TRANE®

Engineering Bulletin

Trane Catalytic Air Cleaning System

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Introduction

Indoor air quality (IAQ) affects comfort, productivity, and occupant health. It is near the top of the list of issues facing building designers, owners, and operators. The quality of the indoor air is the result of contaminant control, humidity management, ventilation, and air cleaning. This bulletin addresses the ventilation and air cleaning aspects of IAQ.

Figure 1. The four elements of IAQ

Ventilation: Issues that Threaten the Process

Ventilation is a process whereby a portion of indoor air is continually replaced with a similar portion of outdoor air. Ventilation dilutes contaminants that are accumulated indoors, thereby keeping the indoor air fresh. The process assumes that the outdoor air is clean and suitable for use.

Issues exist that are impacting ventilation as a way to maintain adequate IAQ. The outdoor air in a some areas of the country have contaminant levels that exceed the recently lowered EPA National Standards for ground-level ozone[20] and ultra-fine particulate.[21] Also, as industry and residential areas merge, chemical by-products and resulting odors from its processes, can foul the outdoor air. The outdoor air must then be cleaned prior to being brought into the building. This points to the need to look at technologies that impact the other elements of IAQ: namely, air cleaning and contaminant source control.

Filtration and Air Cleaning

Filtration is a term that has been historically used to mean particle removal. It has been used in HVAC systems to keep system components—namely, heat transfer coils and fans—clean to maintain their operating efficiency. A secondary benefit of filtration is to help reduce building housekeeping and maintenance.

The building industry has well-established testing and reporting criteria for particle filters. These filters cover a wide range of efficiencies, sizes, and costs. Perhaps the most well-known requirement (ASHRAE Standard 62.1) is for MERV[2] 6 or better filters in HVAC systems to be located upstream of wet surfaces, such as cooling coils and humidifiers.

Air cleaning is a holistic process by which both particulate and gaseous contaminants are removed from the air. The use of gaseous air cleaning equipment, for the removal of specific chemicals, is

a rare occurrence today in commercial buildings. There is evidence, however, that odor control through gaseous air cleaning is becoming more commonplace.

The increased concern for the spread of communicable disease and the desire for improved comfort and productivity is driving better IAQ designs in commercial buildings.

Indoor Air Contaminants

Air contaminants are either particles or gases. The distinction between particles and gases is important when determining the best strategies for controlling them in buildings.

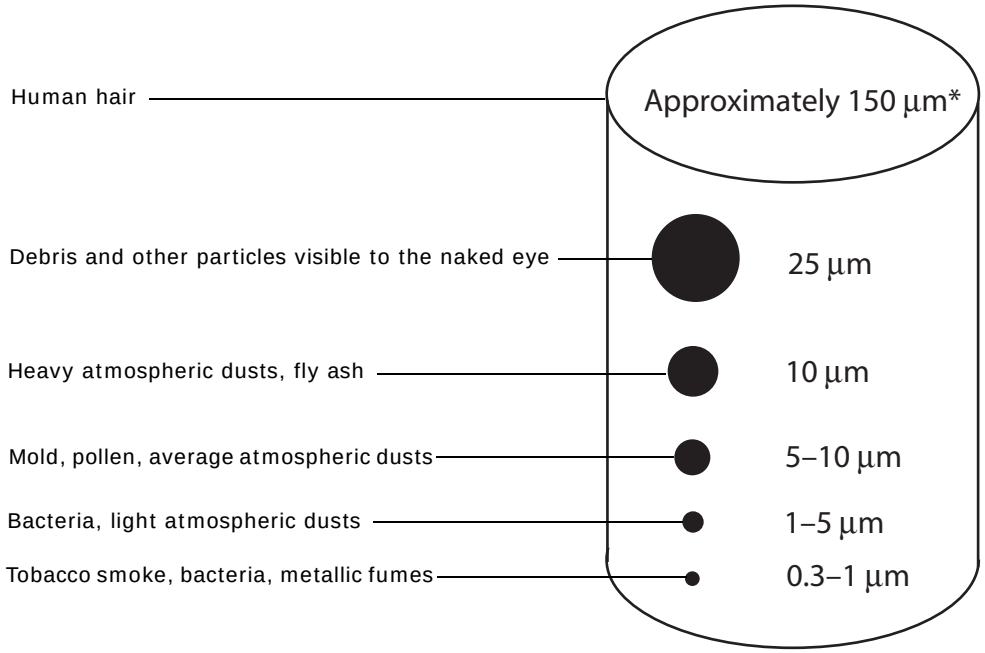
Particulate Matter

Particles may be solid, liquid, or have a solid core surrounded by liquid. They range in size from less than a micrometer (μm),[11] visible only under a microscope, to over 100 μm, which are easily visible to the naked eye. Size is a key characteristic when selecting a filter. Particles smaller than 10 μm are considered inhalable or respirable, and pose a risk to the human respiratory system.[21] (See Figure 2 for examples of relative particle size.)

Particles are made up of organic and inorganic matter. Particles dispersed in air are referred to as aerosols. Many particles found in buildings are bioaerosols, which include viruses, bacteria, and fungi. These particles can be complete organisms or fragments of organisms that are living or were once living. Many can cause irritation, allergic response, or disease in animals and humans.

Particles can also adsorb chemicals. High-efficiency particle filtration can remove some low-level concentrations of chemicals and the odors they produce.

Figure 2. Relative particle size comparison [12]



*1 μm (micrometer or micron) = 1/1000 millimeter = 1/25,400 in.

Gases

Gases are chemical contaminants that exist as free molecules or atoms in air. Even in very low concentrations, many chemicals cause odors perceptible to humans. They are much smaller than particles and can remain mixed indefinitely in the indoor air. Gases can also be organic or inorganic.

