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UV-C for Coronavirus-Resilient Buildings

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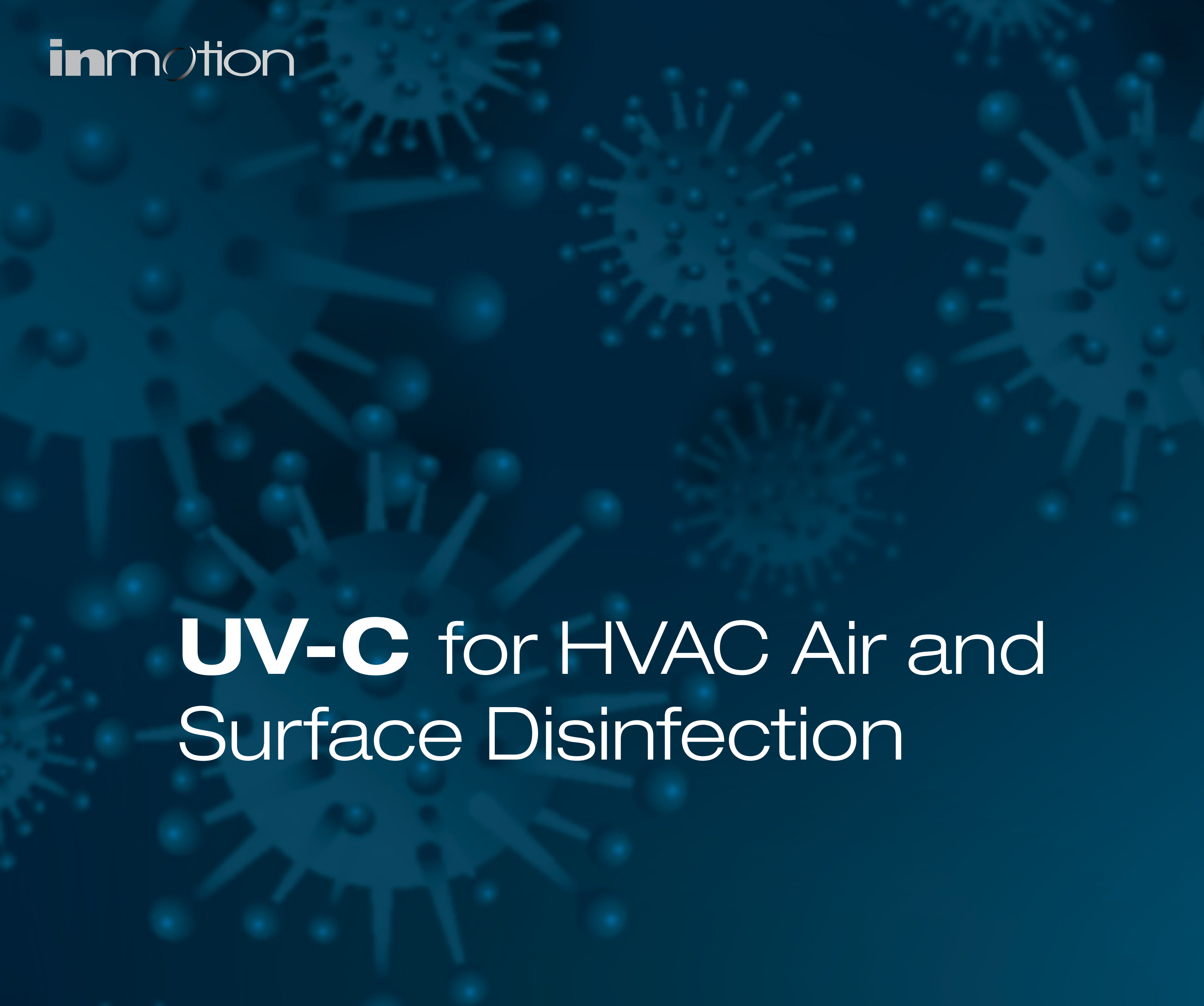

UV-C for HVAC Air and Surface Disinfection

The COVID-19 crisis is sparking interest in a long-established, yet not widely utilized, method of inactivating dangerous microbes.

By **DANIEL JONES** and **MICHAEL IVANOVICH**

For nearly a century, short-wave ultraviolet (UV) C (UV-C) energy—similar to sun rays—has been used to destroy airborne and surface-bound microbes, including chickenpox, measles, mumps, tuberculosis (TB), and cold viruses. Yet, despite decades of research and thousands of applications in hospital emergency and operating rooms, urgent-care centers, universities, and first-responder locations, UV-C has not been widely leveraged. The coronavirus disease 2019 (COVID-19) pandemic, however, is highlighting UV-C's potential as an effective air and surface disinfectant.

This article will provide engineer-level guidance for the use of UV-C light to continuously reduce and even prevent the growth of dangerous microbes in HVAC systems and the circulation of infectious pathogens in air streams.

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Germicidal UV-C Basics

UV light is a band of electromagnetic radiation classified into four wavelength ranges: vacuum UV (100 to 200 nm), UV-C (200 to 280 nm), UV-B (280 to 315 nm), and UV-A (315 to 400 nm). Wavelengths from 100 nm to 280 nm are germicidal. At 253.7 nm (commonly referred to as "UV-C"), the UV wavelength changes the structure of DNA and RNA, the genetic code of all life forms, inhibiting the ability of cells to reproduce. While bacteria and viruses absorb UV-C energy at different rates, no microorganism tested to date has proven resistant when subjected to an appropriate dose.[1]

Although UV-C energy has proven effective in inactivating other coronaviruses, such as the 2003 severe acute respiratory syndrome (SARS) and the 2012 Middle East respiratory syndrome (MERS), scientists have limited information about UV-C's impact on SARS-CoV-2, the virus that causes COVID-19. Early indications from ongoing studies at Columbia University and elsewhere, however, indicate that, "UV is very efficient for killing this virus."[2,3,4]

In May 2020, the Centers for Disease Control and Prevention (CDC) recommended to businesses preparing to reopen following the pandemic the use of germicidal UV to reduce the likelihood of disease transmission.[5]

Killing/Inactivating Airborne Pathogens

During the 1940s, many hospitals began utilizing UV-C energy for the control of airborne infectious diseases. With the arrival and proliferation of antibiotics, use of germicidal UV began to wane. During the 1990s, drug-resistant "superbugs" and hospital-acquired infections renewed interest in UV-C, which can kill virtually any microorganism, including antibiotic-resistant germs.

UV lamps installed inside of an air-handling unit.
Photograph courtesy of UV Resources

ASHRAE has recognized that the UV-C wavelength inactivates virtually all microorganisms living on HVACR surfaces, with kill ratios of up to 99 percent, depending on the intensity of the UV-C and the length of exposure.[6]

UV-C dose is determined by the amount of germicidal energy a pathogen absorbs over a specific period of time. In other words, UV-C dose is a function of time multiplied by intensity. Consider, for example, a surface-disinfection application involving cooling coils. The disinfection target (the coil surface) is stationary, so exposure, or "residence," time is continuous. As a result, the intensity of the UV-C energy striking the surface can be relatively low. In the case of a moving air stream, however, exposure time is limited—a mere fraction of a second, in some cases—so UV-C intensity must be much greater.

It is important to note that microbe inactivation is a nonlinear function of UV-C exposure. In other words, "If a certain UV exposure kills 90 percent of a bacterial population (frequently referred to as 'one-log kill'), doubling the exposure time or intensity can kill only 90 percent of the residual 10 percent, for an overall germicidal efficacy of 99 percent ('two-log kill')."[7]

In addition to reducing HVAC-surface and airborne bacteria, germicidal UV can be used to supplement and improve other infection-control strategies, such as room air exchange. When a required number of air changes per hour (ACH) cannot be achieved using outside-air ventilation alone, upper-room UV systems can perform germicidal "equivalent" ACH. "It has been estimated that when an average UV intensity of 10 μW/cm^2 is present in the upper room, 63 percent of airborne tuberculosis germs that arrive there will be killed in 24 sec (the germicidal equivalent of one room air change), and, therefore, 99 percent will be killed in 2 min (equivalent of five air changes)."[8] This is important, as pathogenic aerosols can be spread through HVAC systems.[9] In fact, in July 2020, more than 200 scientists petitioned the World Health Organization to acknowledge that SARS-CoV-2 can be transmitted through air as an aerosol.[10]

ACH equivalents increase with germicidal intensity (Figure 1).

UV-C can supplement protocols for disinfection, sterilization, and manual cleaning, providing a level of protection in the event a protocol fails. Facility managers are encouraged to implement a layered approach incorporating multiple infection-control measures to ensure that any pathogen that cannot be removed by one method (e.g., filtration, cleaning) is inactivated by another (UV-C).[1]

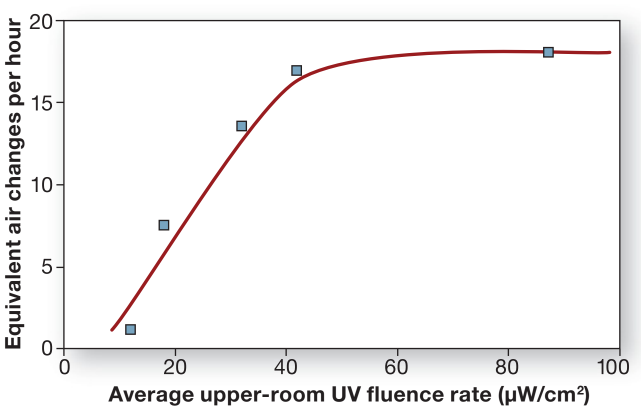

FIGURE 1. UV-C-induced inactivation of* Mycobacterium parafortuitum *in a test room under well-mixed conditions at 50-percent relative humidity.[11]

Applying UV-C Energy

There are three primary means of applying UV-C energy to protect HVAC surfaces and air streams against infectious agents: upper-room/air systems, HVAC air-stream disinfection, and HVAC coil/surface irradiation (Table 1).

Upper-room/air systems. One of the oldest applications of germicidal UV for space infection control, upper-room/air systems work by effectively intercepting pathogens and viruses at their source in room air. These fixtures are efficient against droplet nuclei from coughing, sneezing, or talking, as well as pathogens circulated by drafts, pressure differentials, or the movement of people.

Airborne droplets containing infectious agents can remain in room air for 6 min or longer. Operating 24/7/365, upper-room/air germicidal fixtures can inactivate these microbes in a matter of seconds.

Upper-room/air UV-C fixtures utilize the natural rise and fall of convection or mechanical air currents to circulate airborne infectious agents into the upper room, where they are exposed to UV-C radiation and killed. Studies have shown that one hour of use of an upper-room/air UV-C fixture can be equivalent to 10 to 16 air changes.[11]

Wall-mounted at a height above 7 ft, these fixtures use non-reflective baffles to direct UV-C energy upward and outward, ensuring that stray emissions do not enter the occupied portion of the room. First-pass kill or inactivation ratios of up to 99 percent have been modeled, with concentrations further reduced with each subsequent pass of recirculated air ("multiple dosing"). The goal, relative to coverage, is to maintain a UV-C irradiance level of at least 50 μW/cm^2 in the upper room.

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While upper-room/air UV-C "is very effective in areas with no, or minimal, ventilation,"[12] in spaces with no or weak air circulation, ceiling fans can compensate for the lack of sufficient mechanical air movement and improve inactivation rates (see sidebar, "Improving Upper-Room UV With Ceiling Fans," on Page 11).

HVAC air-stream disinfection. In HVAC air-stream disinfection, UV-C fixtures installed in air-handling-unit (AHU) plenums, air-distribution systems, or HVAC duct-work inactivate microorganisms "on the fly." Simplified, the germicidal dose is determined by the UV-C intensity, exposure time, and target pathogen's susceptibility to UV-C.

In addition to the amount of germicidal energy absorbed by a pathogen over a specific amount of time, a variety of other factors are taken into consideration when UV-C is applied for HVAC air-stream disinfection. These site-specific considerations will be explored in the next section.

HVAC coil/surface irradiation. The most common type of germicidal-UV system, HVAC coil/surface irradiation continuously targets bacteria, viruses, mold, and biofilm that proliferate on coils, air filters, duct walls, and drain pans, preventing them from becoming reservoirs for pathogen growth.

A coil/surface-irradiation system can eliminate up to 30 percent of airborne pathogens on a first-pass basis, with concentrations reduced further with each subsequent pass.

Germicidal Engineering Control	Recommended Application
Upper-room/air systems	• Goal: greater than 50 μW/cm^2 • Wall-mounted • Installation height: above 7 ft in occupied spaces
HVAC air-stream disinfection	• Lamps spaced every 14 in. of coil height • Duct-run length: greater than 24 in. • Air velocity: less than 500 fpm • Minimum exposure time: greater than 0.24 sec • Upstream of coil
HVAC coil/surface irradiation	• Downstream of coil • Lamps spaced every 30 to 40 in. of coil height

TABLE 1. Germicidal-UV application.

For coils, ASHRAE recommends irradiance levels of 50 μW/cm^2 to 100 μW/cm^2.[12] Perhaps a better way to achieve a desired dosage is to convert 100 μW/cm^2 to the more easily understood and specifiable 7.5 lamp watts (as printed on the lamp surface) per square foot of coil surface area.[13] By making this conversion, frontline engineers easily can verify that submittals conform to their specifications.

Environmental Factors

There are many operational and site-specific conditions that impact inactivation or kill rate, including:

- The target pathogen and its susceptibility to UV-C. The amounts of UV-C energy needed to inactivate individual bacteria, viruses, and spores have been identified through decades of research.[14]
- The volume and velocity of air traveling through the HVAC system, which will impact the length of residence time. A higher volume of air and/or faster-moving air requires greater intensity (more UV-C lamps) and/or a longer run of duct to increase residence time. Said differently, as velocity increases beyond the typical 500 fpm, UV intensity must increase with it. Conversely, less UV intensity is required for air velocities below 500 fpm.
- The length of the plenum/duct—the longer the plenum or duct run, the better, as residence time and, thus, dose are increased.
- Fixture spacing—decreasing lamp-row spacing (e.g., from the surface-irradiation standard 36-in. centerlines to 15-in. to 18-in. centerlines) increases UV-C fluence.
- Temperature—because cold air reduces the output of UV-C lamps and high relative humidity affects pathogen susceptibility to UV-C, air-stream-disinfection measures can be more effective on the upstream side of a coil. Although on-the-fly disinfection can be accomplished downstream of coils, it typically requires an increase in UV-C intensity (more lamps).
- The lamps—using more or higher-output lamps will increase the total dose—that is, the microwatt-seconds per square centimeter (μW-s/cm^2). Lamps with 360-degree irradiation allow more UV-C energy to saturate a plenum, increasing UV-C fluence.

