selects for a building. Typically, the 0.4% or 1% weather values are used from the ASHRAE weather data tables. That means the air conditioning equipment will need to operate at a reduced load 99% of the year.

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

**Know when, how to specify a rooftop unit**

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

Manufacturers, in response to stricter code requirements, have been able to improve the part-load operation of this equipment in recent years. Some of these improvements include variable speed compressors, electronically commutated motors and microchannel heat exchangers.

Equipment improvements allow air-cooled equipment to operate at part load much better than they have in the past and reduce energy consumption. These items replace single stage compressors and belt-driven fans that have long been used in package rooftop equipment, which had very limited turndown capabilities. These improvements help avoid the empty movie theater syndrome where the rooftop unit is at its minimum operating point, but there is no load in the space and people have jackets on in the middle of the summer.

## Smoke control equipment

A potential issue when multiple package rooftop units are used with a common return plenum is whether smoke detectors are required. Section 606.2 of the International Mechanical Code requires smoke detectors on all units with a return airflow of 2,000 cubic feet per minute or greater. This would require smoke detectors on package rooftop equipment that are smaller than 5 tons.

## Acoustical considerations

It is important to properly design the acoustics for any HVAC system. There are two key components when working with HVAC acoustics and those are sound power and sound pressure.  Sound power is the acoustical energy emitted by a source (i.e., a rooftop unit) and is a fixed value. Sound pressure is the level of the noise produced by the source. The sound pressure level can vary depending on how far away from the source

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

**Know when, how to specify a rooftop unit**

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

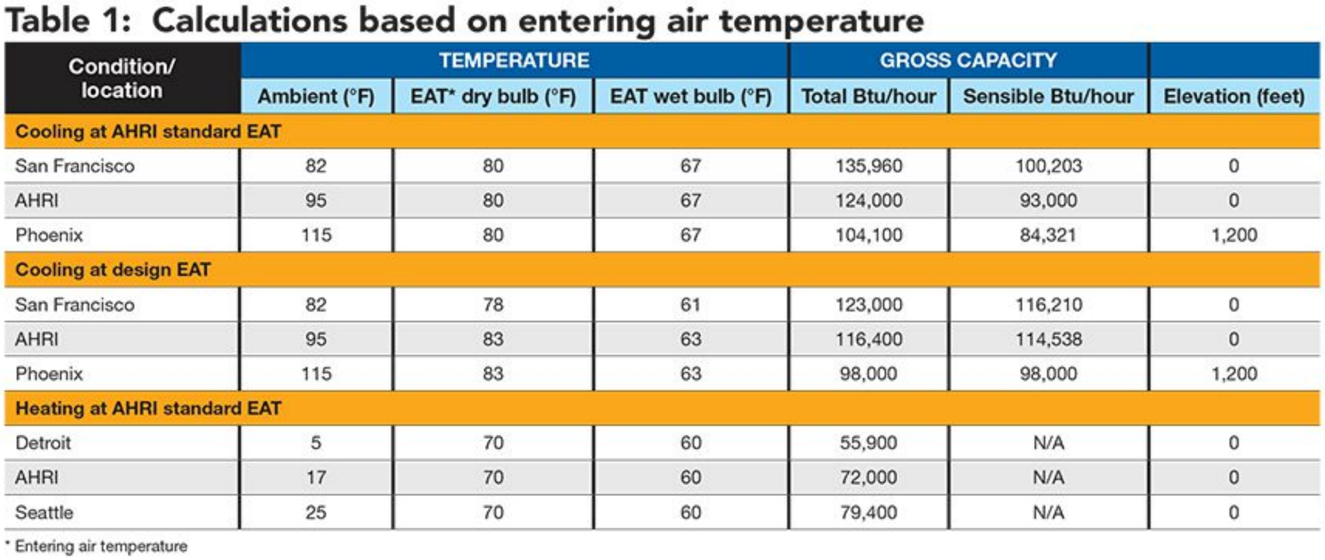

**Table 1: Calculations based on entering air temperature**

| Condition/ location | TEMPERATURE | | | GROSS CAPACITY | | |
|---|---|---|---|---|---|---|
| | Ambient (°F) | EAT* dry bulb (°F) | EAT wet bulb (°F) | Total Btu/hour | Sensible Btu/hour | Elevation (feet) |
| **Cooling at AHRI standard EAT** | | | | | | |
| San Francisco | 82 | 80 | 67 | 135,960 | 100,203 | 0 |
| AHRI | 95 | 80 | 67 | 124,000 | 93,000 | 0 |
| Phoenix | 115 | 80 | 67 | 104,100 | 84,321 | 1,200 |
| **Cooling at design EAT** | | | | | | |
| San Francisco | 82 | 78 | 61 | 123,000 | 116,210 | 0 |
| AHRI | 95 | 83 | 63 | 116,400 | 114,538 | 0 |
| Phoenix | 115 | 83 | 63 | 98,000 | 98,000 | 1,200 |
| **Heating at AHRI standard EAT** | | | | | | |
| Detroit | 5 | 70 | 60 | 55,900 | N/A | 0 |
| AHRI | 17 | 70 | 60 | 72,000 | N/A | 0 |
| Seattle | 25 | 70 | 60 | 79,400 | N/A | 0 |

* Entering air temperature

*Table 1: This data is based on a 10-ton air-cooled heat pump package rooftop unit. Courtesy: SmithGroup*

and what acoustical treatments are between the source and the measurement point.

Where rooftop units are located is important when considering the acoustical impact these types of units can have on an occupied space. Chapter 49 of the 2019 ASHRAE HVAC Applications Handbook states the appropriate noise criterion level that spaces should be designed to be based on the use. It is always best to locate rooftop units over spaces with a higher NC level, such as storage rooms or corridors that have a 40 NC level instead of noise-sensitive spaces such as conference rooms, which have a 30 NC level. Additional design considerations are required when units are located over sound-sensitive spaces or the unit will create more noise than acceptable for the space below.

There are different pathways that have to be considered when dealing with the acous-

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

**Know when, how to specify a rooftop unit**

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

tics of rooftop units:

- Airborne sound is the sound that travels down the ductwork.
- Breakout sound passes through the walls of the ductwork.
- Radiated sound is transmitted through the cabinet of the unit.

Acoustical treatments can be necessary to meet the required NC levels of the various spaces in a building. Typically, acoustical treatments are needed in the lower octave bands of 63, 125 and 250 hertz. These octave bands produce the low rumble sound from a mechanical unit. The other octave bands — 500, 1,000, 2,000, 4,000 and 8,000 hertz — are mid and high frequencies that produce the high-pitched sounds. Depending on the space requirements, the mid and high frequencies may not require as many acoustical treatments as the low frequencies.

Acoustical sounds treatments are usually required when the rooftop units have lower octave band ratings in the 80-decibel range. Larger rooftop units, such as 50-ton and larger units, will often have decibel ratings of 90 decibels or higher in the lower octave bands.

There are several ways accommodate these frequencies when designing HVAC systems. More distance from a unit's supply and return opening before entering the space or a duct takeoff will allow for more sound reduction in the ductwork. Using horizontal supply and return ductwork connections to rooftop units will allow additional straight ductwork and elbows to be installed when compared to using vertical supply and

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

**Know when, how to specify a rooftop unit**

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

return ductwork connections to rooftop units. This also allows for duct liner to be used, which can reduce sound levels in most duct configurations.

*Figure 3: An air-cooled package rooftop unit shows lab exhaust stacks in the background. Courtesy: SmithGroup*

Additional ductwork elbows help reduce the sound levels by reflecting the sound wave. An engineer must balance sound performance with the pressure drop and fan performance with the type of ductwork elbows used. A smooth radius elbow will have different attenuation levels than a mitered elbow with turning vanes.

Another option to reduce sound levels is the use of sound attenuators that replace a section of ductwork. These come in rectangular, circular, T-shape or elbow configurations. There are several options for sound attenuators from the internal baffle type and length. Because the airflow is being restricted through a sound attenuator, there is a static pressure drop that an engineer needs to account for. The pressure drop is based on the velocity so the static pressure drop can vary greatly.

For example, a static pressure loss could be 0.10 inch for a sound attenuator design for a duct velocity of 500 fpm compared to a static pressure drop of 1 inch or more for a duct velocity of 2,000 fpm or greater. Good engineering practice is to design the systems for a static pressure of 0.25 inches or less.  This can be done through a combina-

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

**Know when, how to specify a rooftop unit**

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

tion of increasing duct velocity and selecting the appropriate type of sound attenuator.

It is important to also analyze the return air ductwork path for airborne sound transmission, as sound from the rooftop unit will travel back through the return duct and into the space. All of the airborne treatments mentioned above also need to be considered for the return air path from a rooftop unit. The return path can lead to noise issues in the space if the return ductwork has a direct path to the occupied space.

Supply ductwork breakout noise is often the critical path when dealing with rooftop unit sound levels. Some of these items can help with this such as duct elbows and duct liner. The ceiling type has a significant impact in reducing this sound path.