Organic compounds have a skeleton of carbon atoms that can easily combine to form a chain configuration of more complex chemical compounds, referred to as volatile organic compounds (VOCs). Many VOCs commonly found in buildings originate as vapors from solvents and binders that outgas from manufactured building materials such as carpet, wall covering, and particle board. They are also released by microorganisms as endotoxins and mycotoxins.

The defining characteristic of gaseous contaminants is their concentration in the surrounding air. Most odor-causing gases exist in very low concentrations (parts per billion) making identification and measurement difficult. Industry testing and rating standards for gaseous contaminants are being considered, but formal published standards are likely to be many years away.

Air Cleaning Needs and Expectations Are Changing

During the 1980s and 1990s, indoor air quality interests focused on chemical air pollutants such as radon, carbon monoxide, asbestos, and VOCs. Little attention was given to microbiological contaminants such as fungi, bacteria and dust mite excreta, which can cause allergic reaction and cause discomfort in humans.[4, 1] The ever-growing variety of indoor contaminants and sources indicate a need to broaden that scope and to introduce more holistic air cleaning processes for many buildings. Markets with special challenges regarding indoor air quality are healthcare and education. The healthcare industry is concerned about its ability to manage communicable diseases such as avian and swine influenza. In the United States alone, influenza causes 200,000 people to be hospitalized and over 36,000 to die each year[8]. The Centers for Disease Control and Prevention (CDC) recommends vaccinations, good personal hygiene, and anti-viral medication as traditional control approaches for influenza. This direction assumes that the disease spreads only through direct contact with infectious matter on surfaces or in the air in close proximity to sneezes or coughs.

The rapid and seemingly random spread of the disease indicates that a longer-distance airborne transmission mechanism for fine droplets exists. Also, hospital-acquired infection (HAI) rates are increasing and result in considerable loss of life and added cost burden to the healthcare system.

Recent estimates indicate that 99,000 HAI-related deaths occur per year in the United States[18] at a cost of $13,500 per infection[10]. A specific concern for the healthcare industry is Methicillin-resistant Staphylococcus aureus (MRSA). While most HAIs affect individuals with compromised immune systems or pre-existing medical conditions, MRSA also infects individuals without these risk factors. Despite focused efforts by the industry to strictly enforce the established infection-control procedures, infection rates continue to rise. This indicates that airborne transmission is likely occurring and that additional measures will need to be taken to effectively manage these diseases in the future.

The K-12 education market is also susceptible to disease outbreaks. During the swine flu (H1N1) outbreaks of 2008–2009 in Texas, New York, and other states, entire elementary and middle schools closings for 3–10 days were common as absentee rates for staff and students approached and exceeded 30%. The higher vulnerability for rapid disease transmission in these spaces is driven by the higher population density of elementary and middle schools, along with the fact that many children do not exercise good personal hygiene, such as hand washing and sneeze and cough isolation.

New Information Validates Airborne Disease Transmission

Many of the infection control procedures used today were developed in the 1950s and 1960s to control the spread of tuberculosis (TB), small pox, and measles. These procedures assume that a bacterial virus spreads in two ways:

- Direct contact (touching infectious surfaces)
- Indirect transfer by way of the respiration of infected droplet nuclei resulting from sneezes, coughs, and respiration of infected individuals

Standard precautions include frequent hand washing; limiting touching of eyes, nose, or mouth; minimizing exposure to known sick individuals; and the wearing of masks by infected individuals. Virus particles expelled from the body commonly reside within a mucus shell, forming a droplet. After the mucus shell evaporates, only the viron, or nucleus of the droplet, remains. The belief has been that the droplet nuclei are relatively large and heavy (>10 µm) and travel only about a meter from the source before settling to a surface. Once on a surface, the direct contact precautions of disinfection and sterilization were believed to be sufficient.

Recent studies, however, indicate that the mucus shell evaporates more quickly than initially thought, leaving a much smaller and lighter nucleus that can easily become and remain airborne. Therefore, it is reasonable to expect that the smaller and lighter individual nuclei travel farther than originally assumed and remain viable and a risk for infection much longer than first thought.

Recent Studies

Significant new information from a number of studies of influenza and hospital-acquired infections (HAIs) in healthcare settings seem to validate the airborne disease transmission path.

Measurement of Airborne Influenza Virus in a Hospital Emergency Department sponsored by the National Institute of Occupational Safety and Health (NIOSH), 2008.[5]

A study monitored the emergency department of West Virginia University Hospital at the peak flu season. Multiple air samples collected from areas of the hospital not exposed to infected patients tested positive for viable influenza virus. Of special interest was the fact that over 50% of the infectious viral particles captured were less than 4 µm in size, much smaller than expected. Particles less than 4 µm can remain suspended in room air for long periods of time. The relatively long suspension time increases the potential for infectious particles to move easily around a building by normal air currents and to become entrained in the air being circulated by the HVAC system. Table 1 shows particle settling rates.

Table 1. Particle settling rates

Particle size (µm)	Settling velocity	Settling time from a height of 4 ft
100.00	59.2 ft/min	4.2 sec
50.0	14.8 ft/min	16.2 sec
10.0	7.1 in/min	6.8 min
5.0	2.5 in/min	19.2 min
1.0	1.8 in/hr	26.7 hr
0.5	1.4 in/hr	34.3 hr
0.1	1.13 in/day	42.5 days
<0.1	negligible	unknown

Influenza Transmission and the Role of Personal Protective Respiratory Equipment: An Assessment of the Evidence conducted by the Council of Canadian Academies, 2007.[9]

This study reviewed published documentation regarding the effectiveness of respiratory protection for healthcare workers in past seasonal influenza outbreaks. Quoting from the report:

> Expelled particles can be categorized. . . as "ballistic" and "inhalable" particles. Ballistic particles are those with a mean aerodynamic diametre of greater than approximately 100 µm and are predominantly affected by gravity, as opposed to air resistance. Their infectious range lies very close to the original point of departure—generally less than a metre. Inhalable particles are those with aerodynamic diametres falling in the range of 0.1 to 100 µm . . .
>
> . . . *The time during which a particle is likely to remain in the air is related to its overall size and can range from seconds to days. Some have diametres sufficiently small to allow them to be carried considerable distances depending on air currents and other factors* [italics added] (Evans, 2000).