Duct/Plenum Surface	UV-C Multiplier
Stainless steel	1.40
Galvanized steel	1.50
Aluminum	1.75
Use of reflective materials can increase germicidal-UV disinfection dosage/fluence.	

TABLE 2. Reflectivity of different metals.

Some UV-C lamps are encapsulated with an anti-shatter fluorinated-ethylene-propylene (FEP) coating or outer sleeve that helps to insulate the lamp surface from changes in temperature and/or air volume. This protection can be beneficial when the temperature is low and/or the air-stream velocity is high, but it also can reduce UV output by up to 10 to 12 percent.

- The reflectivity of the plenum—reflective metals boost UV-C dose, as the germicidal wavelength "bounces" throughout the plenum and remains "in play" instead of being absorbed by the surfaces. Different metals have different reflectance multipliers that can significantly increase UV-C fluence levels (Table 2).

Pathogen Susceptibility

Although environmental factors influence UV-C dosing, it is best to consider all aspects of an application in a predictive-modeling formula when designing an air- or surface-disinfection strategy.

In Figure 2, we can calculate the amount of time a pathogen is exposed to UV energy to determine the total exposure time.

Bacteria and viruses vary in susceptibility to UV energy, with environmental organisms, fungal spores, and mycobacteria being relatively harder to kill than more rapidly replicating and non-environmental microbes and most bacteria. But even fungi are killed effectively with high-dose UV.[7] For example, studies have demonstrated that viruses are more susceptible to UV-C inactivation than typical bacteria are (Figure 3).[15]

Lamp Placement

When designing a germicidal-UV disinfection system, engineers should consider the impact AHU location has on performance. Because cold air affects the output of UV-C lamps and high relative humidity affects pathogen susceptibility to UV-C, air-stream disinfection can be more effective when lamps are installed upstream of a coil. In fact, moving UV-C lamps from the typical downstream

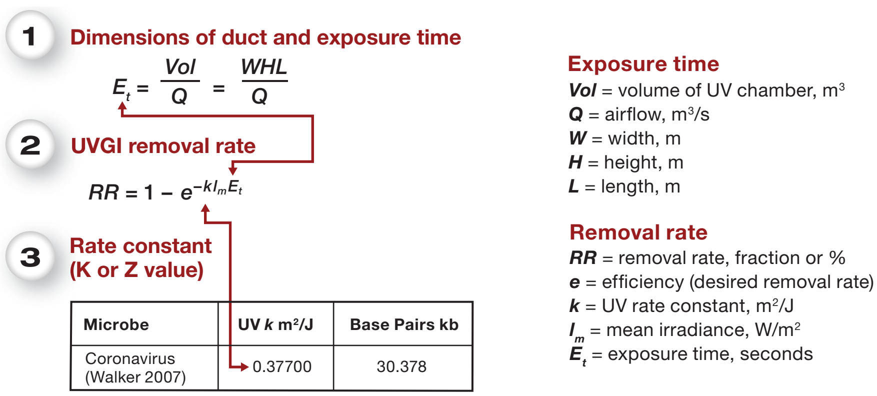

FIGURE 2. Air-stream disinfection.[15]

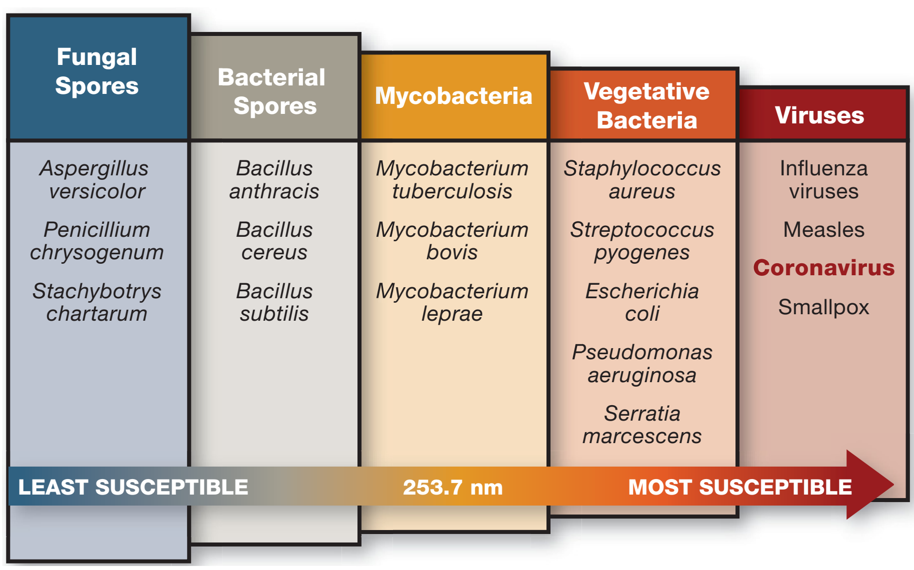

FIGURE 3. Microorganisms susceptible to germicidal UV-C.[12]

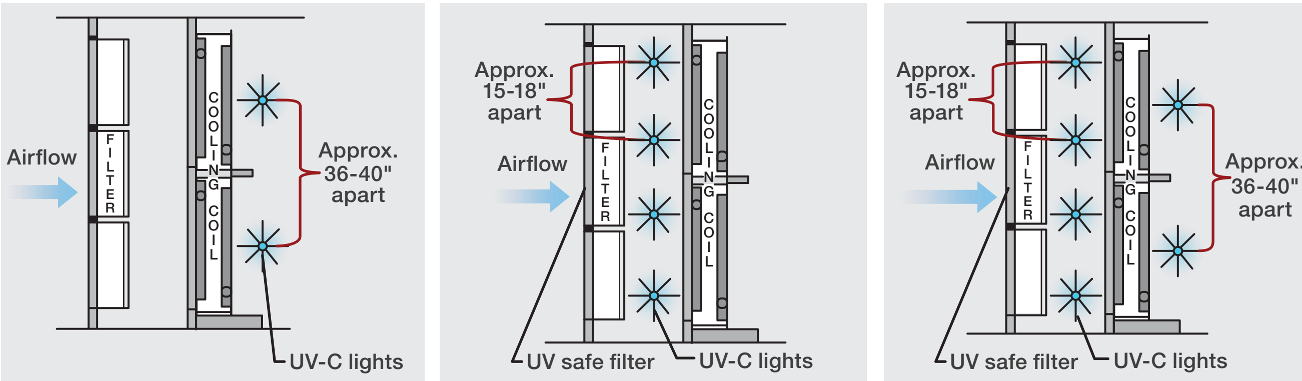

FIGURE 4. Options for UV-fixture placement in an air handler. Left: downstream of a coil for coil/surface cleaning, with fixtures spaced on 36- to 40-in. centerlines. Middle: upstream of a coil for air-stream disinfection (treatment also can be installed downstream). Right: dual application, with more tightly spaced UV-C lamps upstream of a coil for air-stream disinfection and less UV-C intensity downstream of the coil for coil/surface cleaning.

temperature of 55°F to the typical upstream temperature of 70°F can increase lamp output by up to 40 percent (figures 4 and 5).

Cooler temperatures downstream of a coil can be overcome with the use of FEP-coated lamps and/or more lamps.

Conclusion

Facility professionals can utilize germicidal-UV technologies to greatly reduce concentrations of pathogens in a highly reliable and cost-effective fashion.

The UV-C wavelength can kill 99 percent or more of all microorganisms living on HVAC air ducts and evaporator coils, depending on UV-C intensity, length of exposure, UV-lamp placement, and lamp life cycle.[12] Operating 24/7/365, upper-room/air germicidal fixtures can inactivate microbes in under a second.

Germicidal UV has been extensively researched and is recognized in two *ASHRAE Handbook* volumes, *HVAC Applications*[12] and *Fundamentals*[16]; two ASHRAE test standards, ANSI/ASHRAE Standard 185.1, *Method of*

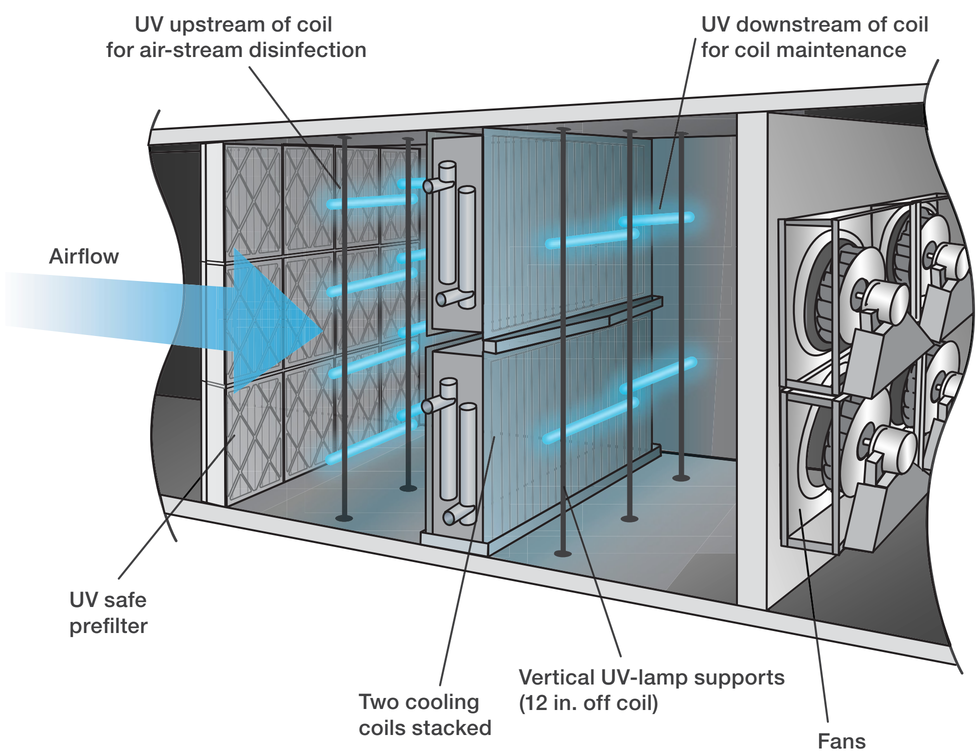

FIGURE 5. UV-C fixtures installed both upstream and downstream of a cooling coil provide both air-stream disinfection and coil cleaning.

Testing UVC Lights for Use in Air Handling Units or Air Ducts to Inactivate Airborne Microorganisms, and ANSI/ASHRAE Standard 185.2, *Method of Testing Ultraviolet Lamps for Use in HVAC&R Units or Air Ducts to Inactivate Microorganisms on Irradiated Surfaces*; and three ASHRAE position documents, Filtration and Air Cleaning,[6] Airborne Infectious Diseases,[17] and Infectious Aerosols.[18]

What's more, germicidal UV has been recognized in CDC guidance for office buildings,[5] health-care facilities,[19,20] and dental settings.[21]

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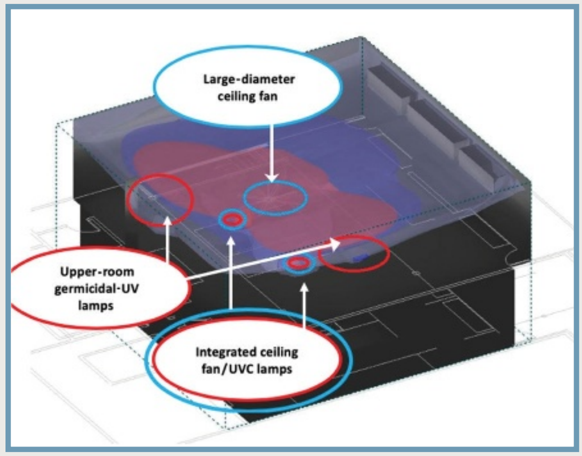
Improving Upper-Room UV With Ceiling Fans

By **DAVID ROSE**

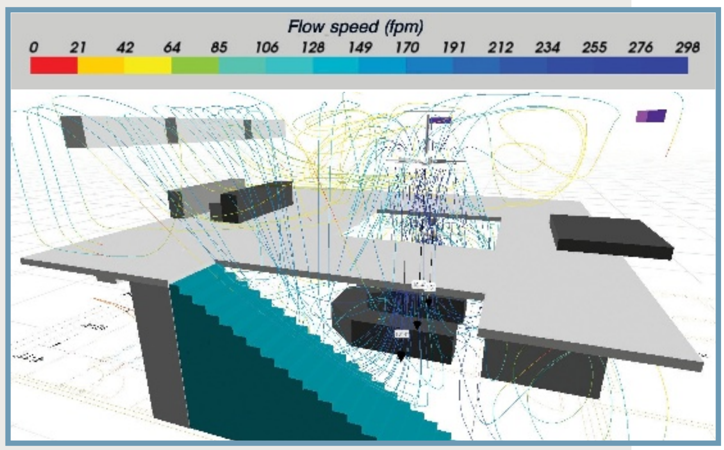
Studies show that, in spaces with limited air mixing, natural convection generated by heat gains from occupants and equipment at the floor level can reduce the effectiveness of upper-room/air UV systems. In such instances, the use of ceiling fans for air mixing has been shown to increase UV effectiveness by more than 60 percent.[1]

This is especially true in the case of facilities with high ceilings, where even HVAC systems with high airflow rates can struggle with air mixing and distribution. This issue is particularly problematic during the heating season, when the rate of illness among occupant populations tends to be the highest.

With ceiling fans, the volume of air that is actively cleaned in the disinfection zone is more frequently circulated back to the occupant level and replaced in the disinfection zone with air that has a higher concentration of contaminants. With continual mixing of the disinfection-zone and occupant-breathing-zone air volumes, the effectiveness of the upper-room/air system is improved, increasing the effective air-change rate. This effect reduces the concentration of contaminants in the space without the need for a three- to six-time increase in outdoor-air-change rate. Once the space air is well-mixed, additional air turnovers are not likely to increase system effectiveness.[2]



Lighting simulation showing upper-room-UV fluence rates (red = 10 uW/cm², dark blue = 5 uW/cm², light blue = 1 uW/cm²).



Computational-fluid-dynamics image tracing exposure of particles to upper-room UV-C lamps (purple rectangles in the upper right and center of the image) with the use of large- and small-diameter ceiling fans. Small-diameter ceiling fans integrated with UV-C lamps are not visible. The height of the large-diameter fan is 18 ft 4 in.; the heights of the small-diameter fans are 10 ft 4 in. and 9 ft 3 in.