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

**Know when, how to specify a rooftop unit**

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

*Figure 4: A vibration curb is used to isolate a rooftop unit from transmitting sound and vibrations to the building structure. Courtesy: SmithGroup*

It is important to work with the architect when determining ductwork breakout noise levels. A ceiling with a higher sound performance can reduce or eliminate some of the HVAC sound mitigation requirements. Ceilings are rated for a noise reduction coefficient value. The ceiling materials are rated in the 250, 500, 1,000 and 2,000 hertz octave band in accordance with ASTM C423. The noise reduction coefficient value ranges from 0 to 1 with the higher the number meaning the more acoustic adsorption the ceiling provides.

Conference room ceilings are typically rated for a 0.9 noise reduction coefficient value. Duct lagging is a flexible mass-produced product that can be used to reduce the effects of ductwork breakout noise. While it is a high-end, expensive solution, it may be appropriate in some applications. Lagging is applied around the outside of the ductwork and typically is available in 1 pound per cubic foot densities.

Radiated sound from rooftop units can cause issues for the spaces underneath where the rooftop units are located. This is becoming more critical as open ceiling concepts have become more popular, as well as if the unit is located over sound-sensitive spaces

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

**Know when, how to specify a rooftop unit**

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

such as conference rooms or private offices. The ceiling has a large effect on radiated sound. Without a ceiling, the sound mitigation becomes critical.

A mass form is often needed in and/or around the rooftop unit to mitigate the sound transmission from the rooftop unit through the roof. This is mostly dealing with the lower octave bands noted above. There are options on how this achieved and varies from building to building. A common solution is to provide additional concrete at the rooftop unit. This can cause issues with the roof structure, so this needs to be coordinated with the structural engineer.

An alternate solution to this is to provide a hollow concrete curb and use acoustical material to infill the curb. This can provide similar acoustical performance to a solid concrete mass as described above and significantly reduce the weight the roof structure must be designed for.

Rooftop units have rotating parts like all other mechanical equipment that produce vibrations. These include the supply fans, exhaust fans, condenser fans and compressors. It is critical to deal with these so the vibrations are not transmitted to the building structure. Several manufacturers internally isolate these parts, but additional means might be necessary. Vibration curbs isolate the entire rooftop unit through a series of spring isolators located around the curb. It is important to coordinate this with the rooftop unit manufacturer so spring isolators are not doubled up. This can lead to a resonance issue, which can be worse than not providing any vibration isolation.

## Applied rooftop units

Although the available options between package rooftop units and applied rooftop

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

**Know when, how to specify a rooftop unit**

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

units are getting less and less, there are still differences. Package rooftop units are limited in the components that are available. These include supply fan, exhaust fan, direct expansion cooling coil and a gas-fired or electric heating coil. These components are sufficient for a lot of building types, though not all.

An applied air-cooled rooftop unit maybe required, depending on the design requirements such as a low entering air temperature that would require a preheat coil. Additional components are available in applied air-cooled rooftop units as manufacturers make improvements that are used in a host of air handling units. These include return fans, chilled water-cooling coils, steam heating coils, energy recovery wheels, additional filtration levels and fan arrays. Return fans might be desired instead of the typical relief or exhaust fan that is only offered in package rooftop units.

Energy recovery systems are available in 30-ton units and larger, depending on the manufacturer. Applied rooftop units have a higher first cost, so it is important to know what the requirements are so there are no surprises with the project budget.

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Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

**Know when, how to specify a rooftop unit**

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

# Case study: Airport expansion includes rooftop units

*The HVAC system at Phoenix Sky Harbor International Airport required two new rooftop units*

A concourse expansion project at Phoenix Sky Harbor International Airport used rooftop units. There were several new mechanical units that were part of the scope of work and two of the units were located on the roof. This was partially due to limited floor space available inside the building.

Locating two of the units on the roof enabled the design team to limit the length of the ductwork that would have be installed if the units were located inside. Determining appropriate locations for outside air intake locations are challenging at an airport. There are more exhaust, containment and security concerns than at most buildings. Locating two of the mechanical units on the roof solved the concern of keeping the outside air intakes far enough away from any pollutants.

The two rooftop units serve the hold rooms, retail and restaurant areas. These areas have a high occupancy and high ventilation rates. The high amount of required outside air along with Phoenix's high ambient design temperatures, pushed the dry bulb entering air temperature to the cooling coil near 90°F. These units were supplied with a chilled water-cooling coil, which could accommodate the high entering air temperature. Special considerations would have had to be designed if the rooftop units were air-cooled.

The project incorporated many acoustical treatments. The rooftop units were located over back-of-house areas such as corridors and public restrooms. This was still not

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

**Case study: Airport expansion includes rooftop units**

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

*Figure 5: New concourse expansion at Phoenix Sky Harbor International Airport will provide additional gates for airlines to use. Courtesy: SmithGroup*

enough to meet the sound requirements of other areas. Duct liner was used in medium- and low-pressure ductwork in both the supply and return duct systems. There was not space on the roof to allow for horizontal supply and return ductwork connections, so vertical supply and return ductwork connections were used.

This required sound attenuators to be used near the connections to the rooftop units. The sound attenuators were straight duct type and varied from 3 to 5 feet in length. Custom vibration isolation curbs were also used to stop any vibration from the units to the building's steel structure. These were provided with ¾-inch deflection spring isolators and coordinated with the internal isolation types of the rooftop unit fans.

The rooftop units needed to be an applied application because of the requirements of the project. There was a cost premium for these units when compared to package rooftop units. The mechanical engineering team worked with the general contractor and mechanical contractor throughout the design phase to keep the cost of the units within the project's overall budget.

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

**Case study: Airport expansion includes rooftop units**

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

The supply fan, return fan and exhaust fan sections were each designed as fan arrays. This kept the size of any one motor to a minimum and also help reduce the sound power levels of the fan. Each fan section was designed to provide full design airflow in case of a fan failure in a N+1 arrangement. This allows for full conditioning to occur if there is a fan failure.

Portions of this expansion are going to be high-occupancy spaces that will require a large amount of outside air. Total enthalpy recovery wheels were used on the appropriate units to increase the energy savings and reduce the load on the existing central plant.  Also, a blank section in each unit was designed for an ionization system to be installed.

As mentioned previously, bringing in clean outside air can be challenging at an airport. This technology has been used in other parts of the airport and it maintains the proper indoor air quality levels for occupants of the airport. The energy recovery wheels, ionization system, reduced lighting loads and electrochromatic glass to adaptively change based on the outdoor conditions will be some of the key factors to help this building achieve the U.S. Green Building Council LEED Silver certification.

Using this technology allows for carbon filters not to be installed in each of the mechanical units. This is a significant cost savings for the energy use that the mechanical unit's fans can operate without the pressure drop of carbon filters and maintenance cost savings with not having to replace the carbon filters on a routine schedule.

**Jon Silhol**

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

**Case study: Airport expansion includes rooftop units**

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality

# Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

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

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

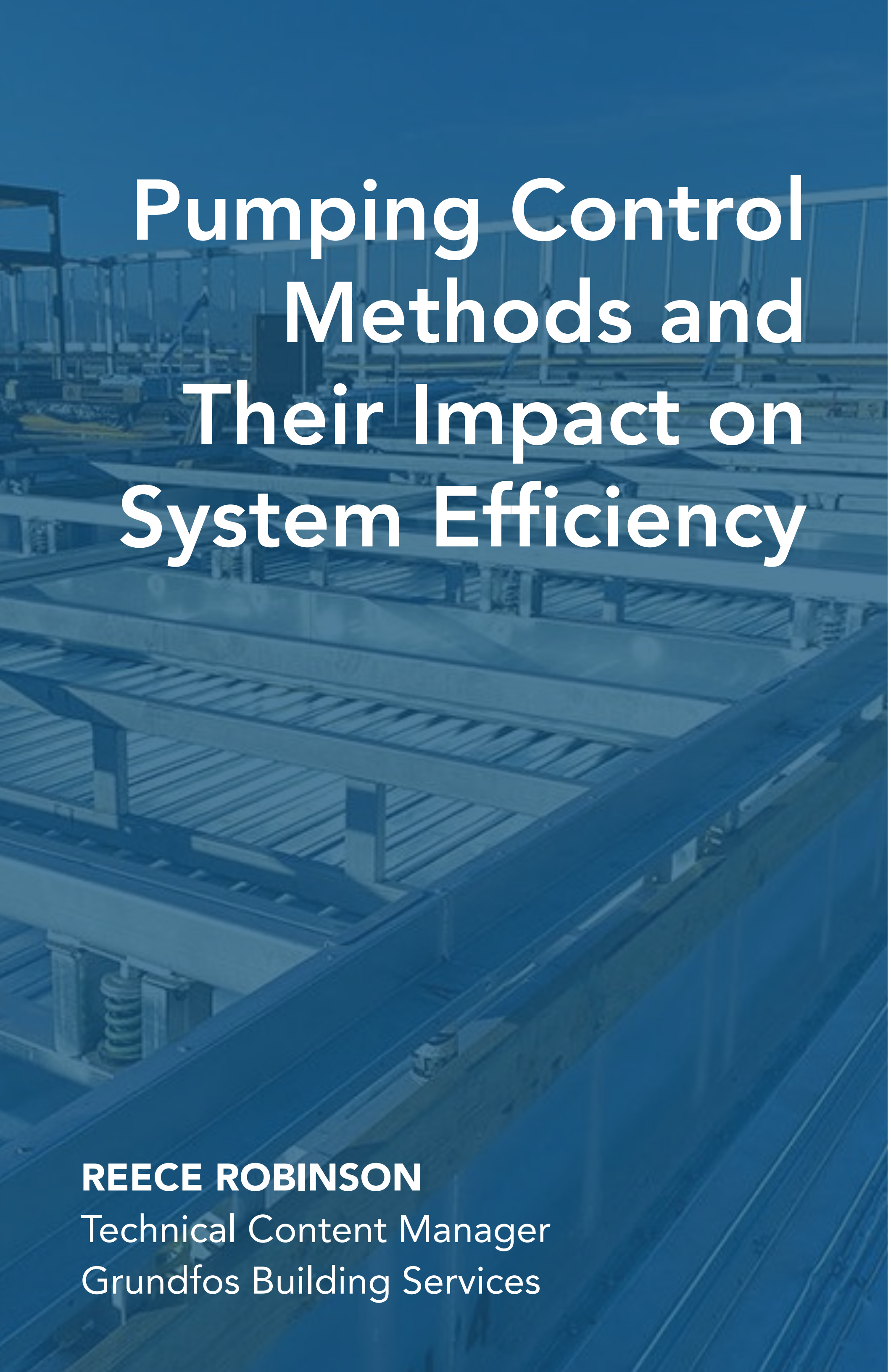
Case study: Airport expansion includes rooftop units

**Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency**

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

Sustaining indoor air quality



# Pumping Control Methods and Their Impact on System Efficiency

**REECE ROBINSON**
Technical Content Manager
Grundfos Building Services

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

## Today's Focus on Efficiency

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

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

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

## The Importance of Pumps

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

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

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

## Variable Pressure Is Key to Efficiency

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

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

**Pumping Control Methods and Their Impact on System Efficiency**

Integrating a BAS into design

Sustaining indoor air quality

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

## Applications

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

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

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

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

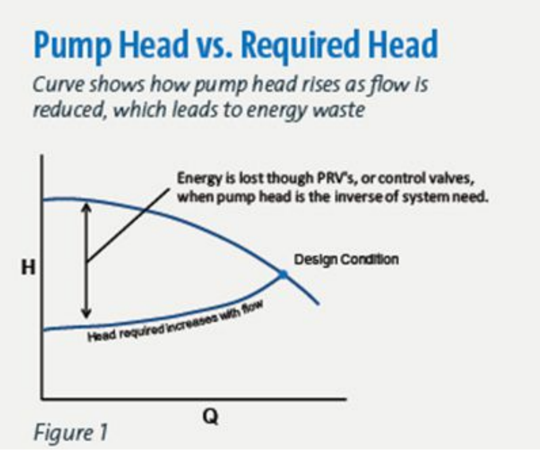

*Figure 1*

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

**Pumping Control Methods and Their Impact on System Efficiency**

Integrating a BAS into design

Sustaining indoor air quality

## Changing Flow Demand

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

## Measuring Pressure

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

**Power-based Control and Relation to Pump Performance Curve**

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

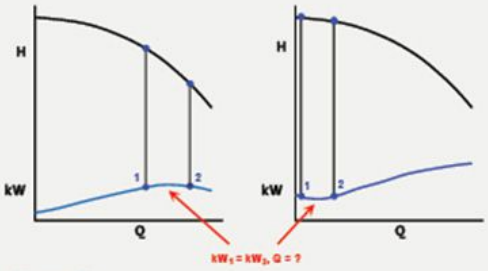

*Figure 2*

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Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

**Pumping Control Methods and Their Impact on System Efficiency**

Integrating a BAS into design

Sustaining indoor air quality

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

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

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

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

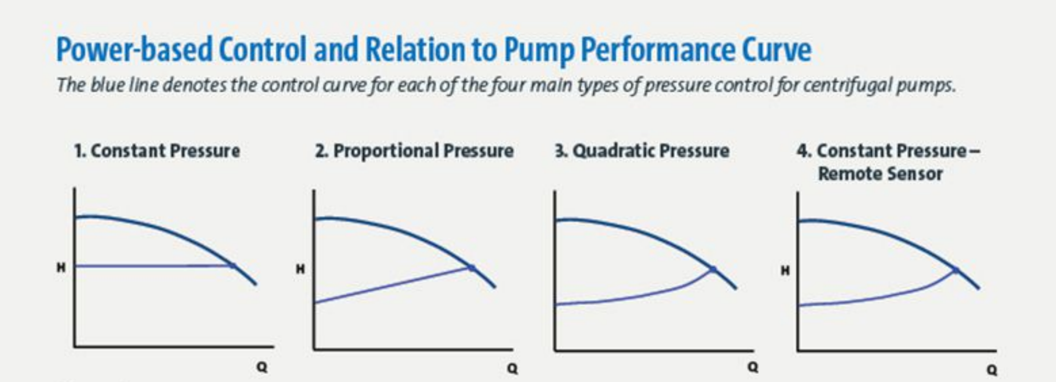

*Figure 3*

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Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

**Pumping Control Methods and Their Impact on System Efficiency**

Integrating a BAS into design

Sustaining indoor air quality

## 1. Constant pressure mode

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

## 2. Proportional pressure mode

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

## 3. Quadratic pressure mode

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

## 4. Constant pressure remote mode

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

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

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

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

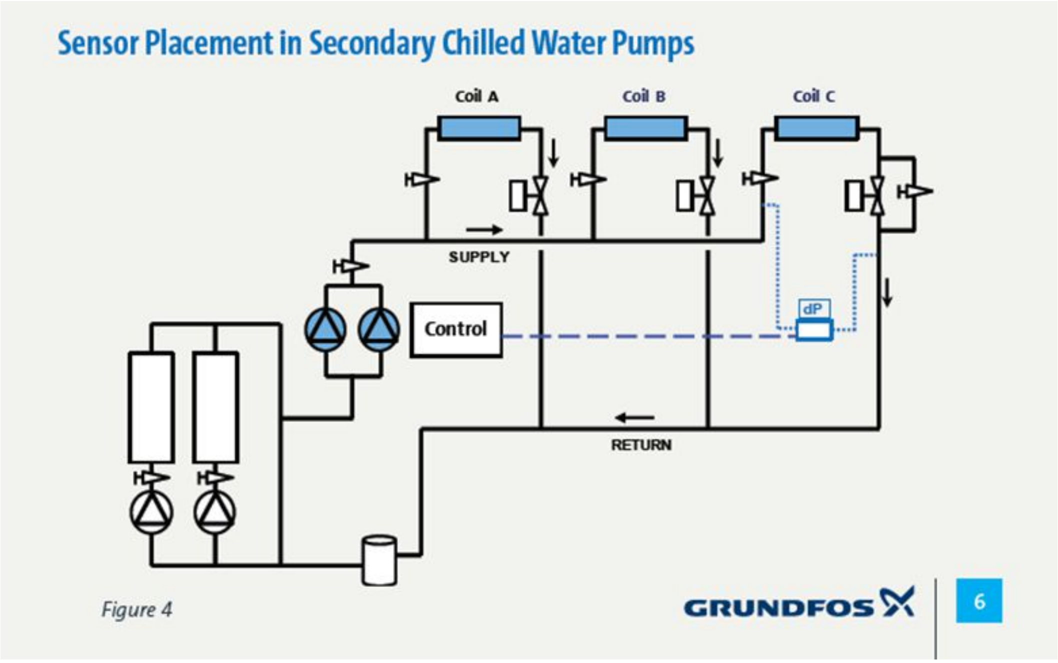
Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