Aerial Dissemination of Clostridium Difficile Spore published by the Pathogen Control Engineering Research Group, University of Leeds, UK, 2008.[13]

This study attempted to determine the potential for airborne transfer of *Closotridium difficile* spores. A frequently occurring hospital-acquired infection (HAI), *Closotridium difficile* associated disease (also known as CDAD, *C. difficile*, or *C. diff*), is responsible for significant morbidity and mortality among elderly patients[15]. The incidence of CDAD is increasing despite best efforts to isolate infected patients along with improved sanitization and decontamination procedures. In an attempt to find the cause, a study was conducted in an elderly care facility in the UK with the focus on culturing *C. difficile* from the air within the facility.

The study concluded that it "produced clear evidence of sporadic aerial dissemination of spores of a clone *C. difficile*, a finding which may help explain why CDAD is so persistent within hospitals and difficult to eradicate".

Significance of Airborne Transmission of Methicillin-Resistant Staphylococcus aureus (MRSA) in an Otolaryngology—Head and Neck Surgery Unit published by Drs. Shiomori, Miyamoto, and Makishima of the School of Medicine, Kitakyushu, Japan, 2001.[14]

The objective of this study was to quantitatively investigate the existence of airborne Methicillin-resistant *Staphylococcus aureus* (MRSA) in a hospital environment. MRSA, another challenging HAI, is a drug-resistant form of "staph" infection.[7] Because of its resistance to broad-spectrum antibiotics, *the CDC reports that MRSA now causes more deaths in the world than AIDS*.[6] There is also compelling evidence that MRSA particles are airborne in patient areas and are recirculated within the surrounding areas of the building.

In this study, samples were collected from the air in patient rooms both during periods of rest and also when patients were being moved and bedding changed. They found about 20% of the isolates of MRSA to be within a respirable range of less than 4 µm. Their study concludes that MRSA:

> . . . was recirculated among the patients, the air, and the inanimate environments, especially when there was movement in the rooms. Airborne MRSA may play a role in MRSA colonization in the nasal cavity or in respiratory tract infections. Measures should be taken to prevent the spread of airborne MRSA to control nosocomial MRSA infection in hospitals.

ASHRAE's Position

On June 24, 2009, ASHRAE's Board of Directors approved a position document on Airborne Infectious Diseases.[3] The document was written by a committee of engineering and health professionals from around the world. The committee examined available information on the health effects of exposure to airborne infectious diseases and the implications of this information on the design, installation, and operation of HVAC systems.

The paper discusses three methods of disease transmission: Direct contact, large droplet contact, and droplet nuclei inhalation. It acknowledges that the HVAC professional is likely to have direct influence only on the transmission of droplet nuclei.

As contact transmission control procedures, such as hand sanitizers and masks, become more commonly used, the transmission of airborne droplet nuclei by natural air currents and HVAC systems will receive more attention as an important pathway of airborne infectious disease.

ASHRAE's position is that:

- Many infectious diseases are transmitted through inhalation of droplet nuclei.
- Droplet nuclei can be disseminated through building ventilation systems.
- Airborne infectious disease transmission can be reduced by using dilution ventilation, in-room flow regimens, room pressure differentials, personalized and source capture ventilation and air cleaning.

ASHRAE recommends that further research be conducted on the development of more engineering control strategies to reduce infectious disease transmission. In the meantime, it seems practical for design professionals to understand and consider the control measures available today, including dilution ventilation, space pressure differential, and UVGI.

Conclusions

A common finding of recent research is that a significant amount of infectious particles are less than 4 μm in size. Particles of this size can remain suspended in indoor air for long periods of time and be recirculated throughout the building by natural air currents and the HVAC system (see Table 1, p. 8). This validates an airborne disease transmission path that is not being adequately addressed by the surface and close-contact precautions being used today.

Based on research findings and on ASHRAE's position, it seems prudent for infection-control professionals and building designers to consider additional control measures for airborne transmission, in addition to the precautions already in use when designing new healthcare facilities and updating existing facilities.

The Trane Catalytic Air Cleaning System

The Trane Catalytic Air Cleaning System (Figure 3) addresses many of the evolving air cleaning needs addressed in the introduction of this engineering bulletin. The system provides an additional level of protection and comfort for building occupants by helping to manage the biological and chemical contaminants that can be recirculated by the HVAC system.

Figure 3. Typical air cleaner installation

Photo: Courtesy of Genesis Air, Inc.

The Technologies Used

This unique air cleaning process employed by this system involves three technologies that holistically control the broad range of airborne contaminants commonly found in commercial buildings:

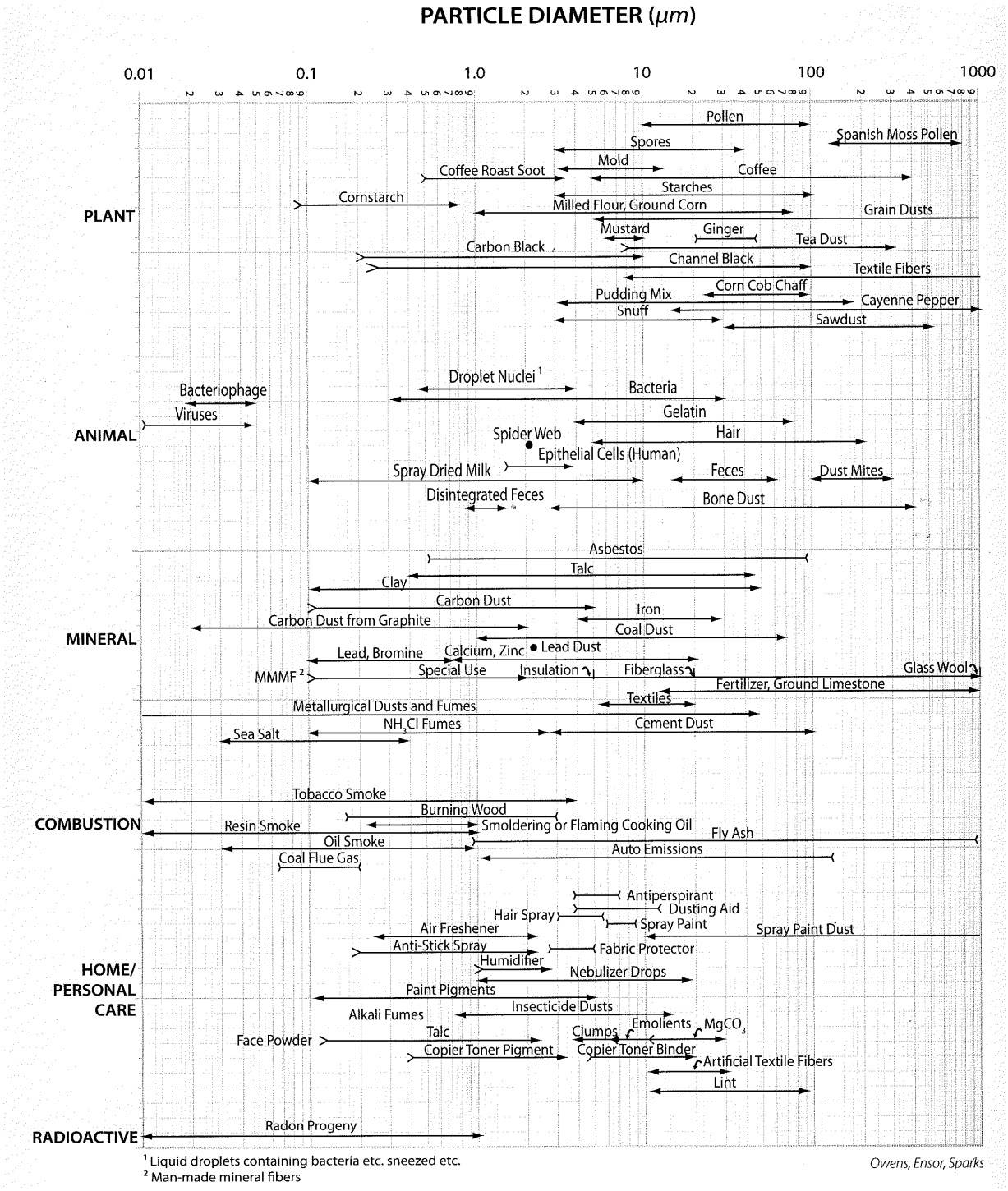
- High-efficiency particle capture
- Ultraviolet germicidal irradiation (UVGI)
- Photo-catalytic oxidation (PCO)

Particle Capture

Effective control of particles is an important element of any air-cleaning strategy. The indoor particles of most concern are atmospheric dust, viral droplet nuclei, and bioaerosols. As shown in Figure 4, p. 12, the majority of these types of particles found in the environment and inside buildings are 0.3 μm and larger. This is within the capture range of commercially available MERV 13 and better particle filters. Fungal and bacterial spores and pollen grains are even larger at 1–40 μm. Viral droplets or droplet nuclei, while very small, are usually surrounded by a mucus shell, making them much larger and easier to remove, provided the droplets get back to the filter.

The Trane Catalytic Air Cleaning System uses a minimum of a MERV 13 filter which removes 75% of 0.3–1.0 μm particles and 90% of the 1–10 μm particles from the air passing through it. Once captured by the filter, some of the living particles quickly die, due to the drying effect of the airstream. Others, such as spores, are more robust and can remain viable on filters and on surfaces for long periods of time.

Figure 4. Comparative particle size chart [12]



Ultraviolet Germicidal Irradiation (UVGI)

Ultraviolet light plays a dual role in the Trane Catalytic Air Cleaning System:

- It is an energy source for the catalytic reactions of the photocatalysis process
- It provides a germicidal effect on microorganisms in the airstream and on interior surfaces of the air handler

UVGI utilizes ultraviolet light in the "C" band (UVc)—ideally, the 253.7 nm wavelength—to damage the DNA and RNA and inactivate a wide range of microorganisms, including fungi, bacteria, and viruses commonly found in buildings. UVc has been applied in upper-air treatment applications in healthcare facilities since the early 1900s for the control of infectious disease, such as tuberculosis (TB). It has more recently been applied in HVAC equipment to keep surfaces free of microbial growth and to inactivate microorganisms flowing through duct systems.

Note: *The actual affect of UVc on maintaining heat transfer efficiency of HVAC systems is anecdotal at this time. Trane does not believe it is a substitute for traditional periodic coil maintenance.*

The ability of UVc to inactivate biological organisms is dependent on the dose (intensity and exposure time) of the UV energy it receives. The UV dose required for inactivation varies widely depending on the organism targeted. In general, viruses require the lowest UV dose. Vegetative forms of bacteria and fungi require the next higher dose. Bacterial and fungal spores require the highest UV dose, making them the most difficult to impact with UVc (see Figure 5).

