Duct Cleaning: The Good, The Bad...and The Need for An International Consensus Standard

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SUMMARY

Cleaning ventilation system ductwork has been a topic of controversy for several years. Guidance documents are available for duct cleaning, but uniformity in application of remediation and cleaning methods is inconsistent in many cases. Means and methods for cleaning range from high-volume negative pressure vacuum cleaning of residential ductwork ...to use of sanitizing agents on the interior of galvanized ducts...to ultraviolet germicidal irradiation for treatment of re-circulated air and control of infectious viral aerosols in operating room suites. A comprehensive visual inspection of the components of the building ventilation system and a risk assessment to determine the nature and magnitude of contamination form the basis of effective remedial cleaning. This presentation describes a proposed industry standard of care for duct cleaning and a quantitative method to determine an acceptable level of cleanliness. The information presented underscores the need for an international consensus standard for duct cleaning.

INTRODUCTION

Over the past decade heating, ventilation and air conditioning (HVAC) system cleaning and decontamination to remove dust and biological growth has expanded into a large industry serving both residential and commercial building markets [1]. Guidelines for duct cleaning are available in Japan, Sweden, the United Kingdom and the United States, but are routinely violated by many contractors. Decisions to remediate ductwork are frequently driven by financial motives and are not always based on sound judgment. Improper remediation of HVAC systems can cause degradation of indoor air. Duct cleaning is often performed without a comprehensive visual inspection due to limited accessibility to HVAC system components, resulting in a failure to properly identify sources and implement corrective actions prior to cleaning.

The focus of this presentation is on mold-impacted and/or particle laden ductwork. HVAC systems are especially conducive to mold growth because they draw supply air, which usually contains fungi and moisture, into a building containing numerous organic materials that provide food sources for mold growth. The remediation of HVAC systems is an extremely sensitive undertaking due to the potential of disturbing and distributing spores or dust throughout the ventilation system.

HVAC system ductwork is an air-conveyance system that requires diligent cleaning methods and a quality assurance process to protect the health of building occupants. The purpose of this presentation is to provide guidance in the proper assessment and remediation of contaminated ductwork and to encourage development of international consensus standards.

METHODS

Building Ventilation Ductwork Components and Characteristics

In a typical building HVAC system, the fan pulls air from the occupied space through return air grilles into ductwork...then through the filter, heating and/or cooling coils and supply ductwork...then back into the occupied space. Various types of ducts and ductwork materials are available. Basic types include: straight metal sections; spiral-wound; flexible and expandable; and plastic made of polyvinyl chloride, reinforced fiberglass, or acrylonitrile butadiene styrene. Ductwork materials include: fiberglass, metal with fiberglass interior, metal externally wrapped with fiberglass, and insulated flex duct. The duct type and material will depend on the type and age of building and ventilation system, the nature of occupancy, the cost of materials and ease of installation, corrosion, temperature and other factors. Galvanized steel is probably the most common duct material; circular, rectangular and oval ducts the most common shapes. Some types and shapes of duct are capable of retaining more particulates regardless of their design velocity. For example fiberglass duct will generally accumulate more particles because of its rough, porous interior surface, compared to galvanized steel which has a relatively smooth surface except at section joints and seams. Duct manufacturers publish friction loss data, based on the surface material, which is useful in determining the potential for particulate loading on interior duct surfaces and the corresponding frequency recommended for maintenance and cleaning. The design of the ductwork will also determine the potential for interior particulate loading. Elbows, junctions, branch entries, and expansions and contractions are areas where there is greater potential for excessive surface deposits compared to straight sections.

Measurement of static pressure losses in a duct provides useful data to evaluate if particulates are being trapped in the duct. A pitot tube connected to an inclined manometer is the primary method of measuring duct static pressure. To reduce static pressure losses in ductwork design: (1) Branch entry angles should be designed at 30º – with a 45º maximum. (2) Expansions and contractions should be gradual – for example, one centimeter of duct diameter change for every five centimeters in length. (3) Rectangular duct should be as square as possible. (4) Seams on spiral-wound ductwork should be sealed with high or low pressure seals and pressure (leak) tested.

To evaluate the potential for particulate loading within HVAC ductwork, it is important to understand airflow in ventilation duct and duct velocity profiles. Airflow in ventilation duct is turbulent, not laminar. Turbulent airflow, in comparison to laminar airflow, is a function of the Reynolds Number – a dimensionless parameter represented by:

$$Re = \frac{VD\rho}{\mu}$$

Nomenclature:
V = air velocity (cm/sec)
D = duct diameter (cm)
ρ = air density (g/cm³)
μ = air viscosity (poise)

If $Re < 1200$: Airflow in duct is laminar, free of eddies and swirls, direction is predictable

If Re 1200 – 3000: Transitional airflow depends on acceleration or deceleration

If $Re > 3000$: Airflow is turbulent

Re in ducts is usually 100,000–1,000,000; therefore, it is always turbulent [2].