**Pumping Control Methods and Their Impact on System Efficiency**

Integrating a BAS into design

Sustaining indoor air quality



## Pump-mounted vs. Remote Sensor

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

## Pump-mounted Sensor

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

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

**Pumping Control Methods and Their Impact on System Efficiency**

Integrating a BAS into design

Sustaining indoor air quality

Sensor Placement in Service Water Booster System

Possible sensor placement in a service water booster system

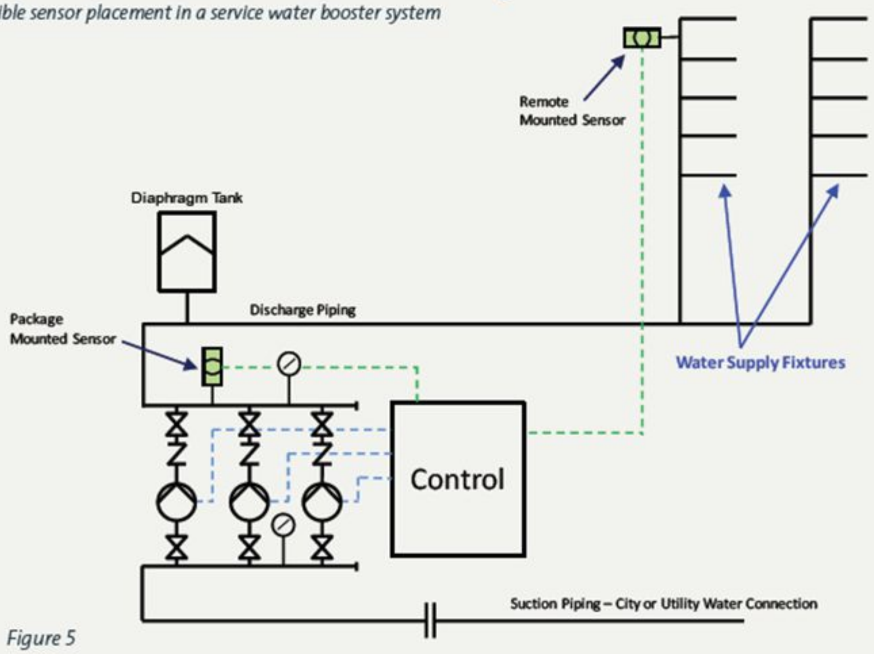


Figure 5

### *Hydronic application:*

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

***Example:***

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

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

Using louvers to prevent snow intake
Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment
Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs
Know when, how to specify a rooftop unit
Case study: Airport expansion includes rooftop units
Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency
**Pumping Control Methods and Their Impact on System Efficiency**
Integrating a BAS into design
Sustaining indoor air quality

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

### *Pressure boosting application:*

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

***Example:***

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

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

**Variable Pressure Control With Pump-mounted Sensors**

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

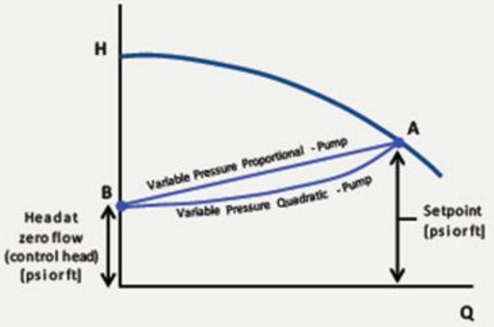


*Figure 6*

**Constant Pressure Control with Remote Sensor**

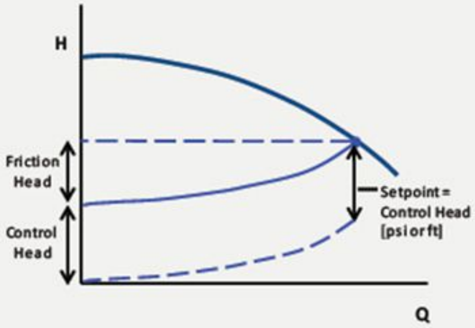


*Figure 7*

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Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

**Pumping Control Methods and Their Impact on System Efficiency**

Integrating a BAS into design

Sustaining indoor air quality

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

## Remote Sensor

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

### *Hydronic application:*

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

### *Pressure boosting application:*

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

Using louvers to prevent snow intake
Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment
Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs
Know when, how to specify a rooftop unit
Case study: Airport expansion includes rooftop units
Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency
**Pumping Control Methods and Their Impact on System Efficiency**
Integrating a BAS into design
Sustaining indoor air quality

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

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

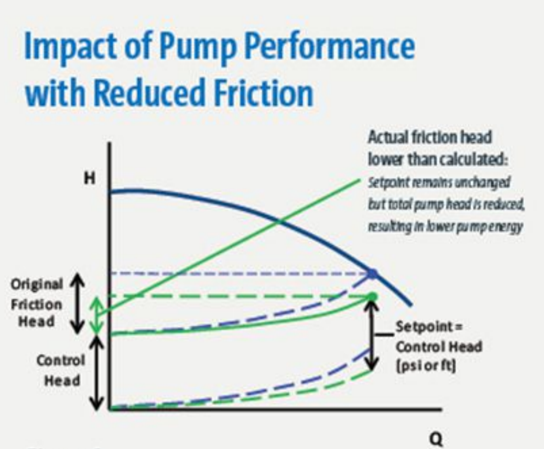

*Figure 8*

***Example:***

*Mode: Quadratic pressure control*

*Total head: 60 feet (26 psi)*

*Fixed head: 30 feet (13 psi)*

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

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

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

**Pumping Control Methods and Their Impact on System Efficiency**

Integrating a BAS into design

Sustaining indoor air quality

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

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

## Impact of ASHRAE Energy Standard 90.1

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

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

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

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

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

**Pumping Control Methods and Their Impact on System Efficiency**

Integrating a BAS into design

Sustaining indoor air quality

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

## Difference in Energy Consumption

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

**Rated Pump Curve**

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

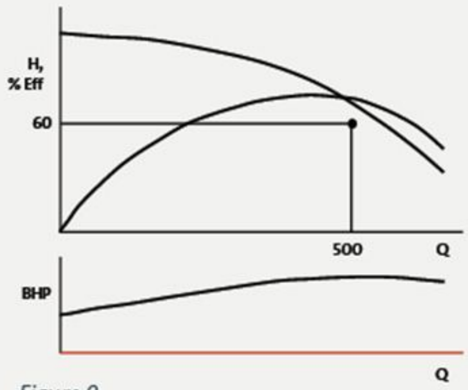

Figure 9

**Rated Pump Curve with Control Curves**

*Control, efficiency and power curves illustrated*

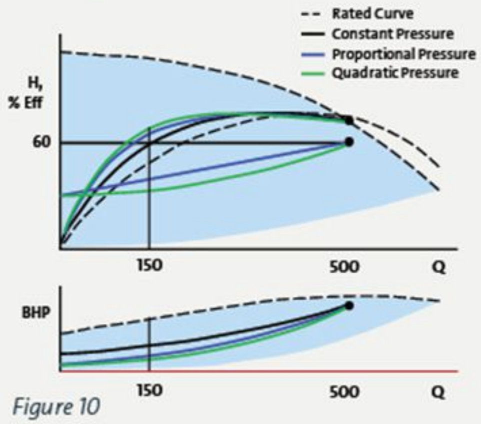

Figure 10

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

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

**Pumping Control Methods and Their Impact on System Efficiency**

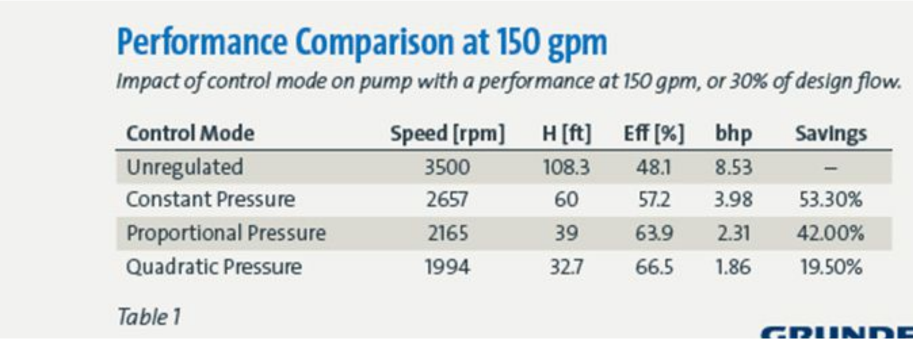
Integrating a BAS into design

Sustaining indoor air quality

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

## Parallel Pump Control

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



**Performance Comparison at 150 gpm**

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

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

*Table 1*

Using louvers to prevent snow intake
Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment
Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs
Know when, how to specify a rooftop unit
Case study: Airport expansion includes rooftop units
Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency
**Pumping Control Methods and Their Impact on System Efficiency**
Integrating a BAS into design
Sustaining indoor air quality

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

**Control Curve for Pumps Connected in Parallel**

*Incorporating all connected duty pumps ensures efficient operation.*

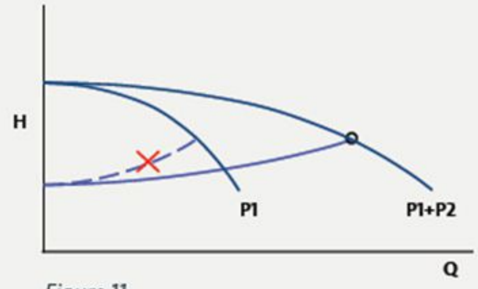


*Figure 11*

## Conclusion

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

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

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

Using louvers to prevent snow intake
Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment
Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs
Know when, how to specify a rooftop unit
Case study: Airport expansion includes rooftop units
Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency
**Pumping Control Methods and Their Impact on System Efficiency**
Integrating a BAS into design
Sustaining indoor air quality

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

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

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

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Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

**Pumping Control Methods and Their Impact on System Efficiency**

Integrating a BAS into design

Sustaining indoor air quality

# Integrating a BAS into design

*Building systems should be high-performing, integrated and accessible — and the building automation system is the key to achieving these goals*

Building automation systems are key to creating high-performing, integrated and accessible spaces. Engineers are experts at designing systems to meet a specific criterion, but the reality is that system capabilities far exceed one specific criterion.