Figure 5. UVC susceptibility of biological contaminants

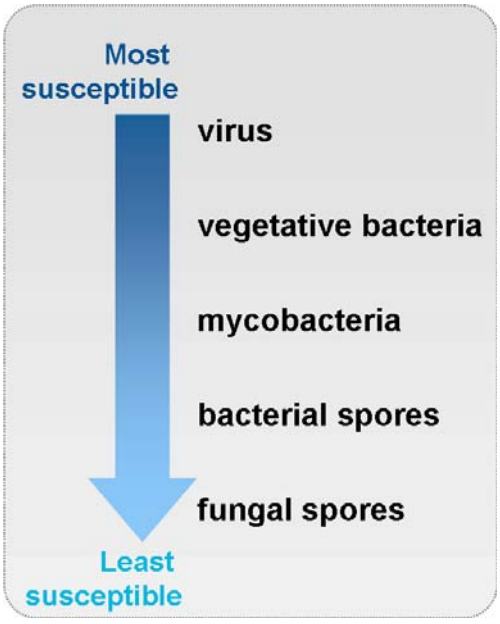
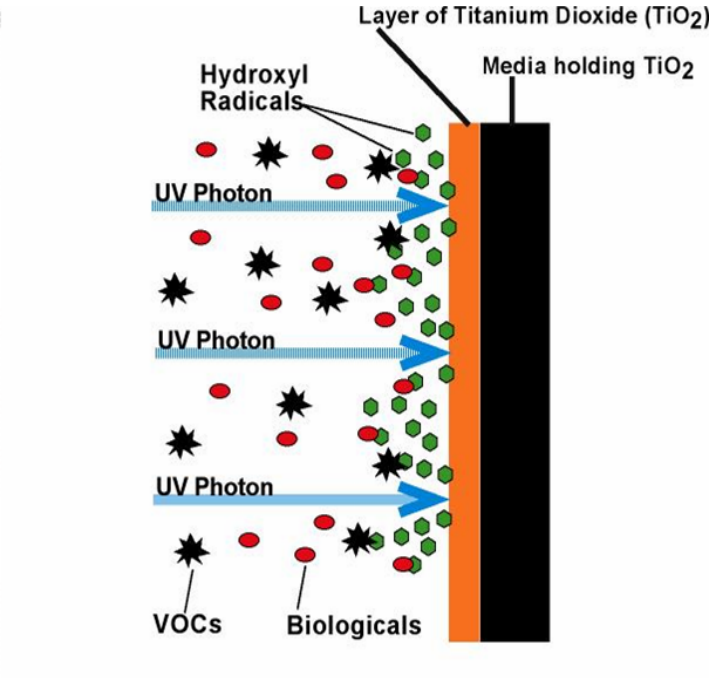


Photo-catalytic oxidation (PCO)

Photo-catalytic oxidation (PCO), also known as the process of photocatalysis, utilizes ultraviolet radiation to create highly reactive hydroxyl radicals and super-oxide ions on the surface of a metal oxide catalyst. Hydroxyl radicals, which are twice the strength of chlorine, are one of the most powerful oxidizing agents in nature (see "Appendix B: Table of Oxidation Potential," p. 23).

Biological contaminants coming into contact with the hydroxyl radicals are oxidized and decomposed. Volatile organic compounds (VOCs) are converted to simpler chemicals, ideally carbon dioxide and water (see Figure 6).

Figure 6. Photo-catalytic oxidation (PCO)



Courtesy of Steven Welty, Green Clean Air ©2010

PCO differs from adsorptive (carbon) or chemisorptive (potassium permanganate) technologies, which are traditionally used for chemical removal, by converting the organic chemical compounds into simpler, harmless chemicals, and discharging them. No capture of storage takes place. Because the PCO process does not capture or store anything, the media does not load or become consumed and does not require the periodic replacement or maintenance associated with traditional technologies. The only regular maintenance required for PCO is the replacement of UVc lamps every 15 to 18 months.

Technology Validation

PCO technology has been implemented in industrial process applications for many years; however, use in commercial HVAC applications is relatively new. Performance of this technology has been validated through laboratory and job site tests. Laboratory testing by independent, third-party laboratories have confirmed that the Trane Catalytic Air Cleaning System does not generate ozone, nor does it produce measurable levels of undesirable by-products. (These test reports are available from Trane by request.)

Additional internal testing was conducted to validate the airside performance at various face velocities. These tests were extended to very high flow rates to verify structural integrity of the PCO media as well as confirm there were no unexpected acoustical anomalies.

Opportunities for a Catalytic Air Cleaning System

While all spaces can benefit from more effective particle, chemical, and bioaerosol removal, the potential benefits are higher for medical and education space types.

Medical Facilities

Medical facilities are at a higher risk of disease transmission due to the higher concentration of sick and infected people that occupy them. As we learned earlier from research studies, there is compelling evidence that diseases such as influenza, MRSA, and *C. difficile* spreads through airborne transmission.

Common areas such as lobbies, hallways, and waiting rooms of medical facilities are shared by infected and healthy individuals. Consequently, the potential to spread disease among these areas is high. Examination and treatment rooms also have a high likelihood to generate infectious airborne droplet nuclei.

While contact control measures such as surface sanitation and masking of infected individuals are important measures that help manage larger, heavier particles, it is also important to consider the suspended, smaller bioaerosols that can pass through masks and be circulated throughout the building.

Medical facilities also use a number of chemicals in the course of treatment and cleaning, many of which create odors to which some people find offensive. While it may be argued that odors are predominately a comfort issue, lack of adequate odor control can negatively impact the environment of care. PCO can reduce low-level concentrations of many odorous organic chemicals. And, again, since the system involves no capture and storage, minimal regular maintenance is required.

Educational Facilities

Educational facilities also have a high potential to transmit disease among building occupants. K-12 classrooms typically have up to 30 people per 1,000 ft^2. That occupant density is up to 6 times higher than that found in other commercial and institutional spaces, such as offices and retail stores. The high density, combined with poor personal hygiene (specifically, handwashing) in younger children, makes the potential high for the spreading of disease in these environments. This situation was confirmed during the swine flu pandemic of 2009, when many schools that had confirmed the existence of the disease closed to reduce its rapid spread.