Dust in ventilation ducts usually has a very minor effect on air flow rates. However, heavy dust accumulations on critical components of the HVAC will limit air flow, for example dust on air supply diffusers, dampers and fan blades. Velocity profiles can help define the potential location of particulate accumulations in ductwork, and are best determined by taking duct velocity Pitot tube traverses. Velocity distributions inside ductwork are not uniform across the area of the duct due to factors such as obstacles in the airflow path and changes in airflow direction. Velocity is always zero at the wall surface of the duct. Velocity in duct must be corrected for the moisture content in the air, temperature and altitude. For air with no industrial particles, duct velocities of 9 to10 mps are considered optimum in main ducts, considering initial and operating costs, noise control, and naturally occurring dust transport. Air velocities in branches near room registers should be lower than in main ducts.

Sources of HVAC System Contamination

The cause(s) of mold growth must be identified and corrective action taken before remediation of either the building or the HVAC system is undertaken. Any identified HVAC deficiencies must be corrected. Sources of water intrusion, moisture accumulation, and/or surface condensation must be resolved prior to remediation. If the HVAC system and building problems are not resolved, recurrence of microbial amplification should be expected. Source identification and control form the basis for an effective and successful remediation.

Over 52% of all indoor air quality problems are caused by inadequate or improper ventilation [3] including poorly designed, installed, operated and maintained building ventilation systems. In some cases there can be widespread mold growth in a building, without a recognizable source of water intrusion, caused by improper moisture control in ventilation design. Proper building pressure management, ventilation system design engineering, and humidity control are critical elements to prevent mold and degradation of indoor air. Whenever the author performs an indoor air quality investigation, he frequently finds the source of the problem in one of "4 Ps" – pollutants, people, pathways or pressure. The latter two areas involve the ventilation system.
Common problems include:

- Poor air filter maintenance and efficiency – causing particulates to build up in ducts and at supply diffusers. Poorly maintained or improperly sized filters allow particulates (including ambient aerosols and those from local sources) to be distributed throughout a building, resulting in an increased risk of microbial contamination. When filters become clogged, the fans use more energy to operate and move less air, causing a detrimental effect on cooling, humidity control and proper air distribution. Filters in HVAC systems should be of the highest grade compatible with the system and the air handler fan – with a filter glass F6 to F7.
- HVAC units that are oversized for an area or a building – resulting in overcooling, system short-circuiting, improper dehumidification, condensation build-up, excess humidity and mold growth.
- Pressure differentials created by ventilation systems – notably if the system operates under negative pressure…as opposed to ideally operating under slightly positive pressure.
- Surface condensation in ductwork immediately downstream of cooling coils caused by moisture wicking off the coils. Condensation also occurs when the temperature of the surface of the ductwork falls below the dew point of the surrounding air. Particles not removed by the filters can collect on surfaces in the HVAC system resulting in microbial growth.
- Surface condensation on the exterior of sheet metal ductwork – caused by water vapor in the air; improper dehumidification; high relative humidity; lack of air circulation; openings in the building envelope; and poor indoor climate control.

- Duct leakage – due to loose-fitting joints and connections; improperly fabricated seams; physical damage to crawl spaces or attics; and leakage of return ducts below floor slabs allowing soil gases and moisture entry into ductwork.
- Use of fiberboard duct in warm, humid climates.
- Ductwork installed in vented attic spaces, especially in warm humid climates.
- Improper location of outdoor air intakes (OAIs) – for example, near exhaust air from kitchens, laundries, bathrooms, parking areas, loading docks, or dumpsters; or unprotected from birds and weather. Rooftop OAIs are especially vulnerable to bioaerosol sources from cooling towers, building exhausts, and standing water.
- Cooling towers providing heat transfer for the building's ventilation system that contain microbial growth on wet surfaces. Regardless of the recommended separation distance between the cooling tower and the OAIs (7.62 m), fastidious maintenance and treatment programs should be implemented to control growth of *Legionella* and other microorganisms in cooling towers [4].