There is a process to manage and meet expectations that is easily scalable to project size and scope. While the process may appear more time-consuming, it is not meant to add time, but rather save time, cost and questions throughout construction and occupancy.

Architects spend countless hours in visioning, conceptual design, programming and planning meetings, along with design charettes to provide a building that meets the owner and occupant needs. Depending on the building typology, detailed or nondetailed room data sheets may be produced to help the engineer define the function of the engineering systems while defining peak loads.

The engineers work with architects and other specialists to validate these peak demands of the space, identify individual room loads and how the main infrastructure should be sized to support future flexibility and adaptability. This translates into certain maximum loads on the heating, ventilation and air conditioning; plumbing; electric and power; lighting; communication; and fire protection and life safety systems.

Many construction documents are fantastic at covering this portion of the design. But what happens when it is not the hottest or coldest day of the year or the space has all

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

**Integrating a BAS into design**

Sustaining indoor air quality

the equipment on but very few people are in the space? How does the system support limited resources by maintenance staff for preventive maintenance? The BAS is often expected to address all aspects of part load conditions, remote monitoring and alarms and integration of all systems.

*Figure 1: The open laboratory concept provides flexibility to changes in research and future programs. The cascading airflow systems require precision but also include capacity to adapt. The control system design is critical to responding to those needs. Courtesy: Justin Maconochie, Stantec*

## Define control system goals

Every building, owner and occupant group is different and the technical ability of the building operators, local trade professionals and parts availability differs. Trying to apply one solution for all projects can lead to challenges. Yet many times, engineers rely on building control system representatives or generic sequences of operation from master specification providers to cover the critical nature of system operation intent.

So, like the programming and planning process that defines the many needs of a building, the control system designer must understand which key stakeholder groups to engage to determine what needs control and why.

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

**Integrating a BAS into design**

Sustaining indoor air quality

During the early phases of design, identify the stakeholders and who will be making a final decision in the case of differing opinions. Determine if there are any client standards in place that will dictate design direction. Also, discuss client preferences for equipment, providers and installers. Overall, what are the goals for the control system, are there any special control requirements, will the new system need to integrate to a new or existing system and is the existing systems compatible with the new system?

It is important to engage all these individuals early to understand all project aspects.

Typical control system stakeholder groups include:

***Facilities management:*** The design team needs to engage the immediate owner, but often there are many interested parties within the owner's organization that also need to be consulted. Usually there is a FM person or team. FM typically provides direction on minimum operating efficiencies, building or campus functions, scheduling needs and other big-picture directives. They may also identify preferences regarding specific systems, providers, components or considerations for future system integrations.

***Energy management:*** Energy managers may want to weigh in on specific metering, monitoring and trend data that are desired to measure and verify system operation. Identify as early as possible the sustainability or energy goals, as the owner may have to cover the associated costs in expenditure models and project budgeting.

***Building operator:*** Depending on market and building typology, a building operator could be part of the facilities management team or, depending on the size of the organization, individuals may be assigned to care for specific buildings or groups of build-

Using louvers to prevent snow intake
Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment
Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs
Know when, how to specify a rooftop unit
Case study: Airport expansion includes rooftop units
Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency
Pumping Control Methods and Their Impact on System Efficiency
**Integrating a BAS into design**
Sustaining indoor air quality

ings. These individuals usually have a wealth of knowledge about a building's history and should be encouraged to share what has or has not worked well. They often know and understand the owner's needs.

Figure 2: The new 169,000-square-foot Central Michigan University biosciences building sits at the heart of campus and was the largest single capital project of the university's 128-year history. Safety and energy use were key design drivers. Courtesy: Justin Maconochie, Stantec

***Other groups:*** Consider including other groups, for example, commissioning agents, engineering experts, construction manager, equipment vendors or maintenance contractors. They all have practical experience on what is available and what typically gets tweaked and adjusted during functional testing and system startup.

In the absence of control system stakeholders, use engineering judgment appropriate to the type, budget and sophistication of the building, client or user and communicate these decisions out to the project team.

## Communicating design intent

There are many individuals and teams that will have input into the control system and there will be many elements that need to be represented and described in the contract documents. How do all the thoughts and ideas make their way to the final construction

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

**Integrating a BAS into design**

Sustaining indoor air quality

documents and ultimately into the final building? It takes planning and appropriate checkpoints to properly achieve the project's successful completion.

Set up clear communication with the client and the entire project team. It is the duty of the design professional to listen, educate and provide recommendations for the owner to make the best decision.

Once preliminary controls diagrams are developed, a meeting with facility users, industry partners (when potential control partners are known), commissioning agents and the design and engineering teams provides a platform to describe the design team's understanding of what should be controlled. This leads into the discussion of how and why. How will each system operate? How will the system communicate and integrate to other components? Why are certain control modes required? Why are certain control and monitoring points desired? Each party has an opportunity to weigh in on the elements, complexities and costs. Resolution may not happen in one discussion and may take multiple meetings, but the process decreases surprises later in the project aiding in project construction, closeout and post-occupancy.

As the project moves into construction documents, it is important to develop sequence of operations to clearly identify the modes of operation and connection between devices. The same group of stakeholders should reconvene to flush out any potential challenges before the project goes into construction. Some of these challenges could be as simple as a disagreement on one section of one sequence of operations or something more major regarding equipment functionality or controllability. Multiple sessions may be necessary to cover all systems and modes of operation.

Using louvers to prevent snow intake
Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment
Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs
Know when, how to specify a rooftop unit
Case study: Airport expansion includes rooftop units
Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency
Pumping Control Methods and Their Impact on System Efficiency
**Integrating a BAS into design**
Sustaining indoor air quality

In construction, the focus shifts from theoretical sequences with their preliminary time functions, setpoints and expected equipment operation to addressing the realities of installation — test and balance setpoint validation, loop tuning, actual equipment performance and other construction-associated modifications. In each case, recording the adjustments in both the record drawings and within the control system is imperative as accidental system resets, power events and staff changes occur and the knowledge of these tweaks can be lost.

While opportunities for collaboration throughout the design and construction process always arise, sometimes it is necessary to force parties engaged through the life of a project to aid in understanding and operational success.

*Figure 3: The building rests on the central spine of campus. The grand concourse and atrium draw students into the building to observe the work including items such as living walls and aquariums. Courtesy: Justin Maconochie, Stantec*

## Documenting control system design intent

Producing construction documents for the control system has several basic components: general requirement notes, control diagrams identifying the arrangement and relationship of components, sequences of operation and identification of all the minimum control and monitoring points. During the design process there are also key

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

**Integrating a BAS into design**

Sustaining indoor air quality

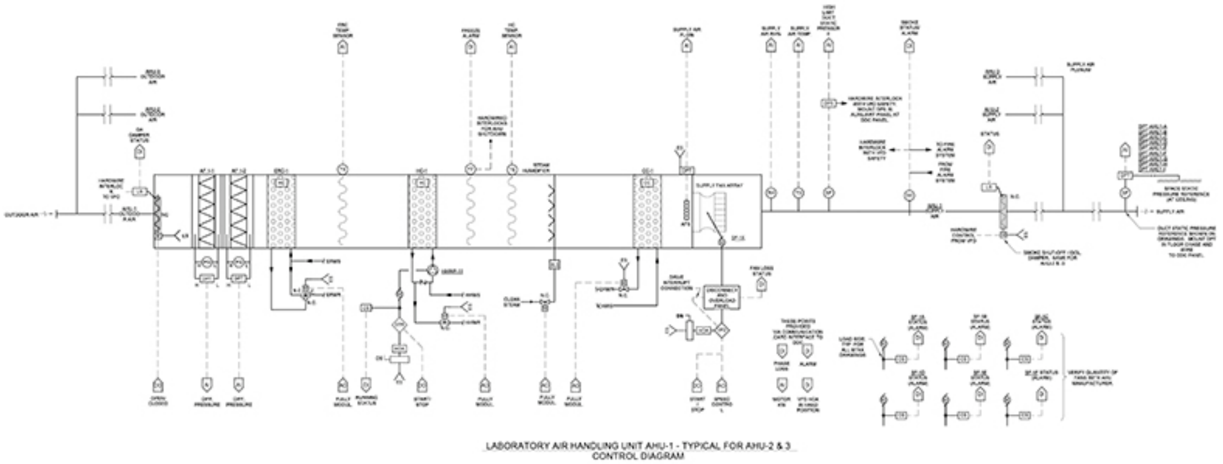

*Figure 4: The laboratory air handling unit control diagram and control points were established in the design development phase. It provided visual discussion with the owner, users and installers to review the intended system function, user interface, cost and sequence of operations development. Courtesy: Stantec*

checkpoints to verify and validate components, control and monitoring points, control modes and trends.

As the design progresses, the control designer develops and presents the overall anticipated architecture, individual control diagrams, sequences and then potential alarms and control trending. Each stage of development represents a key checkpoint.