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Mitigating System Effect to Optimize Fan Performance and Efficiency

MIKHAIL GRACHIKOV/Bigstock

Often resulting from changes to ductwork design made during installation, system effect increases energy consumption and costs as well as stress on system components.

BY **MIKE HUMANN**

Fans used to move air in industrial and commercial applications are tested and rated in a laboratory under ideal conditions—that is, conditions designed to enable the equipment to achieve its maximum performance. As anyone who has set foot on a building site can attest, however, the conditions under which fans are put into service seldom are—and often are far from—ideal. The difference between how a fan performs installed in the field and how it performed when tested in a laboratory can be attributed to a phenomenon known as system effect.

This article will describe system effect, its causes, and its impact on fan performance. Additionally, it will discuss strategies for minimizing, eliminating, or avoiding system effect to achieve optimal, reliable performance once a fan is installed.

System Effect and Its Impacts

System effect refers to losses in air-system performance caused by adverse flow conditions (excess turbulence or swirl) at or near the fan. System effect can occur at a fan's inlet or outlet or both. Often, it results from changes to system design—commonly involving the length, width, and/or transition points of ductwork—made during the fan-installation process.

The only way to overcome system effect and achieve specified airflow volume is to increase fan speed. Increasing fan speed, however, results in increased energy consumption (just a 10-percent increase in fan speed will result in a 33-percent increase in energy consumption) and costs and greater stress on system components. Additionally, it may prevent the motor, electrical conduit, starter, and disconnect from achieving the necessary brake horsepower.

Figure 1 shows the impact system effect has on system performance.

In addition to hindering fan performance, system effect can increase noise and vibration and lead to premature impeller or bearing failure. The

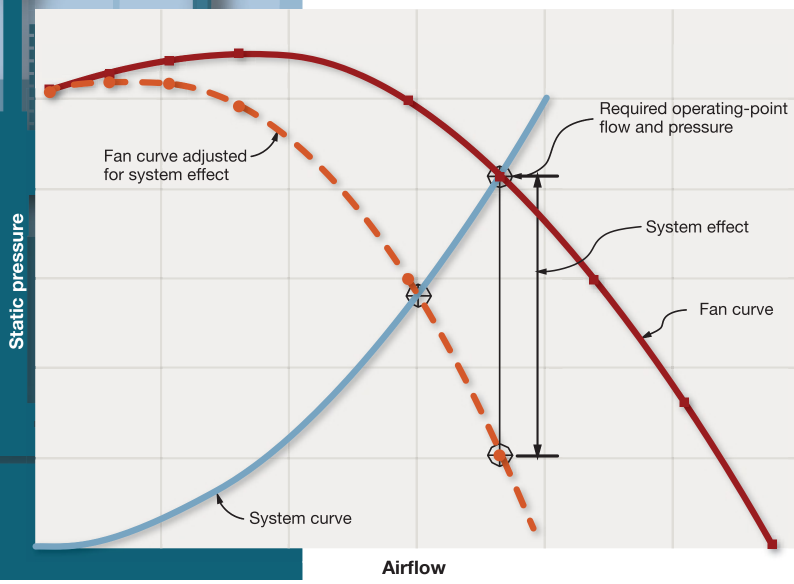

FIGURE 1. Impact of system effect on system performance.
Source: AMCA "System Effect" online educational module

associated performance testing, engineering analysis, field service, long-term maintenance, and lost production from unplanned downtime and extended startup can be costly.

With any installation, system effect and all other system-associated losses must be considered to understand how a fan will perform relative to its laboratory tests once installed. During the fan-selection process, the combined impact of those losses should be taken into account. For optimal system performance and cost-effective operation for years to come, best practices for fan ducting and installation need to be followed.

Laboratory vs. Real-World Conditions

To recognize how system effect impacts air-system performance, it is important to understand the conditions under which fans are tested in a laboratory. Housed fans typically are tested with an open inlet that includes a bell mouth to eliminate entry losses and achieve uniform airflow across the inlet. The discharge includes a straight run of ductwork that produces fully developed airflow (free of swirl or turbulence) prior to the air entering the test chamber. Uniform, fully developed airflow enables a fan to move air efficiently and quietly through a duct system without causing excessive vibration. In the field, however, inlet and outlet conditions rarely mimic those of laboratory-test setups, as the installation and ducting are influenced by the existing infrastructure and space limitations.

Common Causes of System Effect

The most common causes of system effect include uneven or spinning airflow at a fan's inlet, obstructions to airflow at the inlet or outlet, improperly configured ductwork at the inlet or outlet, and/or failure to correct for losses caused by fan accessories.

System effect can be avoided by accounting for all factors, including the shape of the transition points between the fan and existing ducts, ductwork configuration close to the fan, and accessories. For optimum air performance, airflow at the fan's inlet needs to be uniform, symmetrical, and free of swirl. Similarly, airflow must be able to diffuse and fully develop across the fan's outlet. Even minor improvements to airflow stability can reduce system effect and, in turn, increase fan performance and operating efficiency.

An inlet vane damper is a modulating device that affects fan performance. As a damper is closed, air begins to pre-spin into the fan; the fan wheel no longer can move as much air, and flow, pressure, and brake horsepower all decrease. Even when a damper is fully open, the vanes interfere with normal flow and reduce fan performance. If the losses are not accounted for, the fan will have to run at a speed higher than the one specified during fan selection. Fans should be tested with accessories that determine the losses and the fan speed required to overcome them.

Reducing System Effect at a Fan's Inlet

A lack of uniform airflow entering a fan's inlet is one of the greatest and most common causes of system effect. Often, these losses are the result of elbows and isolation dampers being installed too close to a fan's inlet.

Depending on the application, a variety of strategies can be employed to improve airflow at a fan's inlet. Take, for example, the 90-degree round elbow located

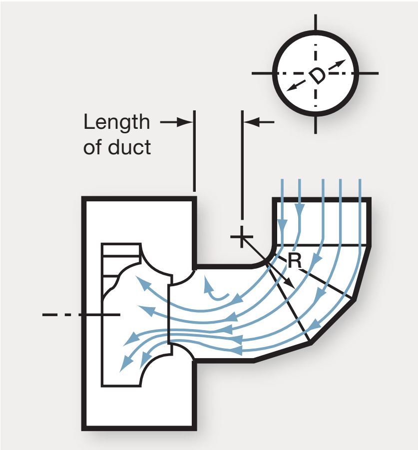

FIGURE 2. Non-uniform airflow into a fan inlet induced by a 90-degree, three-piece section elbow—no turning vanes.

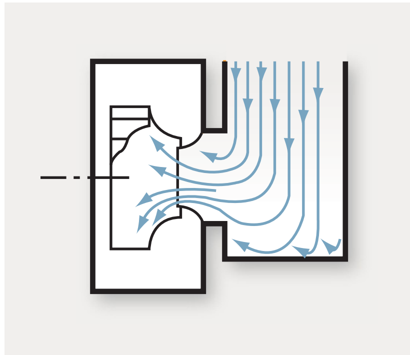

FIGURE 3. Non-uniform airflow into a fan inlet induced by a rectangular inlet duct.

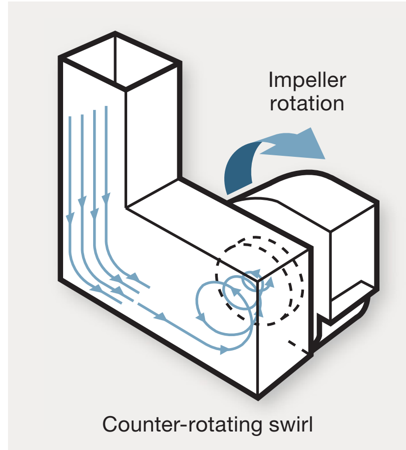

FIGURE 4. Example of a forced inlet vortex.

Source (figures 2-4): *AMCA Publication 201-02 (R2011),* Fans and Systems

at the inlet of a fan shown in Figure 2. Air entering the fan wheel is not uniform, loading on various parts of the fan wheel instead of at the center as designed for optimal performance. Some air is circulating back into the elbow, creating additional losses. In this case, the addition of turning vanes in the elbow will help direct air toward the center of the fan wheel.

Figure 3 shows the effect of a rectangular inlet box mounted directly to the inlet of a fan. Again, the fan wheel is not being uniformly loaded, resulting in performance loss. With an inlet box, the cavity, or dead area, below the outlet is where air will get hung up, creating additional losses. Improving the shape of the inlet box or adding straightening vanes can help to redirect the flow of air into the wheel.

Figure 4 shows air entering a fan from the side as opposed to straight through the inlet. The air is spinning in the opposite direction of the fan wheel. Consequently, the fan is having to work harder, resulting in greater energy consumption and stress on fan components.

Reducing System Effect at a Fan's Outlet

Similar to inlet flow, outlet flow is impacted significantly by the placement and distancing of ductwork and dampers. The effective length of ductwork at a fan's outlet is one of the most important factors in fan and system efficiency. In most cases, the profile of the air coming out of a fan is asymmetrical, causing turbulence and a lack of static-pressure regain.

For symmetrical and uniform flow to be achieved, outlet ducting must be long enough to allow airflow to diffuse and fully develop. This is called 100-percent effective duct length. As a rule of thumb, the effective length of outlet ducting should be no less than 2.5 duct diameters when duct velocity is 2,500 fpm (13 m/s) or less. For every additional 1,000 fpm (5 m/s), one duct diameter should be added.

Figure 5 shows the velocity profile of air as it exits a fan. Air is forced against the outside of the scroll, resulting in uneven flow at the outlet. An effective run

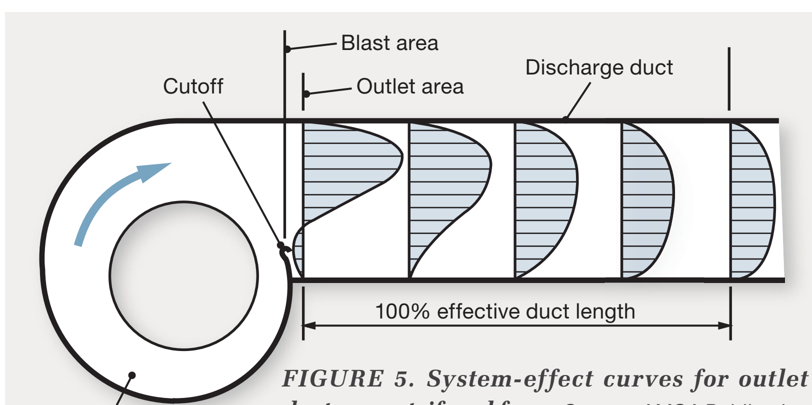

FIGURE 5. System-effect curves for outlet ducts—centrifugal fans. Source: *AMCA Publication 201-02 (R2011),* Fans and Systems

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of ductwork allows for a uniform velocity profile. Note that at approximately 50 percent of effective duct length the fan achieves approximately 80 percent of its pressure regain.

In addition to effective duct length, the placement and direction of elbows is significant at a fan's outlet. An elbow installed too close to the outlet will result in a significant loss of airflow. If the elbow turns in the opposite direction of the fan's rotation, the loss will be even greater. When a design requires the installation of an elbow, a minimum of two to three duct lengths is recommended to allow the velocity profile of air exiting the fan to develop across the ductwork.

Conclusion

By and large, most fan-performance deficiencies are the result of improper system design. This is because fans are simple, standard mechanical devices, while systems are complex and unique, with many installation variables that can adversely impact performance.

When designing a fan system for optimal operation, remember to allow enough room for needed accessories and appropriate ducting connecting the fan to the larger system. The long-term cost savings will be worth the extra effort upfront. Additionally, because fan installations are so customized, it is important to partner with a knowledgeable and experienced vendor to ensure optimum system performance, efficiency, and longevity.

About the Author

Mike Humann *is manager of products and applications for The New York Blower Co. During his 10-year career, he has presented at conferences and conducted training sessions on topics including system effect, fan applications, and custom fan modifications. He has a bachelor's degree with a concentration in physics from Elmhurst University.*

System Effect in Effect

After a neighbor complained about the noise generated by this backward-inclined fan, which exhausted fumes from a tank at a rate of 50,000 cu ft (3,750 lb) per minute, the owner sought to redirect the noise by reversing the flow of air so that the air came back toward the fan. It was a self-defeating proposition: The air turbulence caused by the 180-degree turn at the outlet and the speed at which the fan had to run to overcome the system effect actually increased the noise.

A fan and collector purchased at a salvage auction. The owner used a 50-gal. drum as part of the duct system between the fan and collector. In addition to a base that is unstable, there is no length of ductwork at the fan outlet to establish uniform airflow.

This process fan exhausting to atmosphere has to overcome system effect resulting from the use of a cutoff sheet in conjunction with a rectangular duct and a 90-degree-elbow turn without any run of ductwork.

Instead of a rectangular-to-round transition from the fan inlet, a transition plate is being used in this application, resulting in the bottom-loading of air on the fan wheel.

Pressure blowers used in a combustion-air system. The 90-degree elbows are turning air in the opposite direction it exits the fans. The system effect could have been avoided with upblast fans.

Field Modifications of **Fire, Smoke, and Combination Fire/ Smoke Dampers**


Nabrus/Bigstock

From the simple extension of a damper sleeve to the replacement of a damper actuator, common changes that may be needed for a factory-supplied life-safety damper to be installed properly.

BY **JAMES CARLIN**

In a perfect world, every construction project would run smoothly, with no oversights, delays, or other issues arising from unforeseen circumstances. This would include the installation of life-safety dampers, which, in the somewhat-less-than-perfect world we all inhabit, sometimes require modification in the field to be installed properly. This article will discuss field modifications typically covered in Underwriters Laboratories- (UL-) approved installation instructions and options available when modifications fall outside of those instructions.

The modifications covered in this article apply mainly to fire-, smoke-, and combination fire/smoke-rated dampers. Further, they apply to new construction, specifically buildings not yet commissioned.