Equipment Applications for a Catalytic Air Cleaning System

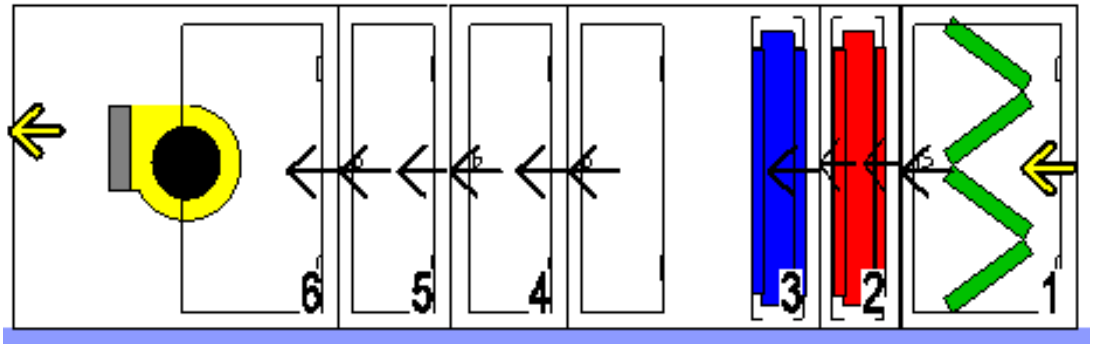
The core UV-PCO technology was developed by Genesis Air, Inc. (patent pending), and is available through Trane in many different configurations:

- Factory-engineered and installed on Trane air handlers
- Field retrofit into existing Trane and other brands of air handlers
- Portable and duct-mounted versions available through Trane Parts Centers

In all of these products, the MERV 13 or better particle filters are located in the standard filter location of the air handler. The UVc/PCO section is typically located immediately downstream of the cooling coil. This location was chosen to optimize the coil-cleaning potential of the UVc and to maximize the hydroxyl radical generation of the PCO process. This area of the air handler is hardened to minimize premature aging effects of the UVc energy. “Hardening” involves substituting or shielding susceptible polymeric materials (plastics, gaskets, wiring, and sealants) from the UV energy. Viewing windows are designed to block UV transmission. Door electrical interlocks are provided at all access points to this area of the unit along with warning signage to alert unsuspecting personnel of the presence of high-intensity UV energy inside. Also, maintenance and safety information is included in the installation, operation, and maintenance information provided with the air handler.

Note: *The air handler-mounted version is currently a design special option. The air cleaning system is also available in standalone and portable configurations through the Trane Parts Centers. This includes free discharge units for floor or ceiling mounting and also duct-mounted arrangements.*

Figure 7. Typical AHU configuration with the Trane Catalytic Air Cleaning System



1—Filter module
2—Heating coil
3—Cooling coil with access door
4—Trane Catalytic Air Cleaning System module and access door
5—Access section with door and viewing window
6—Fan module

Advantages of a Factory-Engineered and Installed Air Cleaning System

It is well recognized that the HVAC industry prefers factory-engineered and -installed options on equipment. The Trane Catalytic Air Cleaning System is no different. Factory-engineering and installation can optimize packaging, performance, reliability, safety, and consistency.

Trane believes that the optimum location for the system is immediately downstream of the cooling coil. This area has the highest relative humidity and thus the greatest potential for microbial growth. Locating the system UV lights in this area optimizes their ability to irradiate the coil face and helps control potential microbial growth. It is also most cost-effective to provide the proper protection and safety measures in this area of the unit. Maintenance, operation and safety information is also included in the installation, operation and maintenance documentation provided with the air handler.

Engineering and installing the Trane Catalytic Air Cleaning System at the factory reduces risk for the designer, contractor and owner by providing single source responsibility including service, parts and warranty support.

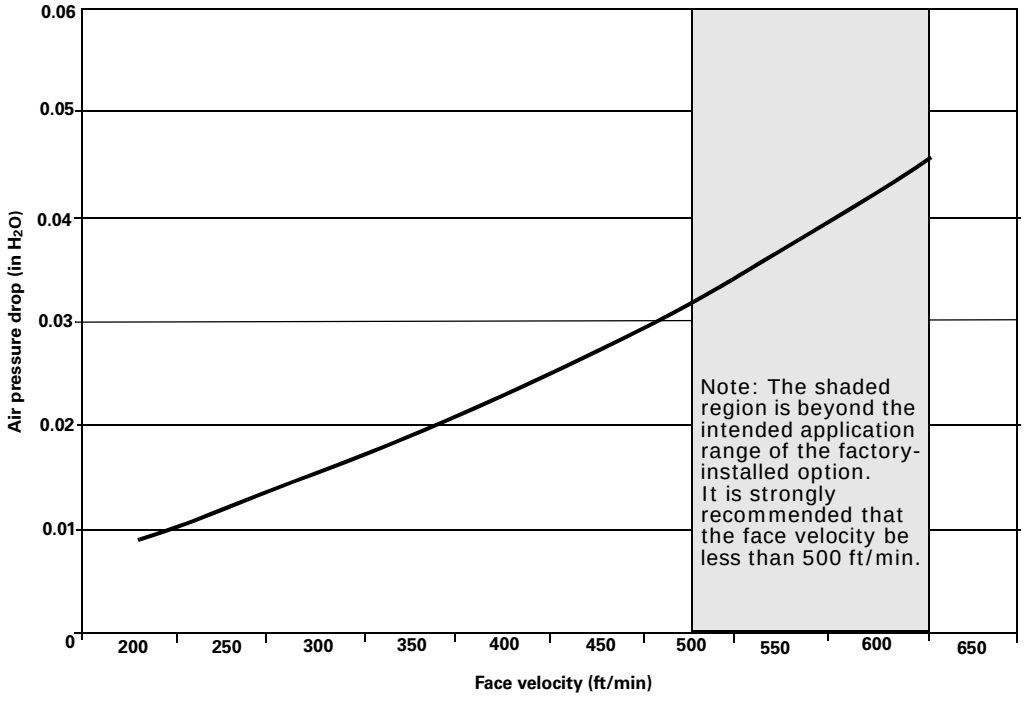
The rigor of factory engineering assures that the design is compliant with the applicable codes and standards. This option is UL listed at the component level and either UL or ETL listed at the product level.