Contract documents identify the minimum construction requirements for the bidding process of a project. Although contract documents are comprised of drawings and specifications, the drawings are typically what get frequently referenced — and are usually what survive, long after the specifications get put away.

Documents that describe a system solely through a narrative may require the controls

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

**Integrating a BAS into design**

Sustaining indoor air quality

installer to interpret design intent and in some cases may result in the lowest-cost system with a minimum level of functionality and flexibility. Clearly identifying the system requirements in both written and drawn formats helps provide distinct intent to the controls vendor.

## Control system architecture, diagrams

Consider developing a system architecture that clearly defines minimum panel requirements and transmission systems such as main communication trunks between network panels and other control devices. These can be variable frequency drives, terminal equipment and other proprietary systems such as a variable refrigerant flow system, the fire alarm, kitchen automation systems and the like. The client may want each central system such as an air handling unit, heating plant or cooling plant on its own control panel to limit interruption of service due to the loss of a panel. Terminal equipment associated with each central system may be desired to be on individual communication networks in lieu of the maximum number of terminal devices on each subnetwork to limit network traffic.

As soon as the mechanical, electrical and plumbing systems are determined, it is a good time to develop preliminary control diagrams for each system. Larger projects have multiple engineers working on specific items. Developing a picture of what you understand the system to be, along with the components associated with it, helps all parties in collaboration of design.

Including important notes that emphasize power requirements, battery backups and the need for virtual points, dead bands and control point adjustability warrant a place on the drawings. If the control drawings use specialized symbology and abbreviations,

Using louvers to prevent snow intake
Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment
Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs
Know when, how to specify a rooftop unit
Case study: Airport expansion includes rooftop units
Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency
Pumping Control Methods and Their Impact on System Efficiency
**Integrating a BAS into design**
Sustaining indoor air quality

separate than what typically exists on the mechanical standard legend and consider a specialized legend for the control series. Each component that needs to be controlled should be identified.

Diagrams comprise the backbone of most control systems. The diagram includes the components to be controlled such as a fan, coil or pump as well as the devices associated with each component like motor starters or variable frequency drives. Elements are typically modulated based on feedback from a sensor or device, which is also indicated on the control diagram and could be documented in the sequence of operations. For a coil, how many valves serve the coil, are the valves normally open or closed, should the valve return to a specific state upon loss of power or signal?

While many of these items can be covered generically in a specification, application may differ for a specific piece of equipment. There are many questions that, if not clearly defined, may not meet the client or the user's needs. The diagram acts as a visual representation of all devices, components and sensors. It plainly identifies the arrangement and relationship between all the elements. The diagram provides a complete picture for each stakeholder to review the proposed design and provide feedback. Each element can be identified for control and monitoring points such as analog or digital inputs or outputs helping the installer and operator better understand the intended system operation.

Which points should be displayed on the graphical user interface? Which of these points is read-only and which is write-access? Graphic depictions of what points should be displayed on the graphical user interface and what points should be writable provide clarity to bidders. Where these visual representations provide clarity, the written

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

**Integrating a BAS into design**

Sustaining indoor air quality

sequence of operations expands the requirements to include the necessary interactions between each element.

## Control sequences of operation

Integration of packaged equipment, controllers and systems are often expected. Through ASHRAE, we have a standard communication language in BACnet. However, packaged equipment and systems offer potentially thousands of control and monitoring points and there are myriad ways of controlling equipment. Providing a sequence of operations, even for packaged systems, helps all parties understand expectations and reduce frustration when systems become operational.

Where the diagram identifies all the components and control devices, the sequence defines scheduling requirements, operating modes, setpoints, alarms, integration and transitions through seasons or operational changes. The sequence should give clear instruction to the programmer on expectations. Some key questions to address are:

- What are the specific modes of operation?
- What device controls each element?
- Is there a specific sequence for components to modulate or enable?
- What time delays are appropriate?
- How does the equipment start?

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

**Integrating a BAS into design**

Sustaining indoor air quality

- Are there limiting factors or time delays before another component can enable or modulate?
- What happens in a planned or emergency shutdown?
- Are there requirements for life safety or secure operation?
- What default values should the system assume when restarting after a power loss or a communications network failure?

If these types of questions are not answered during design, they will result in all parties having to spend more time generate requests for information, cause multiple submittal reviews, adjustments during commissioning, startup, functional testing and long after the building has been occupied to ultimately meet owner expectations.

As the control system is responsible for aspects of operation, an area that is sometimes overlooked is the design intent of redundant equipment. Many systems have a backup pump or fan, but at what time and how often should equipment rotate. Is this setting and process clearly defined and is it readily accessible to make adjustments pending maintenance staff availability? Do rotations happen by system operation or do the operators prefer to schedule switchovers to occur on a particular day?

Like equipment rotation, many contract documents do not describe the intent for staging or modulation of equipment. Lack of clarity puts additional effort on the startup and commissioning teams to tune loops, make decisions about redundant equipment and determine staging for different operating conditions.

Using louvers to prevent snow intake
Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment
Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs
Know when, how to specify a rooftop unit
Case study: Airport expansion includes rooftop units
Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency
Pumping Control Methods and Their Impact on System Efficiency
**Integrating a BAS into design**
Sustaining indoor air quality

## Measurement and verification

A critical item in today's high-performance buildings is understanding real-time energy usage for diagnostics, education and operational efficiency. Having accurate and appropriate sensors feeding data to the applicable meters with proper communication is the first step. The second is ensuring the meters are correctly calibrated.

An important question becomes: "How much data is the required amount to properly accomplish the goals?" Too much data, network traffic and storage may become issues. Not enough data, and the investment might not fully be used in terms of analytics and diagnostics. Best practice suggests designers should specify trend expectations. For example, the system shall have the capacity to store one year's worth of data for all points logged on a 15-minute interval.

Designers are not always clear on what trends should be recorded. Most specifications identify the need for trending but do not offer guidance on which points and how often. Like energy usage, what is the typical goal of specific trends and how much network traffic and data storage is required to accomplish each? What is the duration of certain trends? Consider identifying specific points, recorded every so many minutes, for a set duration and after that period, the data are archived.

During the commissioning process, temporary trends can be established to monitor specific systems. Are these trends deactivated at the completion of commissioning activities? Some processes, equipment or individual zones are critical to the building's operation. What are the specific needs of these trends? The specifics may vary, but the documentation of these need to be recorded. Consider, having the commissioning agent clarify what the specific needs are.

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

**Integrating a BAS into design**

Sustaining indoor air quality

During the beginning of operation and occupancy, sporadic issues that only occur at specific times under specific conditions can be elusive and be difficult to diagnose. Proper trend logging is therefore essential for short and long-term troubleshooting of controls systems. Having parameters defined for trends reduce effort for all parties to add trends when these situations arise.

## Identifying alarms and setpoints

As facilities continue to address budget reductions, the chance a maintenance staff member is always available is becoming less common. The need to classify alarms into different categories is becoming more important. How many levels of alarming is needed for each project? Are there critical alarms that need to be addressed immediately by a monitoring service, on-call staff member or service company, or to address public safety? Alarms that need next-day attention could be tasked out when a staff member arrives. Other alarms may signal equipment maintenance or operations to watch. As these tiers are defined, output from the BAS may be integrated to facility management software through programming.

During design, engineers calculate expected operating setpoints and schedule specific rates or ranges for each system to operate. Adjustments during start up, functional testing and commissioning are common. Some adjustments to lighting control devices such as occupancy sensors may be permanent, whereas a maximum-speed setting on a variable frequency drive may be lost during a power event.

Setpoints determined by a balancer or other trade professionals are critical for efficient operation. While this can be contained in the operations and maintenance manuals, having tags added to equipment or to the graphical user interface helps operators

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

**Integrating a BAS into design**

Sustaining indoor air quality

know where equipment should be controlling to. Additionally, when setpoints are reset for energy saving control, it can be very helpful to operators to see what the current controlling setpoint is, what the default is and what the total operating range value could be.

## Commissioning and occupancy

Commissioning truly begins in design. Having the commissioning agent in design meetings helped define specific elements or sequences they may need to prove out the system. As the level of sophistication increases with more interactions between systems and multiple layers of alarms, the commissioning agent may need a matrix of cause and effect, particularly with large complex buildings (e.g., life safety) so it is clear to everyone how different systems interact.

Owner staff should be engaged during on-site training and commissioning so they can learn about the systems in a hands-on way. This is generally more useful than half a day of in-classroom training. An owner and operator that experience the system as it was constructed and tested will be better able to react to user requests and maintain the performance of the systems.

**Casimir Zalewski and Derek Crowe**

***Casimir Zalewski*** *is a principal at Stantec.* ***Derek Crowe*** *is a senior associate at Stantec.*

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

**Integrating a BAS into design**

Sustaining indoor air quality

# Sustaining indoor air quality

*Maintaining indoor air quality is imperative for occupant health and comfort as well as the reliable operation and longevity of information technology equipment*

Indoor air quality and design has historically been an important — and sometimes overlooked — design topic.