Installation Instructions

Fire and combination fire/smoke dampers are required to prevent the spread of fire and/or smoke through HVAC ductwork penetrating fire-rated barriers (Figure 1). The construction of these barriers is outlined in UL's Fire Resistance Directory.[2] Damper manufacturers' installation instructions work in conjunction with the designs in the directory to

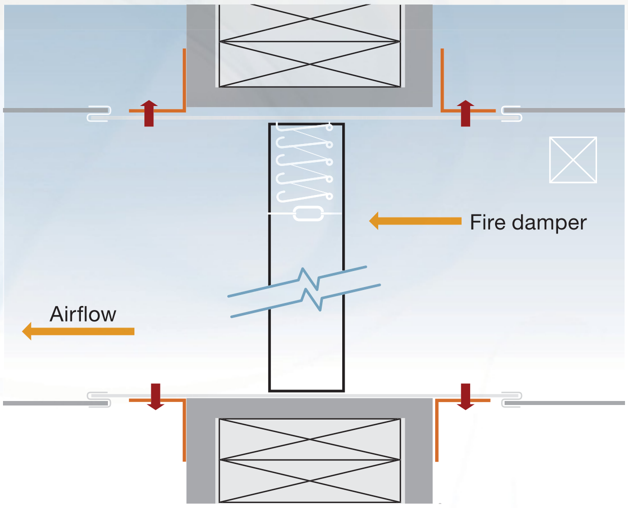


FIGURE 1. Common fire-damper installation.
Recreated from "Dampers Marking and Application Guide"[1]

ensure proper protection. This is of particular importance for dampers installed in wood- or metal-stud barriers, as UL-approved installation instructions show the proper framing needed to construct openings.

For proper installation, manufacturer-supplied instructions and any applicable documents from the Fire Resistance Directory should be referenced. During commissioning, the local authority having jurisdiction (AHJ) will look to the Fire Resistance Directory, architectural and engineering drawings, and installation instructions for guidance when evaluating a life-safety-damper installation. The AHJ will have the final say in all matters regarding the installation of life-safety dampers, whether modifications were made per UL-approved installation instructions or the modifications fall outside of those instructions.

The majority of life-safety dampers are UL-certified. Per UL's "Dampers Marking and Application Guide" (Page 11):

Each damper shipment is supplied with a copy of the installation instructions appropriate for the specific damper model. These instructions are an integral part of the UL certification on the dampers. The instructions contain the information necessary to properly install the damper as well as limitations on the installation of the product such as the type of floor or wall construction that is required for the correct installation.

Some manufacturers elect to provide basic instructions that cover only common installations, and then rely on supplemental instruction pages that cover unique installation scenarios. As with the basic installation instructions, the supplemental instructions are also an integral part of the UL certification program.

Installation instructions for UL-certified dampers are reviewed and approved by UL and typically will bear the UL logo. These installation instructions include field modifications covered by the UL certification, including changes to damper components such as sleeves, mounting angles, and duct connections. Damper manufacturers also have installation instructions covering field modifications outside of UL certification. These installation instructions typically do not bear the UL logo. Installation instructions vary from manufacturer to manufacturer and, thus, should be reviewed in their entirety.

Sleeves

UL requires all life-safety dampers to be mounted in a sleeve, which can be integral to, or attached to, a damper's frame. Sleeves most commonly are factory-supplied, but also can be installed in the field. Field-supplied sleeves need to be installed per UL-approved installation instructions.

PHOTO A. Smoke damper installed with actuator below the ceiling line. The sleeve was extended and the damper was relocated to clear the ceiling line.

Following are common modifications to factory-supplied sleeves that may be needed for a life-safety damper to be installed successfully:

- Extending a sleeve (Photo A) to accommodate a thicker-than-anticipated barrier or other job-site obstruction. Many damper manufacturers have UL-approved instructions outlining the materials to be used and any applicable fasteners needed for the modification.

- Shortening or trimming a sleeve to accommodate UL-approved duct connections. This type of modification commonly is outlined in manufacturer installation instructions allowing sleeves to be shortened or trimmed as long as electrical or mechanical components are not damaged.
- Cutting a hole in a sleeve to route an electrical or pneumatic power connection to an internally mounted actuator, position-indication switch, or other device. Such a penetration should be as small as possible and made per local electrical or mechanical code.

Each of these modifications has the potential to introduce a point of duct leakage, so additional sealing may be needed. All permitted sealants will be listed in UL-approved installation instructions.

As with any installation, it is advised to cycle a damper after a modification is completed to make sure the damper will operate properly.

Mounting/Retaining Angles

The annular space between a damper and a barrier opening (Photo B) allows the damper to expand and work properly during high heat exposure. Typically, damper installation instructions require mounting angles on all four sides of a sleeve to cover the annular space and do not allow any materials to be installed in the annular space. When one side of a damper is too close to a ceiling, wall, or floor, the manufacturer may provide options for removing the mounting angles from that side of the damper. Where mounting angles have been removed, a firestop material or an intumescent caulk can be used to protect the through opening in a fire-rated barrier. Approved firestop materials and correct installation will be outlined in UL-approved installation instructions.

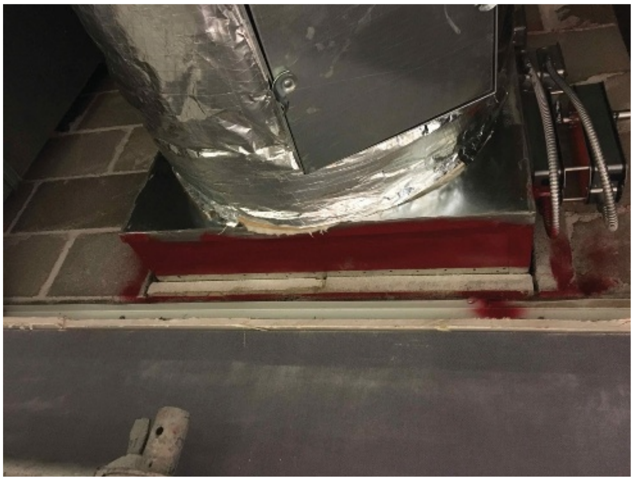


PHOTO B. Annular space between a damper and a barrier opening.

Sealants

Questions concerning gaps between mounting angles and rated barriers and how to seal them sometimes arise. The sealants approved for these applications will be listed in UL-approved installation instructions.

It is common for sealants approved for sleeve modifications also to be approved for sealing gaps between mounting angles and barriers. Note: These sealants typically are not allowed in the annular space between damper sleeves and openings; they are allowed where mounting angles touch a barrier.

Actuators

UL requires all actuators supplied on life-safety dampers to be factory-installed and cycle-tested prior to shipment. “Dampers Marking and Application Guide” (Page 12) states the following with regard to field modifications of actuators:

Smoke dampers and combination fire-smoke dampers are equipped with factory installed electric or pneumatic actuators which remotely control the dampers. The airflow and pressure ratings marked on the dampers are dependent upon the particular combination of damper type, actuator type and linkages between the damper blades and actuator. As such, field mounting or substitution of actuators is not covered within the scope of the UL certification of the product. However, this does not necessarily preclude replacement of actuators in the field. Like any appliance, field servicing of these products is not covered under the scope of the UL certification program. As with any part of the damper, it is expected that replacement of actuators in the field be done in accordance with the damper manufacturer’s normal field servicing program.

Prior to building commissioning, actuator replacement may be needed to accommodate a change in actuator voltage or to swap out an actuator without indication switches for one with indication switches. Often, replacements can be made without a change in actuator model and with little change in overall actuator configuration. More substantial modifications may be required if a different actuator model is needed or if an actuator has to be changed from mounted on the damper sleeve to mounted within the damper sleeve. Such modifications may require additional hardware to complete, so it is best to contact the manufacturer for guidance. Any actuator modifications should be done in accordance with manufacturer instructions and guidelines and, once completed, followed by damper cycling.

Because they are not covered under the UL certification program, actuator modifications may need to be reviewed and approved by the local AHJ.

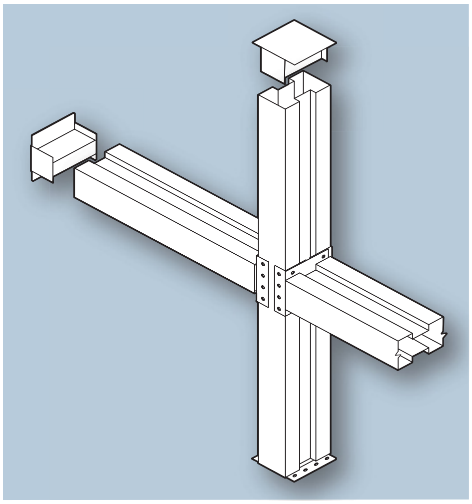


FIGURE 2. Detail B steel mullion for dividing oversized wall openings.

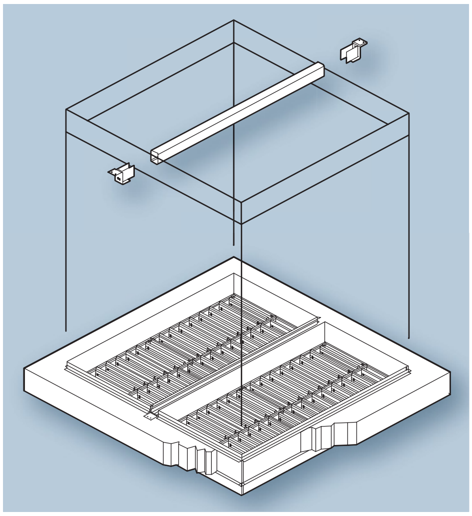


FIGURE 3. Horizontal mullion for dividing oversized opening in concrete floor.

Mullions

All life-safety dampers are certified to a maximum overall size. There are times, however, when an opening exceeds that size. This can be the case when an opening is larger than the furnace used in the testing and certification of a damper. In vertical wall applications, steel mullions can be used to divide an opening into sections. "Dampers Marking and Application Guide" outlines the use of mullions (Page 12):

In certain circumstances, steel mullions can be used to divide a large wall or vertical partition opening into smaller individual openings, allowing fire dampers for use in static systems to be sized and installed within the limitations of the certification. These mullions are generally fabricated in the field. Damper manufacturers can provide installation details covering the fabrication, installation and use of mullions.

Because airflow ratings of fire dampers for use in dynamic systems and combination fire-smoke dampers are size dependent, the use of the mullions discussed herein are only intended for application with fire dampers for use in static systems. Further, the mullions are limited to use in vertical partitions.

Fabrication and sizing of vertical steel mullions (Figure 2) are covered in UL-approved installation instructions. The mullions are approved for use with concrete-block, masonry, brick, or poured-concrete walls only. Additionally, they are approved for use with dampers with a fire-resistance rating of 1½ hr, which can be installed in barriers rated for less than 3 hr.[3]

As the above excerpt states, UL recognizes the use of vertical mullions only in static systems, or systems that cut off airflow in the event of a fire. For dampers installed in dynamic systems, options allowing the use of mullions may be available. One possible option for dynamic systems involves splitting ductwork to make sure mullions do not experience the dynamic forces of the system when dampers close. The use of vertical mullions in dynamic systems requires approval from the local AHJ, who may need additional information from the architect and engineer of record.

"Dampers Marking and Application Guide" does not address the use of mullions in horizontal floor applications. The installation instructions of some manufacturers (Figure 3) do, however, and these instructions typically are UL-approved. Horizontal support mullions for dividing oversized floor openings—typically, concrete floors only—may vary from manufacturer to manufacturer, so it is important to review installation instructions for proper application, construction, and installation, as well as the mullions' maximum fire-resistance rating. In some cases, mullions can be used with dampers having a fire-resistance rating of up to 3 hr. This allows the mullions and dampers to be installed in floors with a fire-resistance rating of more than 3 hr, as 3-hr-rated dampers can be used to protect openings in barriers rated for 3 or more hours.[3]

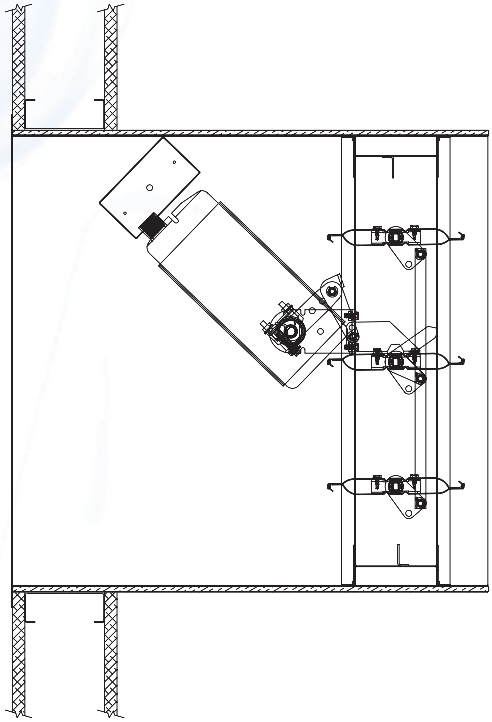


FIGURE 4. Combination fire/smoke damper installed outside of a rated barrier.

Damper Blades

For a fire- or a combination fire/smoke-rated damper to protect an opening in a fire-rated barrier, the blades of the damper must close within the barrier. Many manufacturers, however, have options for factory-supplied dampers with blades that close outside of a barrier. These dampers, which undergo additional testing, typically require an insulated blanket around the damper sleeve.

If a traditional damper needs to be installed outside of a fire-rated barrier (Figure 4), manufacturers have installation instructions detailing the materials needed to modify the damper. This type of modification falls outside of the UL certification service and typically requires approval from the local AHJ.

Summary

This article only begins to address the different types of modifications that may be needed for life-safety dampers to be installed successfully. With building conditions varying from site to site and the obstacles faced by installers often unforeseen, addressing all possible modifications is impossible.

Installation instructions vary by manufacturer. Thus, it is imperative that all supplied installation instructions be reviewed prior to, and followed during, the installation process. Another best practice is to cycle a damper after any modification is made to ensure the damper will function properly.

When conditions requiring modifications falling outside of manufacturer-supplied installation instructions arise, it always is a good idea to contact the manufacturer to determine the best path forward. In addition to providing guidance for the installer, the manufacturer can help the local AHJ understand the modifications that were performed and how those modifications apply to the damper's installation, certification, and overall function.

References

1) UL. (2016). *Dampers marking and application guide*. Retrieved from https://bit.ly/Dampers_Marking

2) UL. (2011). *Fire resistance, directory C*. Northbrook, IL: Underwriters Laboratories.

3) ICC. (2017). *2018 international building code*. Washington, DC: International Code Council.

About the Author

***James Carlin** is product manager, dampers, for Pottorff, a position he has held since 2015. The eight years prior to that, he was a design engineer developing UL-rated and air-control dampers for the company. A graduate of Stevens Institute of Technology with a bachelor's degree in mechanical engineering, he chairs the AMCA Fire and Smoke Damper Subcommittee.*

Straightening Out **Fan Curves**

Despite their complex appearance, fan curves are fairly easy to interpret once one gains an understanding of the conventions and terminology used, enabling selection and specification of the best fan for an application.

