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Project Summary

Phase I Pilot Air Conveyance System Design, Cleaning, and Characterization

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Air conveyance system (ACS) cleaning, is advertised to homeowners as a service having a number of benefits, including the improvement of indoor air quality (IAQ). Because ACS cleaning includes many procedures applied to many different duct systems, evaluation has been difficult and the effectiveness of ACS cleaning has not been adequately measured.

The objective of this project was to develop and refine surface and airborne contamination measurement techniques that could be used to evaluate ACS cleaning. The research was in support of a field study to be conducted later. To this end, a pilot air conveyance system (PACS) using full-size residential heating and air-conditioning (HAC) equipment was constructed and operated to provide a controlled, artificially soiled, ACS environment. The PACS consisted of ducts, an HAC unit, a dust mixing room, an instrument room, and a dust generation and injection system. Three types of duct systems were evaluated with the proposed measurement methods under unsoiled and soiled conditions. Each duct systems was then cleaned by professional ACS cleaners and reevaluated.

As a result of the pilot study, the surface contamination measurement methods were evaluated over a range of conditions and improvements. Surface contamination (microbial and total dust) measurement methods and visual inspection showed that the pilot unit was effectively cleaned by the methods applied during this study. Submicron and larger particle counts were reduced following ACS cleaning, and respirable particle mass was reduced for two of the three duct systems tested. The significance of these results in an actual residence was not determined.

This Project Summary was developed by EPA's National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The overall objectives of the Air Pollution Prevention and Control Division's (APPCD's) Air Duct Cleaning Program are to determine when and how to clean ventilation systems, and evaluate both the effectiveness of such cleaning and its impact on IAQ. Little published research data are available to support the IAQ improvement claims sometimes made by ACS cleaning contractors, and the data that are available are difficult to interpret. A two-phase research program was undertaken to develop evaluation methods to achieve these objectives. This report describes research conducted under Phase I of the program. The research was a cooperative effort, led by RTI, with participation by personnel from APPCD, Acurex Environmental, Inc., and the National Air Duct Cleaners Association (NADCA). Its objective was to develop and operate a PACS as a test bed suitable for:

- Development and testing proposed ACS cleaning evaluation methods, and
- Comparison of IAQ instrumentation, intended for use in the field, under controlled conditions that were also as realistic as possible.

Phase II, a field study to be reported separately, was undertaken to evaluate ACS cleaning in actual residential use.

Though commonly referred to as "duct cleaning," ACS cleaning properly includes the cleaning of all air-side components of a ventilation system: air handler, heat exchanger, humidifier, blower, and duct system. It is sometimes advertised to homeowners as a service capable of preventing and possibly mitigating IAQ problems and may improve the energy efficiency of the relatively dirty systems. ACS cleaning is a broadly defined service, with a wide range of cleaning apparatus used by different contractors and different parts of the system cleaned using different equipment. Many combinations of cleaning procedures can be used on any given system, and there are many types of systems.

Procedures

Pilot Air Conveyance System

A PACS was constructed in a high-bay laboratory to allow artificial soiling of air duct components using a reasonable test aerosol. As shown in Figure 1, the pilot system included commercially available components expected to accumulate dust in varying degrees (e.g., bends, diffusers, registers, grills, blowers, heat exchangers, expansions, contractions, regions of surface irregularity, and dampers) and was designed to allow application of all aspects of the proposed evaluation methods with the exception of evaluation of IAQ in residences, including pre- and post-cleaning inspections and evaluations. The HAC equipment was all scaled for a small residence. The PACS was constructed of the following modules to simplify cleaning and allow substitution of new test components: 1) supply and return air ducts, 2) HAC unit including air-conditioning coil and heat exchanger, 3) dust mixing room, 4) instrument room, and 5) dust generation system. The PACS was operated in two modes:

- normal operation with flow into both rooms, and
- bypass of the instrument room during dust injection.

Standard, commercially available HAC equipment was used when possible. So that evaluation methods could be developed for the three major duct materials, completely separate PACS duct systems were constructed of the three duct materials commonly utilized in residential HAC: galvanized steel, fibrous glass duct liner (FDL), and fibrous glass duct board (FDB). A new air handler was installed for each duct type.