Visual Inspection of HVAC Systems

Inspection of HVAC systems should be an integral part of building preventive maintenance. Inspection procedures and intervals should be based on building use/occupancy, length of heating and cooling season, building age and type of ventilation system, modifications to original building design, preventive maintenance and condition of the building and mechanical systems, and geographic location. In general, the older the ventilation system or building, the more frequent inspections should be conducted. Inspection intervals should not exceed one year. Geographic areas with climates having high humidity require more frequent HVAC system inspections, because of an increased risk of microbial contamination. Building occupancy also determines minimum inspection requirements. For example, a hospital is held to a higher standard of care than a retail outlet. HVAC inspections should include the AHUs, humidifiers and representative areas of the HVAC system components and ductwork [5]. Duct inspections should include a representative portion of supply system and return system ductwork components. Supply diffusers, mixing/control boxes, reheat coils, return air grilles, dampers, return plenums, and make-up air plenums should be inspected. Inspections should be conducted in a manner to prevent disturbance of settled dust and mold amplification. If mold contamination is suspected, then a qualified environmental health professional, such as a Certified Industrial Hygienist (CIH) with experience in performing microbial investigations, should be contacted to conduct an investigation. The cause should be identified and corrective action taken before remediation/cleaning. Safety precautions should be taken during the investigation to prevent aerosolization of fungal growth and microorganisms and cross contamination of other areas. In all cases, a conservative approach should be taken to protect the health and safety of building occupants. A moisture meter and an infrared thermal imaging camera to detect moisture in building materials, and a borescope (an inspection mirror with an illuminating light source to view spaces interstitial spaces, such as wall cavities and ductwork) are useful diagnostic tools. Procedures to identify problems with ductwork include checking supply diffusers for air movement using smoke tubes. If no air movement is detected, then check the fan motors. Improperly wired fan motors or reversed fan blades can cause fans to move air in the wrong direction. Inspect for closed dampers, clogged filters, open service openings, or ductwork leaks. Other specific causes for lack of airflow in ductwork may include air pressure losses from an inadequate fan motor, improper branch entry angles for ductwork, addition of exhaust ventilation hoods, installation of a duct turn or elbow too close to the fan inlet, and duct losses from friction and turbulence. If an inspection indicates that the HVAC system has excessive surface deposits or microbial contamination, then the system should be remediated.

DISCUSSION

Standard of Care for Duct Cleaning

A standard of care for duct cleaning starts with a comprehensive preventive maintenance program to mitigate conditions that created the need for cleaning. Consider installation of monitoring systems for proper climate control and periodic monitoring of air quality parameters – including temperature, relative humidity, air movement, pressure drop across a filter bank, and carbon dioxide – which are all surrogates for problems with degradation of indoor air. The installation of a manometer can provide an immediate indication of filter condition without performing a visual inspection.

The presence of dust in ductwork does not necessarily indicate microbial contamination. A small amount of dust on duct surfaces is normal. Problems with dust and other contamination in ductwork are a function of filtration efficiency, regular HVAC system maintenance, the rate of airflow, and housekeeping practices in the occupied space [6]. Condensation on the interior/exterior of ductwork, however, creates favorable conditions for microbial growth. If particulates accumulate in or on ductwork and the relative humidity reaches the dew point, then condensation occurs and the nutrients in the dust/dirt will cause microbial growth. Mold growth in HVAC systems and buildings requires timely remediation. Because water availability is a critical factor controlling microbial amplification in indoor environments, prompt correction and elimination of water intrusion/moisture sources are imperative.

Water-damaged or mold-impacted ductwork composed of porous or semi-porous materials – including fiberglass duct board, metal duct with fiberglass interior, metal duct externally wrapped with fiberglass insulation and insulated flex duct – should be removed and replaced under controlled conditions. Prior to removal engineering controls should be implemented. Engineering controls refer to equipment and procedures utilized to isolate a work area and to protect the occupants and the remediation workers – for example, temporary containment barriers, negative pressure enclosures, decontamination practices, specialized exhaust fans equipped with high efficiency particulate air (HEPA) filters, dehumidification equipment, and use of respiratory protection. Shut down all mechanical ventilation and HVAC system air handling equipment in the building prior to removal and remediation. All mechanical ventilation in the contaminated area, except that required to maintain the negative pressure, must be sealed off. All HVAC supply and return air vents, floor drains, doors, pipe chases, risers, and other penetrations within the rooms must be sealed with two layers of 6-mil fire retardant polyethylene sheeting to prevent migration of contaminants to other parts of the building. In general, controls are least stringent for building restoration and greatest for protection of sensitive populations [7]. For example, a greater standard of care is required to protect building occupants during remediation in schools and healthcare facilities.