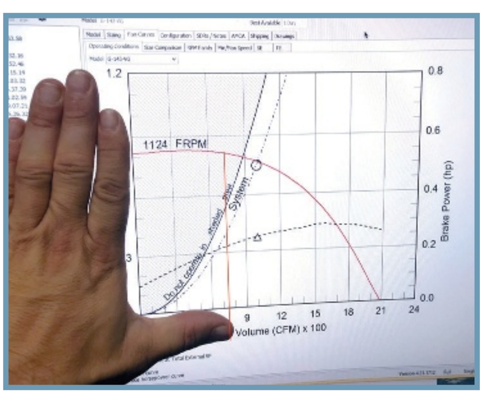
INGA RA/Bigstock

BY **WILLIAM "BILL" HOWARTH**

During the mid-1990s, Ron Michael, regional manager, Loren Cook Co., was conducting a lunch-and-learn at a large engineering firm on the East Coast. As talk turned to fan selection and use of Cook's software program, Ron was interrupted by the head of the firm's mechanical department.

"Show us how to read a fan curve," the head of the mechanical department requested.

Being new to the field, Ron assumed every engineer—especially ones at such a large firm—knew how to read a fan curve, the graphical representation of a fan's performance, specifically the relationship between the amount of airflow and the amount of static pressure produced.



The so-called Rule of Thumb Method.

"My first thought was he actually wants to see if *I* know how to read a fan curve," Ron recently recalled, "so I began my presentation in detail, knowing I could not screw this up."

A few minutes into Ron's explanation, the head of the mechanical department interrupted again.

"We don't have that much time, based on our busy schedules," the head of the mechanical department said, "so we use the Rule of Thumb Method."

"Rule of Thumb Method?" Ron asked.

The Rule of Thumb Method, the head of the mechanical department explained, involves placing the palm of one's left hand on a fan-curve graph so that the index finger is aligned with the left vertical (y-) axis, along which static pressure is plotted, and the thumb is aligned with the horizontal (x-) axis, along which air-volume flow rate is plotted (more on this later). Where a vertical line extending upward from the tip of the thumb intersects the flow-vs.-pressure curve is the fan's operating point (again, more on this later) (see photo).

"I didn't quite know what to say but quickly determined that not many people in the room actually knew how to read a fan curve," Ron reminisced.

Those people were hardly

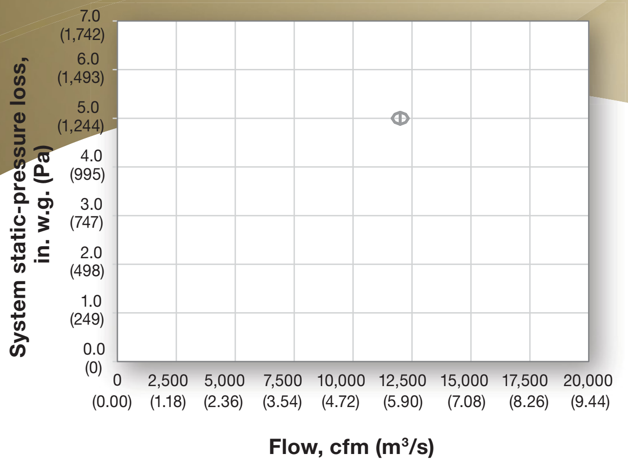


FIGURE 1. Duty point of 12,000 cfm (5.66 m^3/s) at 5.0-in.-w.g. (1,244 Pa) system pressure loss.

alone and would not be lacking company today. While, at first glance, a fan curve can appear complicated, it is fairly easy to interpret once one gains an understanding of the conventions and terminology used. Reading a fan curve (correctly) is a skill worth possessing, as it allows those who select and specify fans to understand the performance characteristics and capabilities of different equipment so they may determine the fan that best suits the requirements of an application. For them, this article will help to straighten out fan curves.

While there is no standard method for graphically representing fan-performance data, this article will cover what one is most likely to see.

Airflow and Pressure Loss

In the design of a ventilation system, the desired airflow rate and system pressure loss (static pressure or total pressure) often are referred to as the duty point. A fan curve depicts duty point.

As stated earlier, on a fan-curve graph, airflow—typically expressed in cubic feet per minute (cfm), cubic meters per second (m^3/s),[1] cubic meters per hour (m^3/h), or liters per second (l/s)—is represented along the x-axis, while system pressure loss—typically expressed in inches of water gauge (in. w.g., or in. H_2O), Pascals (Pa),[1] or millimeters of water gauge (mm H_2O)—is represented along the left y-axis.

In the succeeding examples, the desired airflow and system pressure loss are 12,000 cfm (5.66 m^3/s) and 5.0 in. w.g. (1,244 Pa), respectively (Figure 1).

Fan Selection

Whether via the Internet on their website or as a program to be installed on a user's computer, many fan manufacturers offer software capable of quickly identifying a number of possible fan solutions for a given duty point. Typically, possible fan selections are displayed in a table showing model type, size, flow, pressure, speed, required power, efficiency, outlet velocity, and other relevant data.

Table 1 shows output from one program for our duty point of 12,000 cfm (5.66 m^3/s) at 5.0-in.-w.g. (1,244 Pa)

Type	Size	Dia.	Flow, cfm	P_s, in. w.g.	P_t, in. w.g.	P_v, in. w.g.	RPM	Power, bhp	S. Eff., %
GI Cent.	200AF	20.00	12,000	5.0	6.7	1.7	3,414	21.6	43%
GI Cent.	240AF	24.50	12,000	5.0	5.7	0.8	2,110	14.1	67%
GI Cent.	270AF	27.50	12,000	5.0	5.5	0.5	1,621	12.1	78%
GI Cent.	300AF	30.00	12,000	5.0	5.3	0.3	1,366	11.7	81%
GI Cent.	330AF	33.00	12,000	5.0	5.2	0.2	1,204	12.0	79%
GI Cent.	360AF	36.50	12,000	5.0	5.2	0.2	1,067	12.6	75%
GI Cent.	400AF	40.25	12,000	5.0	5.1	0.1	961	13.6	69%

Type	Size	Dia.	Flow, m^3/s	P_s, Pa	P_t, Pa	P_v, Pa	RPM	Power, kW	S. Eff., %
GI Cent.	200AF	20.00	5.66	1,238	1,657	419.5	3,414	16.1	43%
GI Cent.	240AF	24.50	5.66	1,243	1,431	187.4	2,110	10.5	67%
GI Cent.	270AF	27.50	5.66	1,244	1,371	127.0	1,621	9.0	78%
GI Cent.	300AF	30.00	5.66	1,244	1,330	86.2	1,366	8.7	81%
GI Cent.	330AF	33.00	5.66	1,244	1,303	58.7	1,204	9.0	79%
GI Cent.	360AF	36.50	5.66	1,244	1,283	39.2	1,067	9.4	75%
GI Cent.	400AF	40.25	5.66	1,244	1,271	26.5	961	10.2	69%

TABLE 1. Typical fan-selection table.

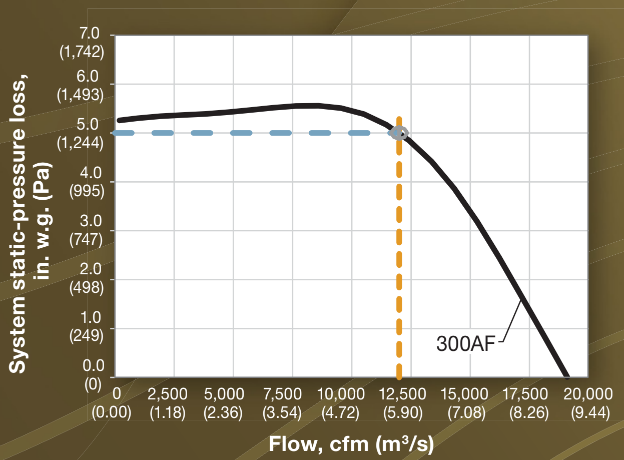


FIGURE 2. Flow-vs.-pressure curve.

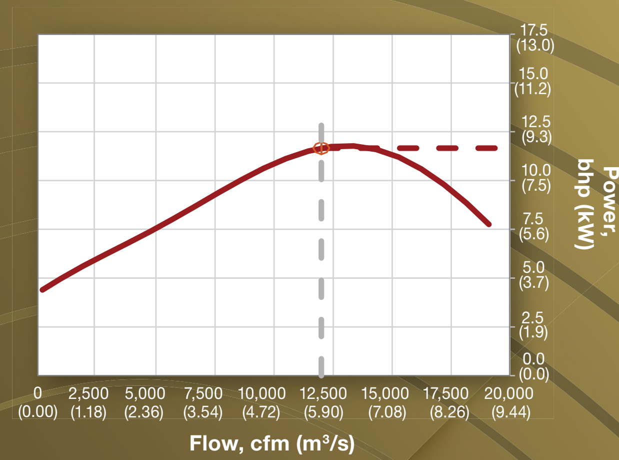


FIGURE 3. Flow-vs.-power curve.

static pressure. The seven selections are for one model type, GI Cent., and one wheel type, AF. A manufacturer's selection program may yield many more options.

All of the selections in Table 1 are capable of achieving the duty point in our example.

Fan Performance Curve

The first point on our graph is the duty point: 12,000 cfm (5.66 m^3/s) at 5.0-in.-w.g. (1,244 Pa) static pressure. Adding data showing fan flow and pressure at points other than the duty point produces the first curve, shown in black in Figure 2.

To read the curve, draw or imagine a line extending vertically from the required flow on the x-axis up to and slightly through the curve (the yellow dashed line in Figure 2). From that intersection of line and curve, draw or imagine a line extending horizontally to the y-axis to determine the pressure produced by the fan (the blue dashed line in Figure 2). This should be the required pressure. In Figure 2, the fan flow curve intersects the duty point at the desired flow and pressure, as required.

Typically, the power required by the fan also is displayed. A power curve can be shown on the left or the right axis and should be read at the required flow. In Figure 3, draw or imagine a line extending from 12,000 cfm (5.66 m^3/s) on the x-axis straight up to the red power curve. From there, read horizontally to the right to determine the power required by the fan. In this case, the required power is 11.7 bhp (8.7 kW).

Generally, the power required by a fan increases as flow through the fan increases. With many airfoil and backward-curved or backward-inclined fans, however, power reaches a peak value and then decreases as flow increases.[2] This type of power curve is known as "non-overloading." If the driving motor power is greater than the peak power on the curve with allowances for temperature and drives, etc., the fan should not overload in operation.

The power curves of many axial propeller fans and ventilators will show power decreasing as flow increases to the point of free delivery.[2]

Though flow-vs.-power curves can be shown on a separate graph, typically they are superimposed with flow-vs.-pressure curves on the same graph, with pressure along the left axis and power along the right (Figure 4).

Figure 4 includes additional information necessary on a fan-curve graph: fan model, fan size or diameter (both included here), revolutions per minute (RPM), air density, and outlet area.[2] Outlet velocity may be provided in lieu of outlet area.

In the case of most industrial exhausters, pressure and combustion blowers, and forward-curved fans, the

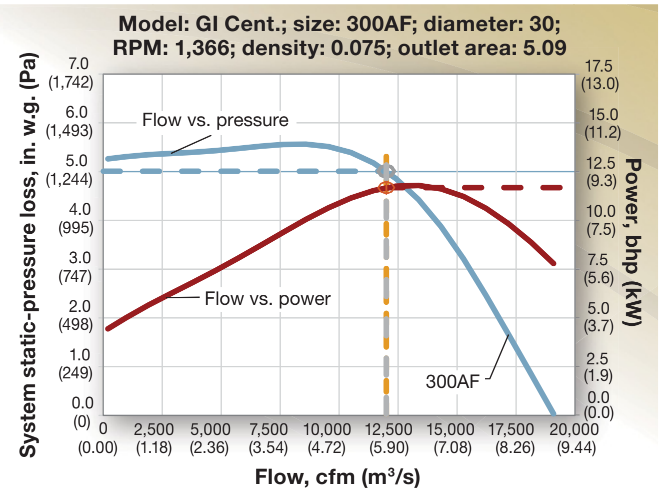
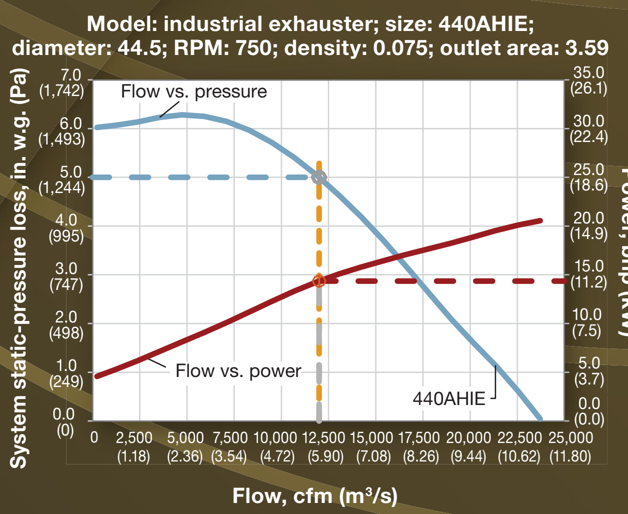


FIGURE 4. Superimposed flow-vs.-pressure and flow-vs.-power curves.



Performance certified for installation Type D: ducted inlet/ducted outlet. Power ratings (bhp) do not include transmission losses. Performance ratings do not include the effects of appurtenances (accessories).

FIGURE 5. Industrial exhauster with increasing power.

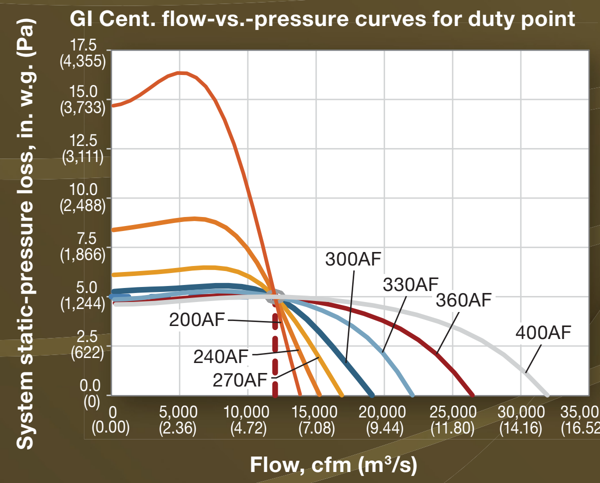


FIGURE 6. Flow-vs.-pressure curves.

power curve increases as flow increases to the point of free delivery.[2] Figure 5 is the fan-curve graph for an industrial exhauster selected for our example duty point. This selection is much less efficient at 14.4 bhp (10.7 kW). The peak power on the power curve is about 20.5 bhp (15.3 kW). The graph includes additional notes regarding how the fan was tested and the performance and power losses that are included. In this case, the test was ducted inlet and ducted outlet. The fan installation should be similar to the test setup to avoid system effects. The power ratings do not include drive losses; V-belt-drive losses will have to be added to the power requirement for the motor.