When designing ventilation systems, it is imperative that the designer understand the applicable code requirements, standards such as ASHRAE Standard 62.1: Ventilation for Acceptable Indoor Air Quality and programs like the U.S. Green Building Council's LEED rating system.

Ventilation is the process of supplying or removing air from a space to control contaminant levels, humidity or temperature. In a typical process, outdoor air and return air are mixed, which effectively dilutes indoor particulates/contaminants and the resulting mixed air stream is subsequently filtered and conditioned before being supplied into the space.

Designers should always investigate outdoor air quality in their region and survey the immediate surroundings to determine the local air quality and its ability to maintain acceptable IAQ. The Environmental Protection Agency collects air quality data and has an interactive map that shows locations of air quality monitoring stations located across the United States. These air quality monitoring stations provide the required data to assist engineers with designing ventilation systems.

Deficient ventilation systems, such as those operating with inadequately sized outdoor

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

**Sustaining indoor air quality**

**Table 1: Current air quality standards**

| Pollutant | Primary/secondary | Averaging time | Level | Form |
|---|---|---|---|---|
| Carbon monoxide (CO) | Primary | 8 hours | 9 ppm | Not to be exceeded more than once per year |
| | | 1 hour | 35 ppm | |
| Lead (Pb) | Primary and secondary | Rolling 3-month average | 0.15 μg/m$^3$ | Not to be exceeded |
| Nitrogen dioxide (NO$_2$) | Primary | 1 hour | 100 ppb | 98th percentile of 1-hour daily maximum concentrations, averaged over three years |
| | Primary and secondary | 1 year | 53 ppb | Annual mean |
| Ozone (O$_3$) | Primary and secondary | 8 hours | 0.070 ppm | Annual fourth-highest daily maximum 8-hour concentration, averaged over three years |
| Particle pollution (PM2.5) | Primary | 1 year | 12.0 μg/m$^3$ | Annual mean, averaged over three years |
| | Secondary | 1 year | 15.0 μg/m$^3$ | Annual mean, averaged over three years |
| | Primary and secondary | 24 hours | 35 μg/m$^3$ | 98th percentile, averaged over three years |
| Particle pollution (PM10) | Primary and secondary | 24 hours | 150 μg/m$^3$ | Not to be exceeded more than once per year on average over three years |
| Sulfur dioxide (SO$_2$) | Primary | 1 hour | 75 ppb | 99th percentile of 1-hour daily maximum concentrations, averaged over three years |
| | Secondary | 3 hour | 0.5 ppm | Not to be exceeded more than once per year |

*Table 1: This outlines the ambient air quality standards established by the Environmental Protection Agency, known as National Ambient Air Quality Standards. Courtesy: ESD*

air quantities or improper ventilation control, can impact occupant health and productivity. Sick building syndrome and building-related illness are some of the negative impacts on occupant health with symptoms ranging from headaches, nausea and chest pain to asthma, Legionnaires' disease and sinusitis. On the other side of the spectrum is excessive ventilation, which increases energy use and increases indoor concentration of outdoor contaminants if ambient air quality is unsatisfactory.

There are studies relating sick building syndrome prevalence and the amount of outdoor air provided. These studies show that when the ventilation rate is increased, sick building syndrome prevalence is reduced. There are also studies that indicate a direct correlation between performance and amount of outdoor air introduced in office build-

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

**Sustaining indoor air quality**

ings. It is important to balance the outdoor airflow rate with the additional power and energy required to condition the air. This is where codes, standards and other rating systems can be a useful tool.

ASHRAE Standard 62.1 is frequently referenced or incorporated in codes for ensuring acceptable IAQ. ASHRAE Standard 62.1 defines acceptable IAQ as air in which there are no known contaminants at harmful concentrations as determined by applicable authorities and where 80% or more of people do not express dissatisfaction when exposed to the air.

## IAQ for human occupants

ASHRAE Standard 62.1 specifies the minimum ventilation rates and related measures to ensure acceptable IAQ and minimize adverse health effects. The standard applies to spaces intended for human occupancy within buildings except for dwelling units in residential occupancies with nontransient occupants. The origin of Standard 62.1 dates back to 1973. It has been revised multiple times since; the latest version is 2019.

In addition to outlining the design requirements, the standard also provides requirements related to installation, commissioning and operations and maintenance of equipment. Ensuring compliance and acceptable IAQ therefore requires coordination and collaboration among stakeholders and continued diligent efforts on the O&M side.

Some frequently overlooked items in Standard 62.1 as it applies to commercial buildings are:

Design related:

- Quality of ambient air and its ability to maintain acceptable IAQ should be inves-

Using louvers to prevent snow intake
Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment
Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs
Know when, how to specify a rooftop unit
Case study: Airport expansion includes rooftop units
Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency
Pumping Control Methods and Their Impact on System Efficiency
Integrating a BAS into design
**Sustaining indoor air quality**

tigated during design. The EPA has established the National Ambient Air Quality Standards as authorized by the Clean Air Act and quality standards for six primary pollutants have been established: carbon monoxide, lead, nitrogen dioxide, ozone, particle pollution or particulate matter and sulphur dioxide.

  - Refer to Table 1 for the EPA established air pollutant standards.
  - For buildings located within areas where PM10 (particulate matter with a 10-micrometer diameter or smaller) threshold is exceeded, filters or air cleaning devices with minimum efficiency reporting value 8 should be provided to treat outdoor air before introduction into buildings.
  - For buildings located within areas where PM2.5 (particulate matter with a 2.5-micrometer diameter or smaller) threshold is exceeded, filters or air cleaning devices with minimum rating of MERV 11 should be provided to treat outdoor air before introduction into buildings. Refer to Table 2 for filter ratings and common applications.
  - For buildings located within areas where the most recent three-year average annual fourth-highest daily maximum eight-hour average ozone concentration exceeds 0.100 parts per million, ozone cleaning devices with a volumetric removal efficiency of minimum 40% should be provided. The devices need to be operated when ambient ozone levels are expected to exceed 0.100 ppm.

- Following are the exceptions to the ozone cleaning requirement:
  - Design outdoor airflow is 1.5 air changes per hour or less.

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

**Sustaining indoor air quality**

  - The system is equipped with controls that can sense ambient ozone level and reduce outdoor air to 1.5 air changes per hour or less while still complying with the other requirements.
  - Direct fired makeup air units are used to heat outdoor air introduced into the building.

- An observational survey of the building site and immediate surroundings is required to be conducted during expected hours of occupancy. The intent is to identify local contaminants that could impact IAQ if introduced into the building.
- Exhaust ducts conveying Class 4 air should be negatively pressurized relative to ducts, plenums or occupiable spaces through which they pass to eliminate the possibility of contaminant leakage. Positively pressurized exhaust ducts conveying Class 2 or Class 3 air should not extend through plenums or occupiable spaces other than the space from which the exhaust air is drawn. However, positively pressurized ducts conveying Class 2 air and sealed in accordance with SMACNA Seal Class A are an exception to the requirement. SMACNA Seal Class A requires all transverse duct joints, longitudinal seams and duct penetrations be sealed to minimize air leakage. Refer to Table 3 for air classification based on subjective contaminant concentration.
- Filters with minimum rating of MERV 8 are required upstream of cooling coils handling latent loads and other components with wet surfaces such as evaporative humidifiers.

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

**Sustaining indoor air quality**

- For buildings using mechanical cooling equipment, dehumidification provisions are needed to ensure indoor humidity levels do not exceed 60°F dewpoint at any time (occupied and unoccupied hours) when the ambient dewpoint is in excess of 60°F. Among other exceptions, the requirement does not apply to overnight unoccupied periods not exceeding 12 hours, provided the indoor relative humidity does not exceed 65% during that timeframe.

- Drain pans beneath wet components such as cooling coils and direct evaporative humidifiers should begin at the leading face or edge of the device and extend downstream a distance of half the vertical dimension of the device or as necessary to limit water carry-over beyond the drain pan to 0.0044 ounce/square foot of face area per hour under peak sensible and peak dewpoint conditions.

- Access doors or panels are required in infrastructure such as equipment, ductwork, plenums to allow for inspection, cleaning and maintenance of the following components:
    - Air cleaners.
    - Drain pans and seals.
    - Fans.
    - Humidifers.
    - Mixed air plenums.
    - Outside air plenums.

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

**Sustaining indoor air quality**

    - Upstream and downstream of each heating, cooling and heat-recovery coil comprised of more than four rows and direct evaporative coolers, air washers, heat wheels and other heat exchangers.

    - Upstream of heating, cooling and heat-recovery coil comprised of four rows or fewer.

Construction and startup related:

- Filters should be installed at equipment before startup to prevent fouling.

- Contaminants generated due to construction should be confined to the construction area and migration to occupied areas should be minimized by employing suitable measures.
- Drain pans should be field tested under conditions most restrictive to condensate flow to ensure they drain properly and water stagnation is eliminated.