Application Information

The air pressure drop of the Trane Catalytic Air Cleaning System needs to be accounted for in the air handler selection. The pressure drop for the particulate filter is predicted directly from the selection program, based on the selected filter type.

The pressure drop for the air cleaner section needs to be added as an additional static pressure selection program input for the access section in which the air cleaner will be installed. This additional static pressure value can be obtained from either the output of the configurator tool or from Figure 8.

Figure 8. Air Pressure Drop of the Trane Catalytic Air Cleaner (less particle filtration)



Performance

Performance testing was conducted on the Catalytic Air Cleaning System by independent third-party laboratories to verify its ability to reduce biological and organic chemical contaminants. The tests were conducted under specific laboratory conditions. Full test reports [16, 17] are available by request.

The performance of the air cleaner under specific job site conditions will be affected by many variables including but not limited to the types, concentrations, and interactions of the contaminants, thermal conditions, system air velocity, and chamber recirculation rate. Final responsibility for predicting the effectiveness of this device under specific job sight conditions is the responsibility of the system designer.

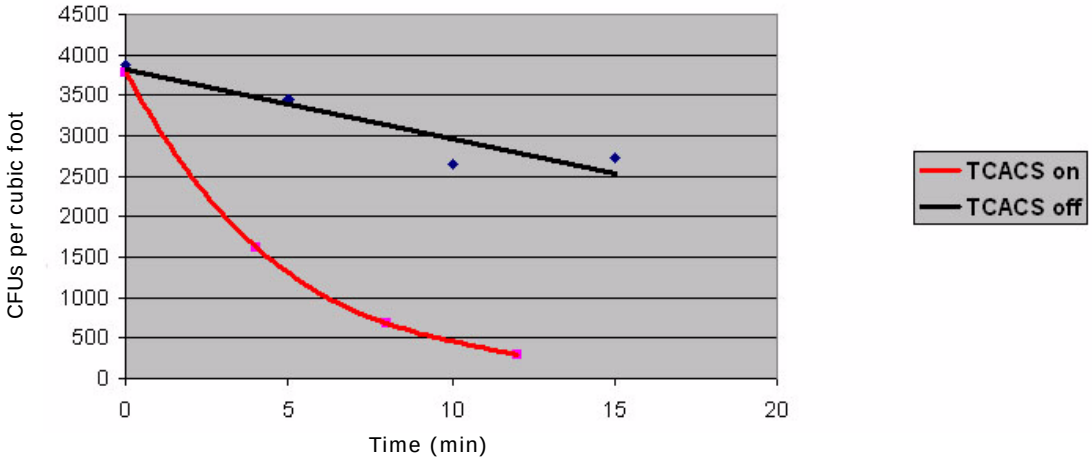
Biological Contaminant Reduction Performance

The biological removal and inactivation effectiveness of the Trane Catalytic Air Cleaning System including upstream MERV 13 filtration was tested by RTI International for MS2, an H1N1 influenza virus simulant, and for Staphylococcus epidermis, a bacterial strain closely related to Methicillian-resistant Staphylococcus aureus (MRSA).

Figures 9 and 10 represents the measured rate of decay, in colony-forming units (CFUs), of the target contaminant over time inside a 640 cubic foot chamber. The air cleaner, located inside the chamber, operated at a recirculation flow rate of 166 CFM. Decay plots are shown below.

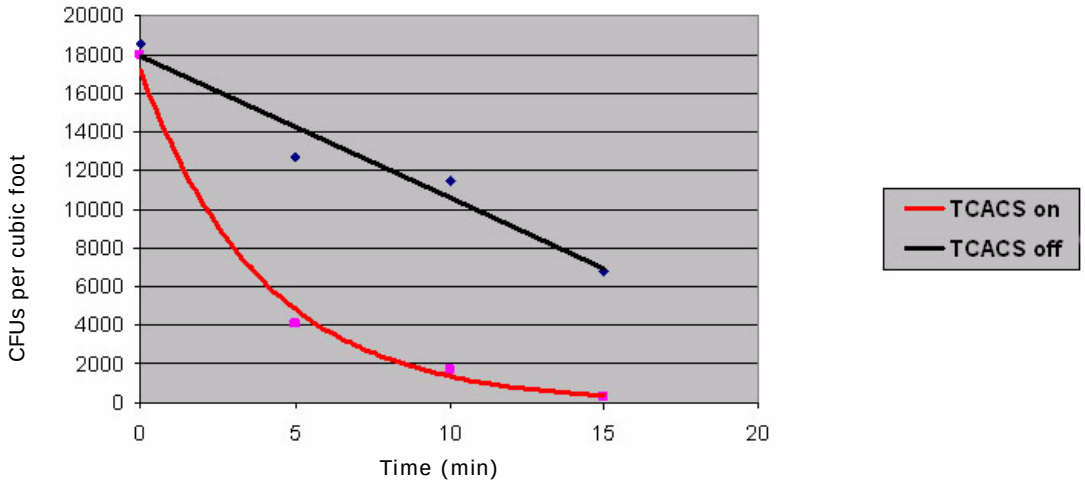
***Staphylococcus epidermidis* (Se).** Se is a common human shedding organism considered to be representative of a broad range of vegetative bacteria found in spaces occupied by humans. It is believed to be a frequent cause of nosocomial sepsis (infections) and is closely related to Staphylococcus aureus associated with Methicillin-resistant *Staphylococcus aureus* (MRSA).