A quick review of the fan curves of the seven fan selections in our example narrows the field of acceptable options. In Figure 6, the flow-vs.-pressure curve of each selection is superimposed on a single graph. Generally, a fan will exhibit some degree of flow and pressure instability to the left of peak pressure. A fan's operating point should be to the right of peak pressure. Using 95 percent of peak pressure as a guide for selection in this case eliminates the 400AF and 360AF selections. Most manufacturers' software will identify, or not select, fans to the left of or near peak pressure.

Smaller fans operating at lower efficiencies can be found operating closer to free delivery, farther to the right than other selections, on the fan curve. In this case, the 240AF selection is operating to the right, while the 200AF selection is operating far to the right.

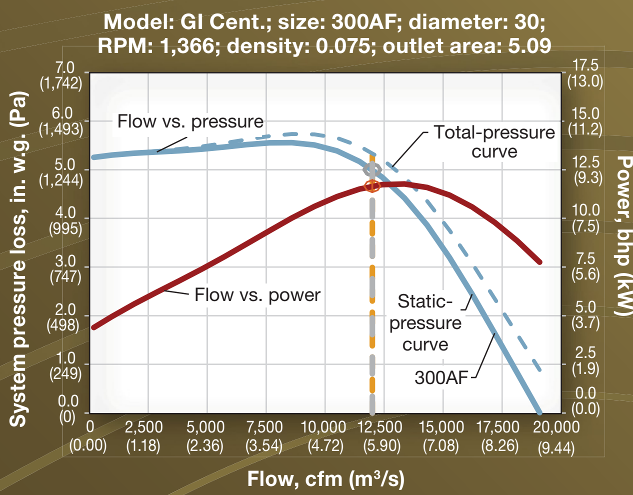
Static- and Total-Pressure Curves

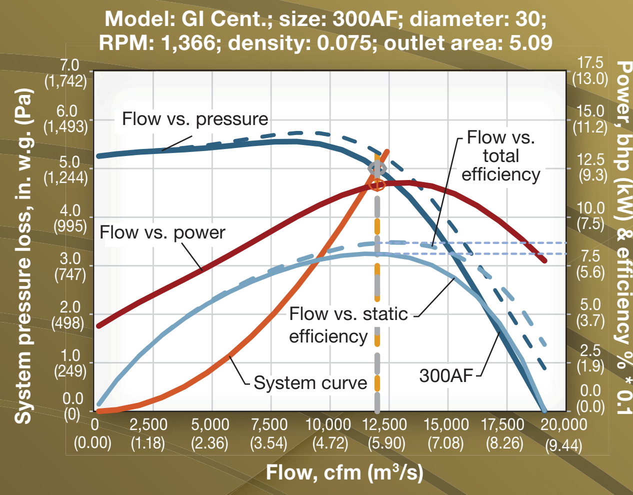
Corresponding to average air velocity at a specified fan outlet, fan velocity pressure is added to the fan static pressure at each flow point to develop the fan-flow-vs.-total-pressure curve.[3] Fan total pressure is equal to the sum of fan static pressure and fan velocity pressure. In Figure 7, the total-pressure curve is shown by the dashed blue line. In this example, the outlet velocity for the 300AF fan is 2,359 fpm (12 m/s), the velocity pressure is 0.35 in. w.g. (86 Pa), and the total pressure is 5.35 in. w.g. (1,331 Pa) at the flow point of 12,000 cfm (5.66 m^3/s).

The required system velocity may be determined based on the approximate duct size for the flow. Lower velocities require larger ducts, which, of course, take up more space. Higher velocities require smaller ducts, which often produce more noise. Other factors, such as cost, space, and conveying velocity, are important considerations when determining velocities.[3]

Fan Efficiency

Flow-vs.-static-efficiency or flow-vs.-total-efficiency curves also are included on many performance graphs. Scaling the display of efficiency-curve values to match the displayed power- or pressure-scale value can be challenging. In Figure 8, the static-efficiency curve is the light-blue line. At 12,000 cfm (5.66 m^3/s), the static-efficiency value is 81.1 (8.11, 811% × 0.1) percent (scaling





Performance certified for installation Type D: ducted inlet/ducted outlet. Power ratings (bhp) do not include transmission losses. Performance ratings do not include the effects of appurtenances (accessories).

FIGURE 7. Flow vs. static- and total-pressure curves.

FIGURE 8. Flow-vs.-static-efficiency and flow-vs.-total-efficiency curves and system curve.

factor from the right axis). The total efficiency is 86.8 percent. In this example, the fan is selected just to the left of peak efficiency.

System Curve

Figure 8 also includes an orange parabola representing system resistance at various flows, the system curve. Resistance generally varies as the square of flow ratio:[2]

$$P_2 = P_1 \cdot \left[\frac{Q_2}{Q_1}\right]^2$$

The fan will operate at the intersection of the system curve and the fan curve.[4]

Conclusion

This article covered the fan curves most commonly encountered. There are additional curves with multiple speeds, multiple blade angles, and combinations of fan-performance data. Curves with fan-energy-index (FEI) operating bubbles,[5] motor-sizing limits, inlet-turning-vane data, and other information are derived from the curves shown here. Knowing to start at the required system flow and work up to the pressure, power, efficiency, or system curve is the key to untangling fan curves.

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About the Author

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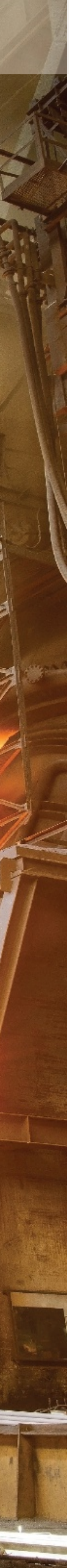
Specifying **High-Temperature Industrial Fans**

In a high-temperature manufacturing environment, failure of a fan can have a devastating effect on operations. To specify a fan for maximum service life, it is important to understand factors influencing fan design and construction.

BY **AARON SALDANHA**

Whether it is optimizing the mix and temperature of a chemical composition in a petrochemical plant, regulating process conditions in a metal furnace, or simply circulating hot air through an industrial bakery oven, fans play a critical role in many manufacturing operations. It should come as no surprise, then, that failure of these fans can have dire consequences. This is especially true with high-temperature applications, given that, when a fan fails, the system typically needs to be shut down. Once a replacement fan is installed, the system may take a few days to reach its optimum temperature, resulting in significant productivity loss.

The key to ensuring proper selection and construction of a fan for a high-temperature environment is good communication between the consulting engineer or end user and the manufacturer by way of the specification. This article will discuss important considerations that go into the selection and construction of a fan for a high-temperature environment.



There is no formal definition of high-temperature fan. Most industrial-fan manufacturers, however, consider a high-temperature fan to be a fan capable of withstanding operating air-stream temperatures 250°F (approximately 120°C) and higher. Air-stream temperature is the temperature of air/gas inside of a fan; it is different from ambient temperature, or the temperature of the air surrounding the motor, bearings, and external accessories of a fan (Figure 1). It is important to understand how these two temperatures impact the design of a fan.

High-Temperature Air Streams, Continuous Operation

A high-temperature fan can fail in a number of ways.

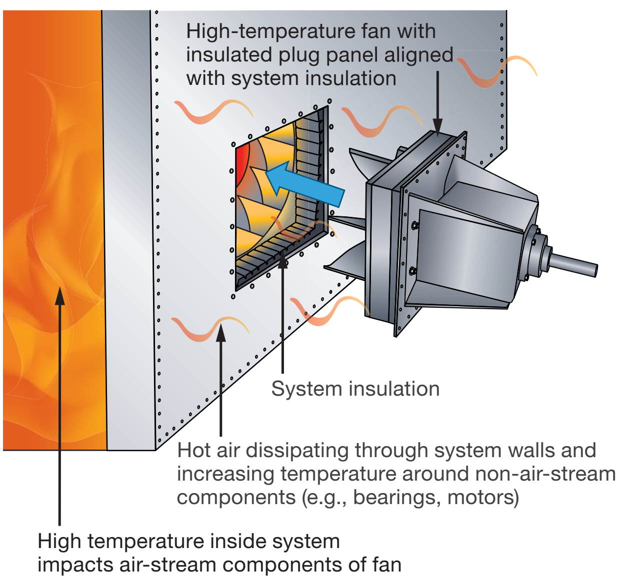


FIGURE 1. Air-stream temperature vs. ambient temperature.

Temperature/ Atmosphere	Material	Material Cost
Up to 900°F (482°C)	Carbon steel	X
900°F to 1,550°F (482°C to 843°C)	Stainless steel	3X
1,550°F to 2,000°F (843°C to 1,093°C)	Cobalt-laden alloys	141X
Corrosive and high temperature	Nickel-chromium alloys	46X

TABLE 1. Optimal material selection.

Source: Garden City Fan High Temperature Fan Engineering Quality Standard EQS-12.0

Wheel failure. Wheel failure can be evidenced by not only breakage, but distortion. One of the main contributing factors is thermal creep. Fan manufacturers account for thermal creep through proper selection of the materials of construction of air-stream components (Table 1).

For temperatures greater than 1,550°F (843°C), many manufacturers use special casting alloys to reduce welding and mitigate issues caused by thermal creep. Often, this increases both costs and lead time.

Though shrouded wheels with airfoil, backward-curved, or backward-inclined blades are the most efficient, they typically have a maximum-temperature capability of 900°F (482°C). For higher temperatures, forward-curved (Figure 2), propeller (Figure 3), or radial-blade (Figure 4)

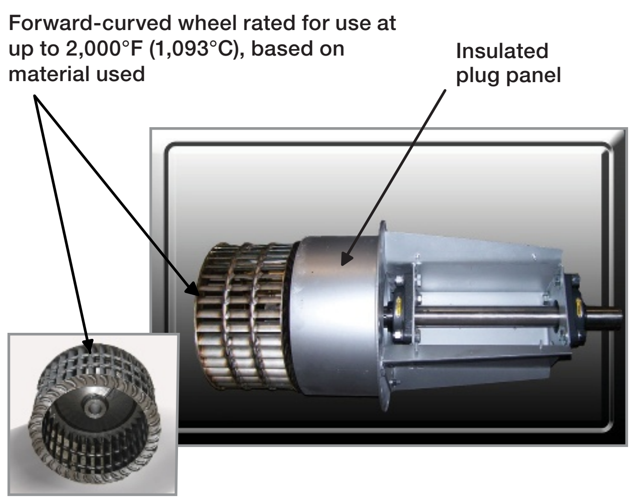


FIGURE 2. Forward-curved high-temperature fan.

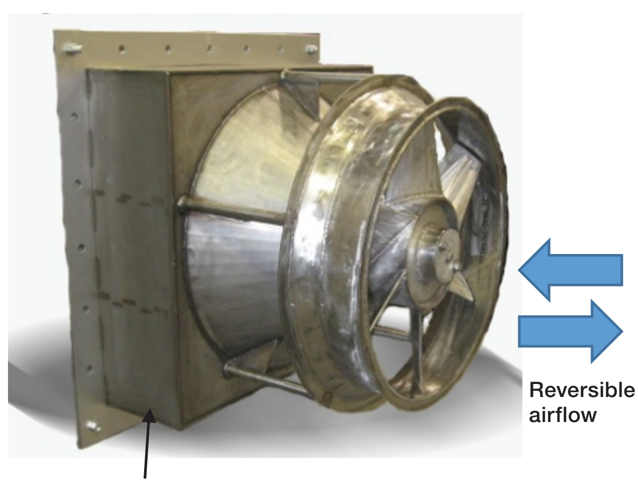


FIGURE 3. High-temperature propeller fan (2,000°F/1,093°C).

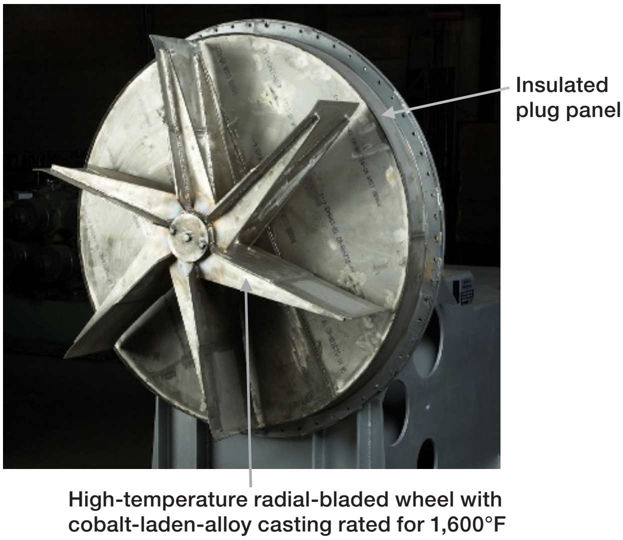


FIGURE 4. Radial-blade fan.