Unlined sheet metal ductwork that is not physically damaged or corroded should be cleaned using mechanical agitation methods to dislodge attached particulate and debris and convey it to a collection device in a controlled manner. Agitation devices include: cable-driven brush, compressed air, and power water wash systems; pneumatic and electric driven brushes; and hand brushing tools. The collection device should be capable of creating a negative pressure differential between the ductwork and the surrounding area. It must maintain a minimum capture velocity to keep loosened particulate entrained during vacuuming, to prevent particle settling on the interior of HVAC system surfaces while being conveyed to the collection device. Minimum capture velocities depend upon the type of particulate and its aerodynamic diameter, particle size and density. Capture velocities required for dust transport range from

0.25 mps for small particulates in quiet air to 10 mps for large particulates released at high initial velocity into an area at very rapid air motion. The American Conference of Governmental Industrial Hygienists (ACGIH) *Industrial Ventilation: A Manual of Recommended Practice*, 26th ed., provides velocity requirements for contaminant removal.

Dry duct cleaning methods are preferred in almost all cases. Cleaning using water wash systems should be performed with extreme caution to prevent microbial growth. This method should be used only in places where porous insulation materials are not present on internal or external duct lining or in close proximity to the ductwork. Clean contaminated surfaces of non-porous ductwork using HEPA vacuums. Surfaces of the ductwork should then be damp-wiped with clean cloths using a water and detergent solution and HEPA vacuumed a second time. Ductwork components and the AHU should also be cleaned of mold-contamination and particulates. Return air grilles, supply diffusers, fan blades, and blower wheels should be cleaned and restored to their original position. Restorative drying equipment, such as portable power fans and dehumidifiers should be used to completely dry the ductwork after cleaning. The ductwork and HVAC system components should be clean and dry prior to re-starting the system. Biocides should not be used for cleaning ductwork. Biocides are not recommended for remediation because they: do not remove allergens and other metabolites from mold, do not kill all mold spores, and may pose health risk to some individuals.

Particle-laden ductwork composed of porous or semi-porous materials has a large surface area which can trap dust/dirt and absorb water compared to sheet metal ductwork. Procedures for cleaning sheet metal ducts should not be used for cleaning particulates from fiberglass-lined ductwork. Cleaning of lined ducts should be performed according to proven industry procedures described in the National Air Duct Cleaners Association (NADCA) *ACR 2006*: *Assessment, Cleaning and Restoration of HVAC Systems.* Lined ducts require a special type of cleaning to maintain their integrity and prevent damage to the lining. Fiberglass ductwork that shows evidence of damage, deterioration, delaminating, friable material, microbial growth, biological material, water damage or moisture accumulation should be replaced. The components being cleaned must be under a consistent negative pressure differential to the surrounding work area. It is extremely important that the cleaning procedure does not create abrasions, breaks, tears or other damage to fiberglass liner or duct board surfaces. Fiberglass materials that become wet during cleaning should be removed and the ductwork replaced.

Duct cleaning should be scheduled during periods when the building is unoccupied. Negative air pressure must be maintained at all times in the duct cleaning area to prevent migration of particulates and contaminants into occupied areas. Large high-volume vacuum equipment should be used with extreme care because negative pressure, together with limited airflow, can collapse ducts. Use existing duct system openings for cleaning unless the ductwork can be safely dismantled and removed under controlled conditions. Duct cleaning should be performed according to project-specific protocols described in a written mold remediation work plan. The plan should be developed by a qualified environmental health professional, such as a CIH, and detail specifications for scope of work, engineering controls, isolation and containment, proper personal protective equipment, and other protective measures necessary during the course of remediation. Specific protocols should be based on consensus guidelines developed by the Institute of Inspection, Cleaning and Restoration Certification (IICRC) S520 *Standard and Reference Guide for Professional Mold Remediation*; the U.S. Environmental Protection Agency (USEPA); NADCA ACR 2006; the New York City Department of Health; and other organizations. Remediation of mold impacted building materials and contents should be included in the work plan [8]. If the building containing the HVAC system has moderate, large or extensive areas of mold contamination, then HVAC remediation should be conducted after remediation of the building and contents is completed to prevent recontamination of the building's ventilation system. HVAC system remediation should be monitored by a qualified environmental health professional during all project phases, to ensure implementation of project-specific engineering controls and cleaning procedures. Maintaining the integrity of containments must be a high priority throughout the project.