Figure 9. *Staphyococcus epideris* (Se) decay



MS2 virus. MS2 is an *E. coli* bacteriophage commonly used as a human virus simulant representative of human influenza A virus.

Figure 10. MS2 virus decay



Organic Chemical Reduction Performance

The ability of the Genesis Air PCO technology to breakdown volatile organic compounds (VOCs) was laboratory tested by GD Air Testing, Inc. The results are shown in Table 2. Known concentrations of numerous VOCs were injected into a 144 ft^3 sealed chamber. The air cleaner was placed inside the chamber and the chamber air was circulated through the air cleaner at a rate of approximately 200 ft^3/min. This recirculation rate may not reflect typical job conditions. The data reflects reduction performance of the air cleaner after 2, 4, and 12 hours of continuous operation.

Table 2. VOC reduction performance test results [(a)]

Constituent	0117-1 0 hours	0117-2 2 hours	Removal %	0117-3 4 hours	Removal %	0117-4 12 hours	Removal %
Benzene	13.7	1.46	89.3	1.30	90.5	1.40	89.8
Benzylchloride	ND	ND	NA	ND	NA	ND	NA
Bromomethane	14.5	11.5	20.7	7.99	44.9	2.36	83.7
Carbon tetrachloride	12.5	1.35	89.2	1.13	91.0	1.10	91.2
Chlorobenzene	11.7	ND	100	ND	100	ND	100
Chloroethane	12.5	10.2	18.4	8.38	33.0	4.59	63.3
Chloroform	12.9	2.64	79.5	2.25	82.6	2.04	84.2
Chloromethane	12.7	12.1	4.7	10.5	17.3	6.33	50.2
1,2-dibromoethane	12.5	0.25	98.0	ND	100	ND	100
1,2-dichlorobenzene	12.1	0.38	96.9	0.36	97.0	ND	100
1,3-dichlorobenzene	12.7	0.34	97.4	0.34	97.3	ND	100
1,4-dichlorobenzene	12.0	0.43	96.4	0.43	96.5	ND	100
1,1-dichloroethane	13.3	3.72	72.0	3.27	75.4	2.75	79.3
1,1-dichlorethene	12.2	6.03	50.6	5.04	58.7	3.64	70.2
Dichlorodifluoromethane	13.1	11.4	13.0	9.22	29.6	4.90	62.6
Dichlorotetrafluoroethane	12.7	9.44	25.7	7.78	38.7	4.34	65.8
1,2-dichloroethane (EDC)	80.5	134	-66.5	134	-66.5	150	-86.3
cis-1,2-dichloroethene	15.2	5.63	63.0	5.35	64.8	5.37	64.7
trans-1,2-dichloroethene	ND	ND	NA	ND	NA	ND	NA
Dichloromethane	14.2	9.62	32.3	8.27	41.8	6.20	56.3
1,2-dichloropropane	12.5	0.46	96.3	0.34	97.3	0.344	97.2
cis-1,3-dichloropropene	14.5	0.34	97.7	0.30	97.9	ND	100
trans-1,3-dichloropropene	16.7	ND	100	ND	100	ND	100
Ethylbenzene	14.2	ND	100	ND	100	ND	100
Hexachlorobutadiene	33.1	1.18	96.4	5.83	82.4	ND	100
Styrene	13.7	ND	100	ND	100	ND	100
1,1,2,2-tetrachloroethane	10.6	ND	100	ND	100	ND	100
Tetrachloroethene (PCE)	13.9	ND	100	ND	100	ND	100
Toluene	17.6	5.20	70.5	4.79	72.8	5.26	70.1
1,1,1-trichloroethane (TCA)	12.2	1.23	89.9	0.97	92.0	0.998	91.8
1,1,2-trichloroethane	11.9	ND	100	ND	100	ND	100
1,3,5-TMB/4-ethyltoluene	16.7	ND	100	ND	100	ND	100
1,2,4-trimethylbenzene	16.2	ND	100	ND	100	ND	100
1,2,4-trichlorobenzene	58.9	6.53	88.9	5.32	91.0	ND	100
Trichloroethene (TCE)	12.8	0.88	93.1	0.785	93.9	0.717	94.4
Trichlorofluoromethane (F-11)	12.1	7.45	38.4	6.34	47.6	4.29	64.5

Table 2. VOC reduction performance test results (continued)[a]

Constituent	0117-1 0 hours	0117-2 2 hours	Removal %	0117-3 4 hours	Removal %	0117-4 12 hours	Removal %
Trichloritrifluoroethane (F-113)	12.2	2.63	78.4	2.17	82.2	1.98	83.8
Vinyl chloride	13.5	11.8	12.6	9.35	30.7	4.47	66.9
m&p-xylenes	29.0	0.348	98.8	0.305	98.9	0.399	98.6
o-xylenes	13.8	ND	100	ND	100	ND	100
Formaldehyde	2.82	0.71	74.8	0.45	84.0	0.28	90.1
Carbon monoxide	1080	120	88.9	110	89.8	59	94.5

(a) Test results published by GD Air Testing, Inc., March 11, 2004.

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Appendix B: Table of Oxidation Potential

Relative power of chemical oxidants[(a)]

Compound	Oxidation potential (V)	Relative oxidizing power (Cl_2 = 1.0)
Hydroxyl radical	2.8	2.1
Sulfate radical	2.6	1.9
Ozone	2.1	1.5
Hydrogen peroxide	1.8	1.3
Permanganate	1.7	1.2
Chlorine dioxide	1.5	1.1
Chlorine	1.4	1.0
Oxygen	1.2	0.90
Bromine	1.1	0.80
Iodine	0.76	0.54

(a) Source: U.S. EPA

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