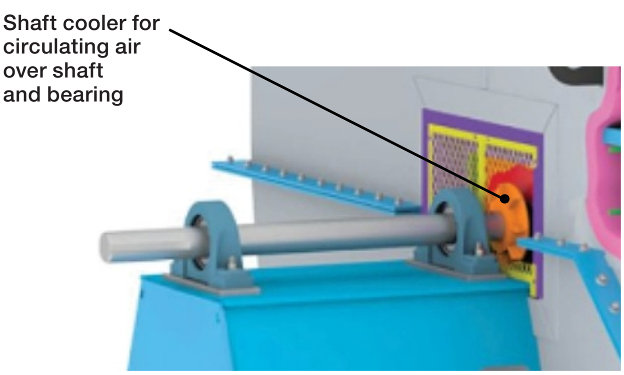


FIGURE 5. Solid shafts with heat slingers.
Image courtesy of Twin City Fan

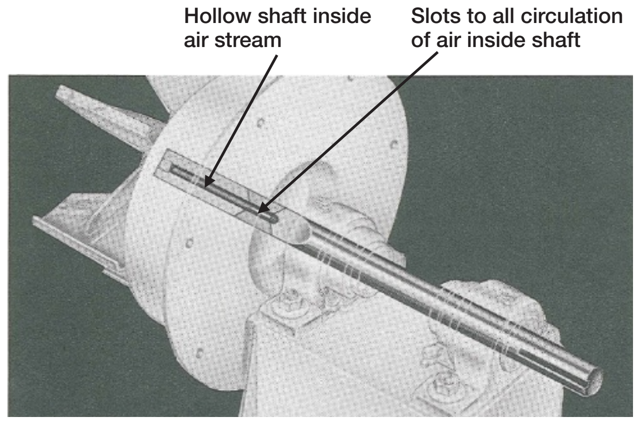


FIGURE 6. Air-cooled shafts with heat slingers.
Source: Garden City Fan High Temperature Fan Engineering Quality Standard EQS-12.0

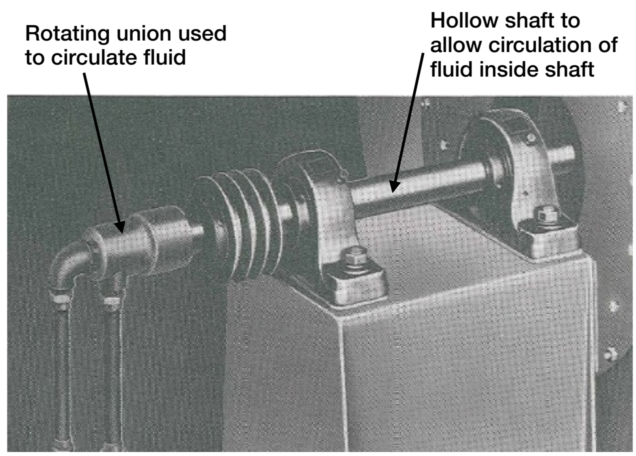


FIGURE 7. Water-cooled shafts with heat slingers.
Source: Garden City Fan High Temperature Fan Engineering Quality Standard EQS-12.0

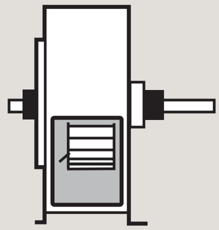
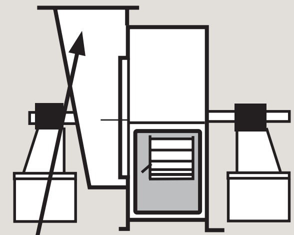
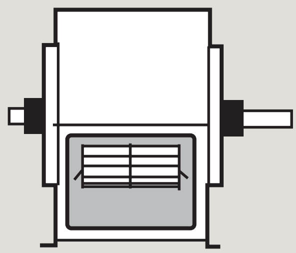
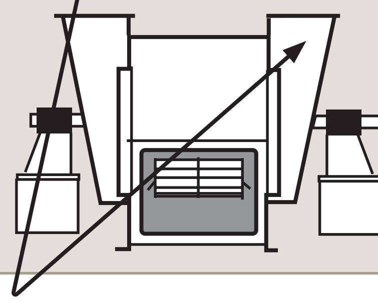
fans normally are recommended, depending on the application. As temperature increases, the maximum speed of these fans often is derated. If you plan to increase operating temperature or fan speed, it is important to check with the fan manufacturer to avoid wheel or shaft failure.

Shaft failure. As with wheels, the most common mode of failure with shafts is bending or breaking. Shaft materials of construction vary based on temperature, fan speed, fan arrangement, and load. The method by which a shaft is cooled also is important. The most commonly used types of shafts are:

- Solid shafts with heat slingers, for temperatures up to 900°F (482°C) (Figure 5).
- Air-cooled shafts with heat slingers, for temperatures from 900°F to 1,850°F (482°C to 1,010°C) (Figure 6).
- Water-cooled shafts with heat slingers, for temperatures above 1,850°F (above 1,010°C) (Figure 7).

Often, the bending of a shaft will cause bearing failure and vibration before the shaft fails completely.

Bearing failure. Depending on the load and fan speed, the selection of bearings for high-temperature fans is similar to that for traditional fans—that is, self-aligning ball bearings or spherical roller bearings. The main difference is that, in the case of most high-temperature fans, bearings with C3 internal clearance and appropriate lubrication are used. Lubrication quantity and type are dependent on bearing temperature. If bearing temperature exceeds a lubricant's rated temperature, the lubricant will lose viscosity and cause bearing failure. When replacing lubricant, check with the fan or bearing vendor.

			Typically used for clean-air applications	Typically used for corrosive, abrasive, and/or high-temperature applications
3 SWSI	3 or 11 (Arr. 3 with sub-base)	For belt or direct drive Impeller mounted on shaft between bearings supported by fan casing Alternative: bearings mounted on independent pedestals, with or without inlet box		
# DWDI	6 or 18 (Arr. 6 with sub-base)	For belt or direct drive Impeller mounted on shaft between bearings supported by fan casing Alternative: bearings mounted on independent pedestals, with or without inlet box		

Inlet box used to keep bearing outside high-temperature air stream

FIGURE 8. Fan arrangements with bearings outside the air stream. Source: *ANSI/AMCA Standard 99,* Standards Handbook

Drive arrangement. ANSI/AMCA Standard 99, *Standards Handbook*, prescribes drive configurations for different types of fans. With high-temperature fans, the bearings must be outside of the air stream. For these fans, then, Drive Arrangement 1 (two bearings mounted on a pedestal and the wheel overhung to one side), 2 (similar to Arrangement 1, except the bearing pedestal is supported by the fan housing), 8 (similar to Arrangement 1, but with a smaller "outrigger" motor or turbine base connected to the bearing pedestal), or 9 (similar to Arrangement 1, but with the motor mounted on the fan, rather than on the "floor") typically is recommended. For double-width fans or applications requiring Drive Arrangement 3 (a bearing bracket-mounted on each side of the housing or wheel), an inlet box with the bearings outside of the air stream is recommended (Figure 8). The extended shaft length needed to account for the inlet boxes often presents a design challenge, however. Drive Arrangement 4 (the wheel directly mounted on the motor's shaft and bearings) is restricted by the maximum allowable temperature at the motor shaft, which usually corresponds to an air-stream temperature of 250°F (approximately 120°C). Some manufacturers use a custom motor to achieve air-stream temperatures of 450°F (approximately 230°C) for a Drive Arrangement 4 fan. For certain high-temperature applications, such as tunnel ventilation, axial fans with the motor in the air stream are used. These are rated for use for only a short period (i.e., 1.5 to 2 hr), however. This will be covered further in the "Applications of High-Temperature Fans" section.

Housing design. Expansion of housing material needs to be accounted for in housing design. With centrifugal fans, this is particularly important in defining the axial and radial gap between wheel and inlet. With axial fans, tip gap (Figure 9) is increased to account for thermal growth attributed to elevated temperature. When these fans are run at standard temperature, their efficiency will be lower, as the higher the tip gap, the lower the efficiency.

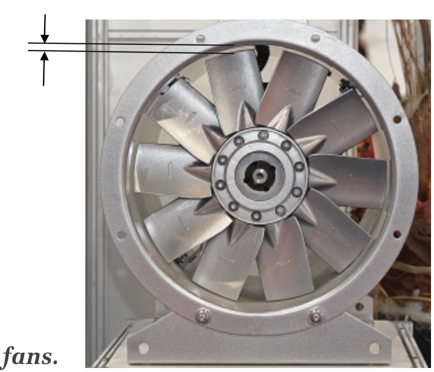


FIGURE 9. Tip gap in axial fans.

Housing insulation. Fan-housing insulation requirements come down to a few considerations:

- Surface temperature—The surface temperature of a fan is dependent on the temperature of the air stream and the amount of heat that dissipates through the surface of the fan housing.
- Location—If a fan is located near workers, insulation often will be required to prevent burns. Apart from that, heat dissipating from the fan's surface can cause a rise in ambient temperature, which might make working conditions uncomfortable. This is especially true when multiple high-temperature fans are present.
- System efficiency—Heat dissipating through the surface of a fan's housing can cause a reduction in system temperature and, thus, a reduction in system efficiency, depending on the application. Insulating the housing will reduce this impact.

There is more than one way to insulate a fan housing. The most robust, but also most expensive, is double jacketing (Figure 10). Double jacketing involves building a second housing around a fan with insulating material (ceramic fiber for temperatures greater than 1,000°F [537°C]) between the two housings. The other method of insulating a fan housing is to ask the fan vendor to provide insulation pins (Figure 11) on the housing so that an insulation jacket or insulating material can be put onto the housing at the building site. It is important to also request that the fan vendor add an extended inlet funnel, a raised access door, and an extended drain pipe, if applicable, to the design to account for the insulation that will be added at the building site.

Sealing/semi-gastight construction. Although, depending on their size and method of construction, many fans cannot be made 100-percent gastight, precautions can be taken during design to reduce the impact of hot-gas leakage. For higher temperatures, use of a mechanical shaft seal is recommended. The body and internal components of the seal must be designed to handle the air-stream temperature. In many cases, a carbon ring seal with nitrogen purge (Figure 12) is used not just to improve sealing efficiency, but to cool the seal.

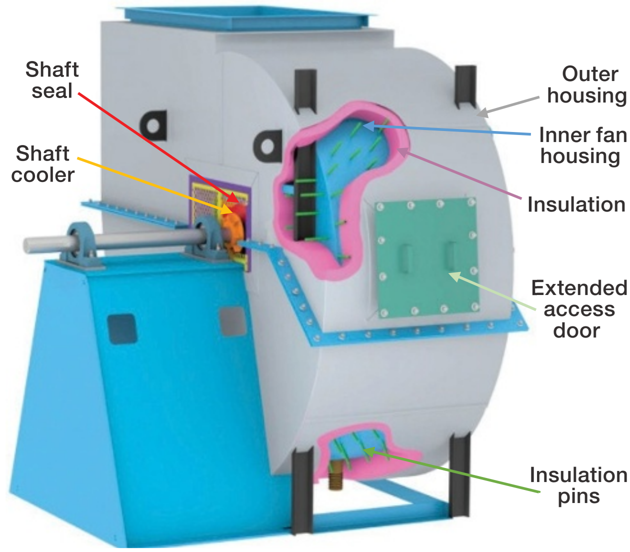


FIGURE 10. High-temperature fan with insulated housing. *Image courtesy of Twin City Fan*

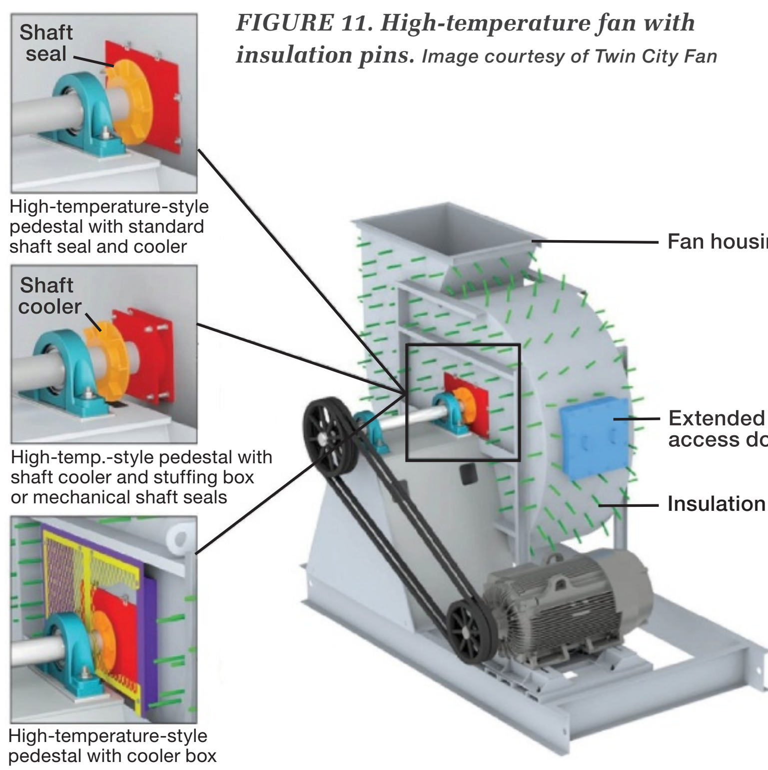


FIGURE 11. High-temperature fan with insulation pins. *Image courtesy of Twin City Fan*

NOTE: Cooler box provides uninsulated open area around shaft cooler for dissipation of heat. Standard on fans with aluminum-clad insulation and housing with insulation pins.

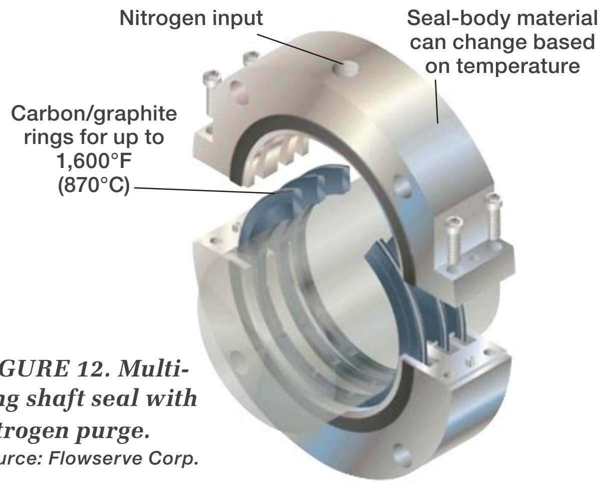


FIGURE 12. Multi-ring shaft seal with nitrogen purge.
Source: Flowserve Corp.

When using a gasket on a high-temperature fan, ensure the gasket is rated for the air-stream temperature. This is especially important when replacing gaskets during fan maintenance.

Motors and VFDs. In many cases, there is a power-saving advantage to using a variable-frequency drive (VFD) on a high-temperature fan. Consider, for example, a requirement to move 33,000 cfm (15.57 m^3/s) of air with 10.2 in. w.c. (2,538 Pa) of static pressure at an air-stream temperature of 450°F (232°C), which corresponds to an operating density of 0.044 lb/ft^3 (0.705 kg/m^3). At this operating condition and density, a 40.2-in.- (1,021 mm) diameter centrifugal fan operating at 1,770 RPM would absorb 67 hp (50 kW) of power and require a 75-hp (55 kW) motor if used with a VFD. The fan would start at approximately 30 Hz when the system is at ambient temperature (70°F/20°C) and slowly speed up as the system temperature increased. At the rated operating temperature, the fan speed would be the rated speed of 1,770 RPM (Figure 13). If a VFD were not used, the power needed to start the fan when the system is at ambient temperature would be 114 hp (85 kW), and a 125-hp (93 kW) motor would be required. Apart from the motor cost, the owner would need to invest in panels/cables rated for 125 hp, as opposed to 75 hp. In many cases, this would be more expensive than a VFD. That being the case, it always is beneficial to do a cost-benefit analysis when investing in a high-temperature fan.