Verification of Ductwork Cleanliness

Verification of ductwork cleanliness by means of a visual inspection should be performed by a qualified environmental health professional after cleaning, prior to HVAC system startup, to protect the health of building occupants. Measuring the effectiveness of cleaning may include a quantitative assessment as a secondary method if the results of the visual inspection are inconclusive. Visual inspection of the ductwork should be performed – to ensure that it is visibly clean, dry and free of contamination – while the containment is still intact. Service openings in the ductwork should be accessed to perform a visual inspection and closed afterward. The author typically performs a crude "white glove test" to help make a simple qualitative determination of cleanliness of non-porous surfaces (such as the interior of sheet metal duct immediately upstream of supply diffusers and downstream of the filter bank). The area within the containment should also be inspected to ensure that contaminated materials, visible dust and debris have been removed. There should be no malodors detected in the remediated area. If qualitative judgment in verifying ductwork cleanliness is not sufficient, then a quantitative assessment should be considered. Measuring the effectiveness of cleaning using secondary quantitative methods is best accomplished by a combination of methods: air sampling, surface sampling, laser particle counting, and moisture measurements. Samples and measurements for each method should be obtained before cleaning is performed to establish a baseline for comparison and after cleaning as part of post-remediation verification.

Air sampling is performed using a calibrated air sampling pump operating at a flow rate of 15.0 or 28.3 LPM. Fungal spore samples should be collected from the ambient indoor air and the outdoor air intake. One sample should be collected from the ambient indoor room air; another at a supply air diffuser; and another near the outdoor air intake. An additional outdoor sample should be taken at ground level outside the building for reference control purposes. Each sample should be collected for 2 to 5 minutes. The microbial samples should be analyzed by an Environmental Microbiology Accredited Laboratory using cultured methods, direct microscopy or Quantitative Polymerase Chain Reaction (Q-PCR) analysis. Although more costly, Q-PCR analysis appears to be the most likely technology to be used in the future because it provides very rapid turnaround and greater accuracy, sensitivity, and precision in identifying microbial species present. Microbial air samples are interpreted by comparing the types, distribution and levels of fungal spores found in suspect areas to non-suspect areas or outdoor control areas. General guidelines for interpretation of fungal spore data specify that indoor levels of mold spores should be less than outdoors. The biodiversity of fungal spores indoors should also be similar to outdoors. Surface sampling for fungal growth should be performed using sterile sampling swabs or tape lifts. A one square-centimeter surface should be sampled in each collection area. Samples should be collected on the interior of ductwork: one from the return and one from the supply air ducts. Samples should also be collected in a non-suspect/uncontaminated part of the building. The surface samples should be analyzed by an Environmental Microbiology Accredited Laboratory using cultured methods or direct microscopy. A general guideline for contamination using surface sampling is a comparison of samples collected from suspect and non-suspect areas. The sampling results should also be compared to those collected prior to duct cleaning. A decrease in spore counts should be observed after cleaning.

Particle counting is performed using a calibrated laser particle counter operating at a flow rate of 0.1 CFM. Particle measurements should be taken at approximately 50% of supply air diffusers and at a return air grille. Three samples should be taken at a representative return air grille. A sampling probe should be used for the return air measurements and an isokinetic probe for supply air measurements. Each sample should be collected for one minute. A printout should be generated from each sample enumerating individual particle sizes in the respirable size ranges of 0.3, 0.5, 0.7, 1.0, 2.0, and 5.0 µm. The data collected should be used to calculate the percentage increase or decrease in particulates measured in the air using the following formula:

$$\text{\% Increase or Decrease} = 100 \left(\frac{\text{Supply Air}}{\text{Return Air}} - 1 \right) \quad [9]$$

The data should be plotted on a modified ASHRAE filter efficiency performance chart. The data should also be compared to pre-cleaning measurements to evaluate the effectiveness of cleaning efforts. The data is also useful to evaluate the performance of the HVAC system filters and could demonstrate the need for upgrades in filter efficiency. Choice of the appropriate filter and proper maintenance are critical to keep ductwork clean.
The remediated ductwork should be both clean and dry after cleaning. Moisture measurements should be taken on the ductwork and components using infrared thermal imaging cameras or non-penetrating moisture meters. Ambient indoor conditions should be monitored during and after cleaning. Relative humidity in occupied spaces should be maintained below 60% and ideally 30 to 50% to increase comfort and minimize the growth of allergenic or pathogenic organisms. After post-remediation verification is completed and deemed to be satisfactory, new HVAC filters should be installed and the system operated to allow at least eight air changes prior to occupancy.

In conclusion, risk assessment, source identification, mechanical and building corrections, HVAC system cleaning, and post-remediation verification is a course of action that should be incorporated into best management practices for building HVAC systems throughout the world. Properly designed, operated and maintained HVAC system ductwork is paramount to achieve healthy indoor air in order to protect human health.

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