O&M related:

- The standard has detailed requirement regarding maintenance activities and frequencies for system components that impact IAQ of the facility such as cooling towers, cooling and heating coils, louvers, bird screens, mist eliminators and the like. Continued compliance with these maintenance requirements is imperative to maintaining IAQ over the life of a facility. While the designer is not responsible for the maintenance of a mechanical system, the designer is responsible for ensuring the systems are provided with the proper features to allow for regular maintenance.

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Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

**Sustaining indoor air quality**

## IAQ for data centers

Mechanical systems for data centers are unique in that their purpose is to maintain an operating temperature range and acceptable IAQ for information technology equipment. In the United States, the Toxic Substances Control Act influences materials of construction for ITE. The TSCA does restrict the use of certain materials similar to the European Union's Directive 2002/95/EC – Restriction of Hazardous Substances.

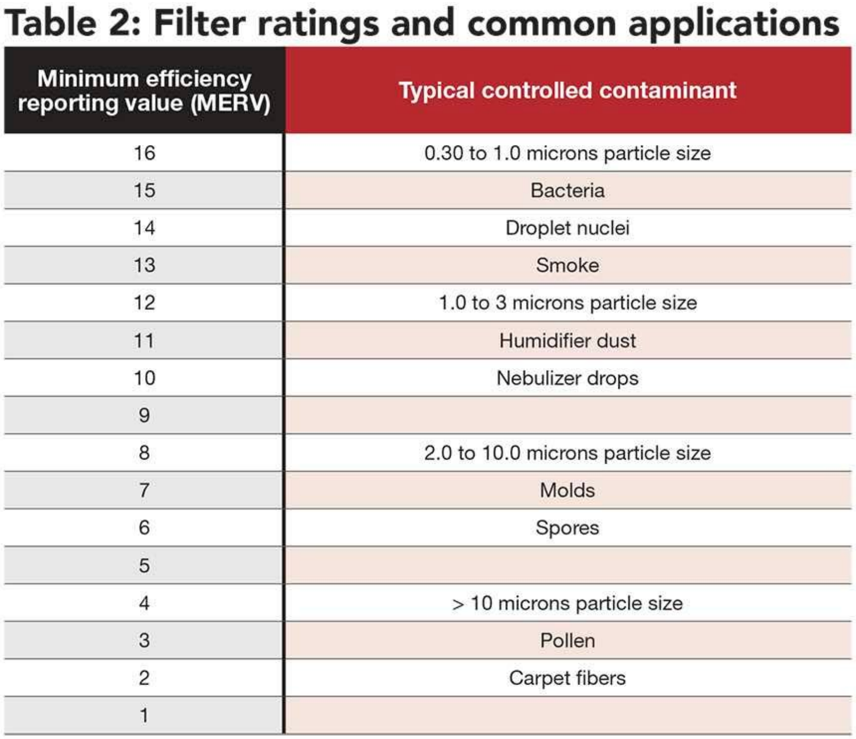

**Table 2: Filter ratings and common applications**

| Minimum efficiency reporting value (MERV) | Typical controlled contaminant |
|---|---|
| 16 | 0.30 to 1.0 microns particle size |
| 15 | Bacteria |
| 14 | Droplet nuclei |
| 13 | Smoke |
| 12 | 1.0 to 3 microns particle size |
| 11 | Humidifier dust |
| 10 | Nebulizer drops |
| 9 | |
| 8 | 2.0 to 10.0 microns particle size |
| 7 | Molds |
| 6 | Spores |
| 5 | |
| 4 | > 10 microns particle size |
| 3 | Pollen |
| 2 | Carpet fibers |
| 1 | |

*Table 2: Air contaminants and the corresponding minimum efficiency reporting value rating of filters to control them are outlined. Courtesy: ESD*

The EU Directive restricts the use of materials commonly used in electronics and electrical equipment by banning the use of lead (with exceptions), mercury, cadmium, hexavalent chromium, polybrominated biphenyls, polybrominated diphenyl ethers and various phthalates. Almost all major server and hard disk drive manufacturers comply with the EU Directive. However, this also causes IT equipment to be more susceptible to corrosion. This led to an increase in ITE failures in regions with higher concentrations of specific pollutants.

Using louvers to prevent snow intake

Air Solution Company Cottonwood Filter Screens For HVAC and Cooling Tower Equipment

Why Specifying Mechanical Engineers Should Build Cottonwood Filter Screens into Their Cooling System Designs

Know when, how to specify a rooftop unit

Case study: Airport expansion includes rooftop units

Modular Pumping Systems for HVAC: Delivering and Maintaining Building Efficiency

Pumping Control Methods and Their Impact on System Efficiency

Integrating a BAS into design

**Sustaining indoor air quality**

Poor IAQ can lead to premature failure of ITE and the losses can be in millions of dollars for large data centers. Gaseous contaminants such as sulfur dioxide, hydrogen sulfide, ozone and nitrogen dioxide can promote corrosion of common materials used to construct ITE.

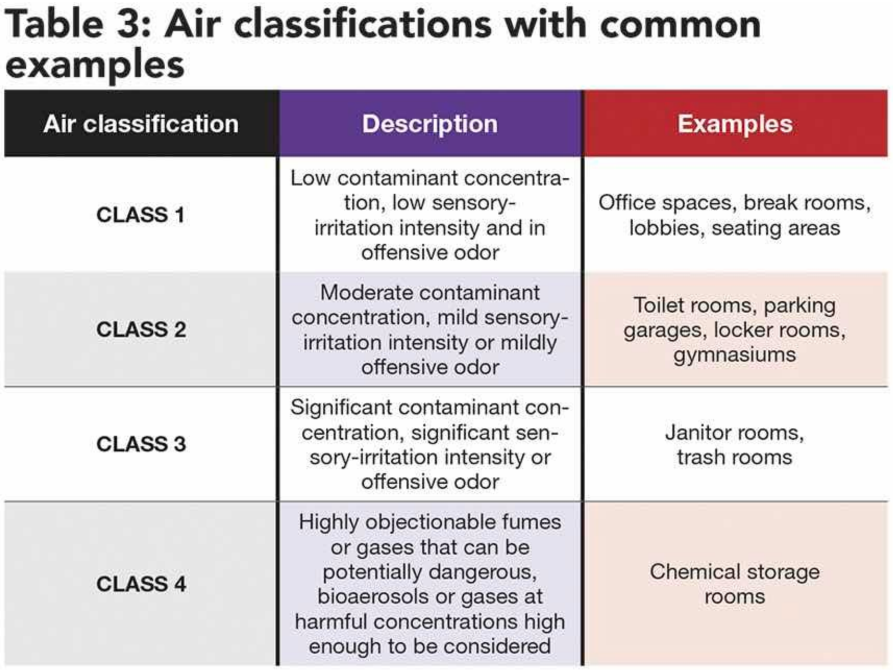

**Table 3: Air classifications with common examples**

| Air classification | Description | Examples |
|---|---|---|
| CLASS 1 | Low contaminant concentration, low sensory-irritation intensity and in offensive odor | Office spaces, break rooms, lobbies, seating areas |
| CLASS 2 | Moderate contaminant concentration, mild sensory-irritation intensity or mildly offensive odor | Toilet rooms, parking garages, locker rooms, gymnasiums |
| CLASS 3 | Significant contaminant concentration, significant sensory-irritation intensity or offensive odor | Janitor rooms, trash rooms |
| CLASS 4 | Highly objectionable fumes or gases that can be potentially dangerous, bioaerosols or gases at harmful concentrations high enough to be considered | Chemical storage rooms |

*Table 3: Common examples of the four classes of air per ASHRAE Standard 62.1 are outlined. Courtesy: ESD*

The most common failure that is a direct result of poor IAQ is creep corrosion on printed circuit boards. Silver and copper have been widely used as replacement for lead in solder. Silver and copper-based terminations on system that have corroded can lead to shorted electrical circuits on these circuit boards.

Particulate contaminants (dust) can hinder cooling airflow, reduce the effectiveness of heat sinks, interfere with moving parts, cause abrasion and promote corrosion within ITE among other things. Particulate and gaseous contaminants are the most common threats to IAQ.

The following are the best practices for ensuring satisfactory IAQ within the data center

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critical environment, based on ASHRAE resources such as ASHRAE TC9.9 white papers:

- Recirculated air within the data center should be filtered using a minimum of MERV 8 filters.
- Air introduced into the data centers by systems such as makeup air units, direct airside economization, direct evaporative cooling, etc. should be filtered using MERV 11 or MERV 13 filters.
- Gas phase filtration should be incorporated where gaseous contamination is a concern. The corrosion rates, as measured by copper and silver foil coupons within the data centers, should be within the following thresholds:
    - Copper reactivity rate of less than 300 Angstrom/month.
    - Silver reactivity rate of less than 200 Angstrom/month.

Occupants rarely think about the air they breathe — and they shouldn't have to. Maintaining good indoor air quality is imperative for occupant health and comfort as well as the longevity of ITE. If you have questions about indoor air quality, always refer to ASHRAE for the latest research and resources. That way, your space will always be the picture of health.

**Michael Streich and Saahil Tumber**

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