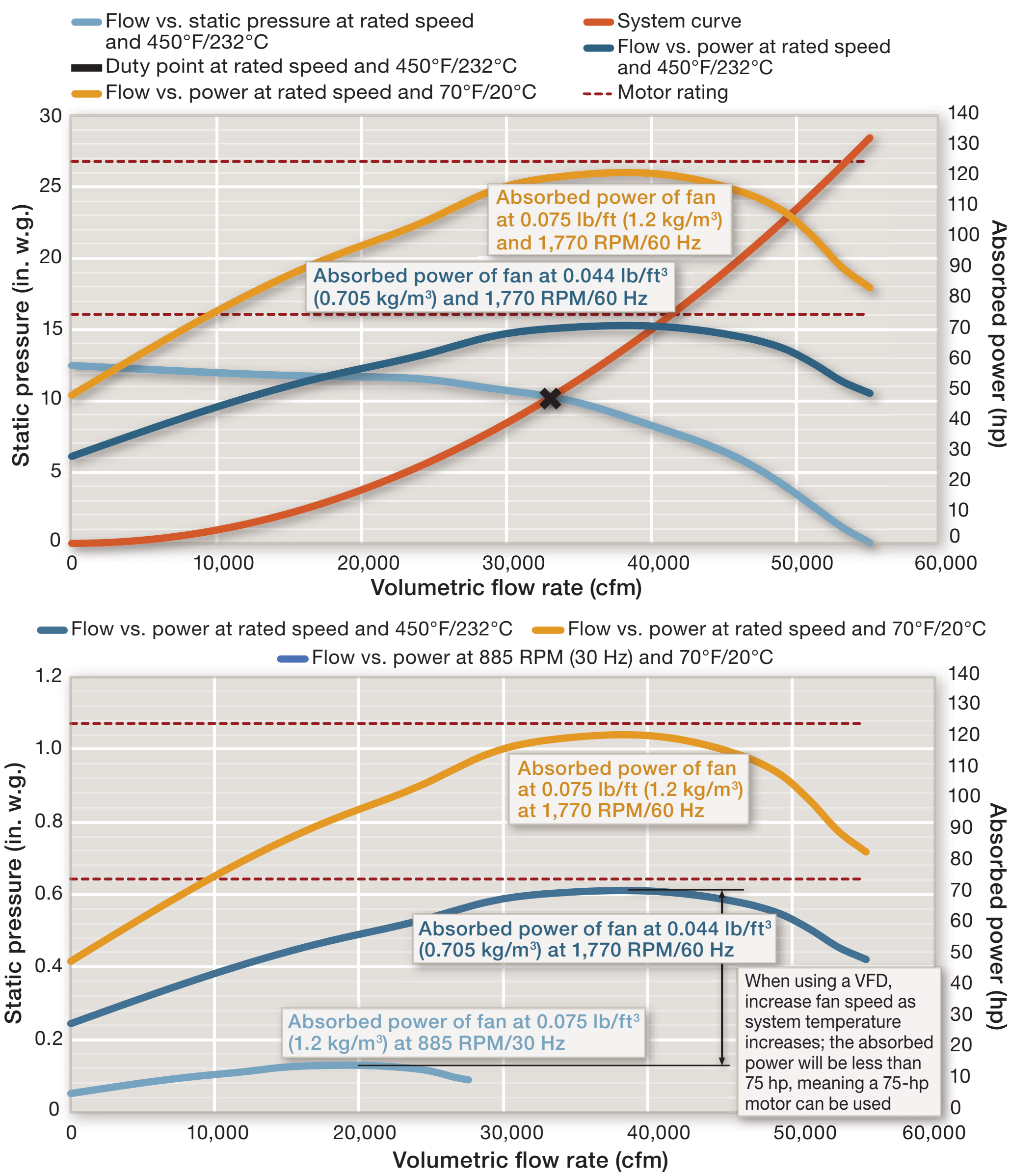


FIGURE 13. Impact of VFDs on motor selection for high-temperature fans.

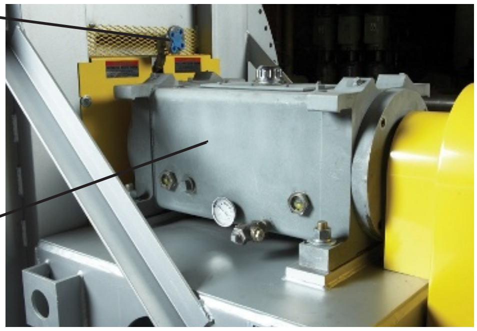


FIGURE 14. Mono-block bearing suitable for oil-circulation system.

FIGURE 15. Reversible tunnel-ventilation fan.

High-Temperature Ambient Conditions, Continuous Operation

As mentioned earlier, the temperature of the air surrounding motors, bearings, belts (drive arrangements 1, 3, 9, and 10), and all other outside-the-air-stream accessories requires precautions.

Motors. The temperature of the air surrounding a totally enclosed, fan-cooled motor should not exceed the temperature for which the motor was rated. If it does, the motor's temperature can be lowered through the use of a water jacket or an external cooling system. Ensure the motor's bearings and lubrication are designed for the temperature requirement.

Bearings. In many high-temperature applications, an oil-circulation system is used to ensure bearing temperatures are maintained (Figure 14).

Applications of High-Temperature Fans

Depending on a fan's intended use, the amount of time the fan can be expected to be exposed to high-temperature air can vary. Thus, a fan can be rated for a short, defined duration or it can be rated for continuous operation.

Take, for example, main ventilation fans and jet fans used in a roadway or transit tunnel (Figure 15). Because their purpose is to evacuate air in the event of a fire, these fans are rated for a short duration, normally 1 or 2 hr. Most other fans, such as those for petrochemical processing (Figure 16) and those for forced circulation or recirculation of air or gas in furnaces, ovens, kilns, and dryers, are rated for continuous operation.

Conclusion

Most high-temperature applications have unique requirements that can make fan specification complicated. The key is identifying the system information the fan manufacturer needs to design and supply a product optimized for the application.

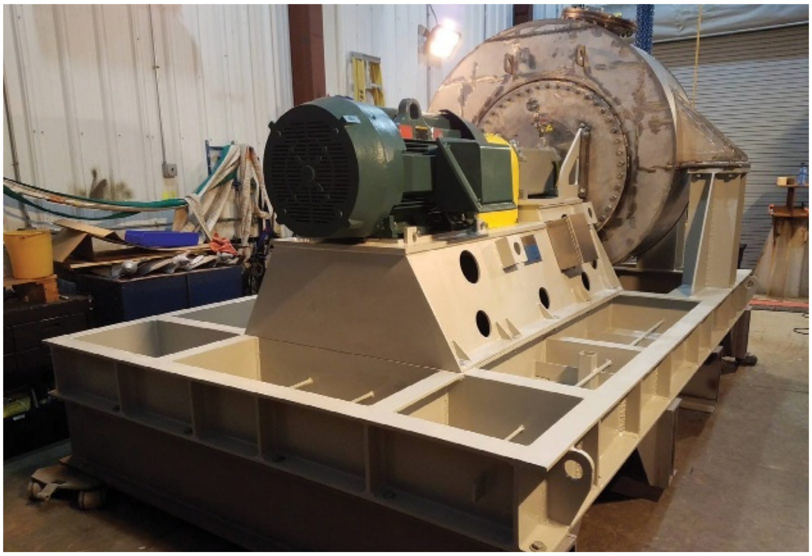


FIGURE 16. Catalyst-regeneration blower.

About the Author

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BY **MDM SL GOH**

China's New Fan-Efficiency Standard: What to Expect

On May 29, 2020, China published an update of mandatory national standard GB 19761, *Minimum Allowable Values of Energy Efficiency and Energy Efficiency Grades for Fan*, which will take effect June 1, 2021. Compared with the current (2009) version of the standard, GB 19761-2020 reduces some target efficiencies.

Under the standard, fan type, pressure coefficient, and speed are considered for centrifugal fans, while fan type and hub ratio are considered for axial fans. Based on peak efficiency, impeller efficiency for centrifugal and axial fans, and overall (combination of fan and drive) efficiency for forward-curved fans with external rotors, fan efficiency is classified into three grades in the updated standard: Grade 1, Grade 2, and Grade 3, of which Grade 3 represents the minimum allowable values for fan energy efficiency. Additionally, the metric for evaluating energy conservation for Grade 2 fans in the 2009 version has been removed.

Perhaps the most significant change concerns centrifugal fans. The pressure-coefficient ranges in tables 1 (0.95 to 1.55) and 2 (0.25 to 0.95) for general-purpose centrifugal fans and Table 4 (1.0 to greater than 1.4) for forward-curved centrifugal fans with external rotors were adjusted. Additionally, for some centrifugal-fan types, the deduction of a certain percentage from the target efficiency in Table 1 or Table 2 will be allowed. For double-inlet centrifugal fans and centrifugal fans for HVAC, the deduction will be 1 percent for grades 1 and 2 and 3 percent for Grade 3. The standard also defines fan inlet boxes' effect on energy performance. The deduction

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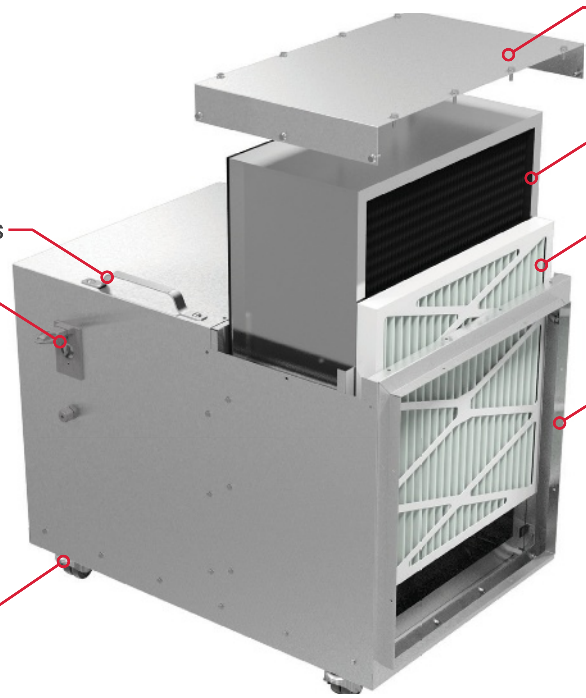

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from the target efficiency for centrifugal fans with inlet boxes in tables 1 and 2 will be 4 percentage points for all grades.

There also will be some special provisions for axial fans. For example, for axial fans with inlet boxes, a 3-percentage-point deduction from the target efficiency in Table 3 will be allowed for each grade. Additionally:

- In recognition of the impact of outlet diffusers on axial-fan efficiency, all axial fans with outlet diffusers will be required to meet the requirements in the fan-size-greater-than-or-equal-to-10 and 0.55-to-0.75 hub-ratio columns in Table 3. The target efficiency for axial fans without outlet diffusers in Table 3, on the other hand, will be 2 percentage points higher.
- For dynamic-pitch-angle-adjustable axial fans without inlet boxes and diffusers, the limitation on fan efficiency for grades 1, 2, and 3 will be 89.5 percent, 87 percent, and 82 percent, respectively.
- The target efficiency for reversible axial fans will be allowed to be 8 percentage points lower than the corresponding value in Table 3.

It should be noted that the 2009 version of the standard defines term-of-service range as the operation range in which fan efficiency is no less than 90 percent of peak efficiency, or the performance range specified in the fan catalog. In the 2020 version of the standard, the term has been replaced with "stable operation range."

Standard GB 19761-2020 can be purchased in English and Chinese at *http://bit.ly/GB_19761-2020*.

***Mdm SL Goh** is executive director of Asia AMCA.*

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AMCA MIDDLE EAST UPDATE

By **HASSAN YOUNES**

COVID-19 Calls Attention to Indoor-Air Quality

As buildings in the Middle East that were closed because of the coronavirus disease 2019 (COVID-19) pandemic reopen, we are seeing intensifying focus on indoor-air quality—specifically, an increase in projects involving the upgrade of filtration, the addition of ultraviolet fixtures, and the use of portable filters, all measures to reduce the possibility of airborne transmission.

The World Health Organization (WHO) does not consider airborne transmission a primary means of SARS-CoV-2—the virus that causes COVID-19—spread. Following publication of an open letter signed by 239 experts from around the world arguing the virus lingers in the air, however, the WHO is reconsidering and investigating airborne transmission. In the near future, I expect there will be guidelines and recommendations from government entities addressing the airborne transmission of SARS-CoV-2 in buildings. This will depend greatly on whether the WHO changes its stance on the matter.

We have, unfortunately, seen some energy-efficiency projects put on hold because of building closures. As buildings reopen, I believe we will see a comeback of such projects.

I also believe there will be a focus on the residential sector, which has seen an increase in consumption and a decrease in rents, which is the best formula for energy-efficiency projects.

The governments around the Gulf Cooperation Council (GCC) still are pushing their energy-efficiency and demand-side-management (DSM) agendas. With the launch of the Abu Dhabi Energy Services Co. and the perseverance of the Dubai and Saudi Super ESCOs, I believe the retrofit sector will continue growing. The renewable-energy sector also will see growth as we approach 2030, which is a major milestone for DSM for many cities around the GCC.

A pillar of many of the DSM strategies of GCC cities, building codes are being revised to increase the efficiency of new construction. The need for net-zero-energy buildings is increasing, with construction of the first net-zero government building in Dubai under way. With a gross floor area of 105,000 sq m, Dubai Electricity and Water Authority's (DEWA's) new headquarters, Al-Shera'a, will be the largest net-zero-energy building in the world.

Whether a project falls under the new-construction or the retrofit category, occupant well-being, building resilience, and energy efficiency will be looked at almost equally, with occupant well-being perhaps getting a bit more attention. As a result, there will be more focus on building-operation-related regulations, training of operations-and-maintenance personnel, certification, and applying minimum-qualifications requirements when selecting a facility-management company.

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