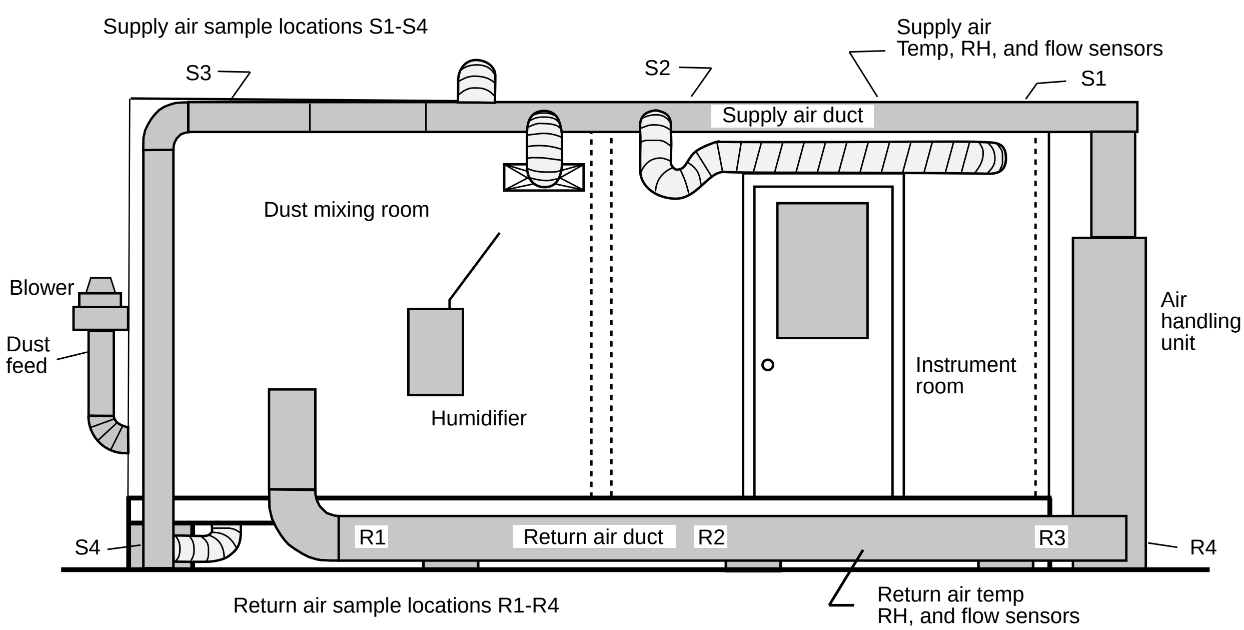

***Figure 1**. Elevation view of PACS.*

ACS Cleaning Measurement Methods

The measurement parameters and sampling and analysis methods evaluated were: 1) total surface dust loading, 2) culturable microbial surface loading, 3) respirable aerosol concentrations (PM_{10} and $PM_{2.5}$), 4) size dependent particle number concentration, 5) airborne fiber mass and counts, and 6) fungal bioaerosol concentrations.

The primary sampling method being evaluated (and hence, the parameter of greatest interest during the study) was measurement of the mass of dust on surfaces of the ACS components prior to and following ACS cleaning. Several variations of vacuum sample collection were evaluated, the most promising being the Medium Volume Dust Sampler (MVDS), which drew 10 L/min of air through a small brush or a custom designed slit nozzle.

A second important parameter measured was the number of culturable microbial organisms deposited on the duct and HAC surfaces within a 10 cm^2 template area, as measured with a swab technique and a 10 L/min vacuum method. Because of the short time between injecting the dust and sampling during most of these tests, microbial growth on the duct was not an issue during this research.

Airborne particle mass was measured with integrated size dependent impactor samplers at 10 L/min. Continuous optical particle monitors were set up in the instrumentation room of the PACS, measuring number concentration in three ranges: greater than 0.5 µm, greater than 5 µm, and over 16 differential channels between 0.1 and about 10 µm. Bioaerosol samples were also collected in the room using a 28.3 L/min slit to agar impactor. Although the data, particularly those collected with the continuous optical particle counters, showed changes in particle concentrations during the test, the reader is cautioned not to draw conclusions about the impact of ACS cleaning on airborne particle concentrations based on the data presented in the report due to the limited scope of the measurements and the artificial nature of the dust deposits and physical arrangement of the room in which the measurements were made.

Application of the Test Methods in the PACS

A complete test series for a single duct system consisted of a number of operating periods: 1) installation of the new duct system and checkout; 2) pre-soiling evaluation of the duct and HAC unit, 3) duct soiling and deposited dust conditioning, 4) post-soiling, pre-cleaning evaluation of the duct and HAC unit, 5) post-soiling, pre-cleaning air sampling, 6) cleaning the ventilation system, 7) post-cleaning evaluation before restarting the HAC unit, 8) immediate post-cleaning air sampling, 9) post-cleaning air sampling for total particles after cleaning, and 10) post-cleaning (24-hr) sampling.

ACS Cleaning Methods

Several procedures used during the cleaning phase of PACS operation were common to all three duct systems: 1) the supply and return grills were removed, power washed, and replaced as one of the final steps; 2) the interior of the HAC unit and the blower were cleaned each time; 3) the evaporator coil in the HAC unit was inspected and cleaned each time using a commercial coil cleaner; 4) negative system pressure was achieved each time by placing large portions of the duct system under vacuum so that the dust and debris loosened and entrained by the cleaning devices were transported to a large vacuum blower/filter unit capable of drawing 1 m^3/s (2000 cfm). It remained running as long as debris was being generated.

The three duct systems were cleaned using similar techniques. With the duct system isolated and under negative pressure, the galvanized steel duct was cleaned using primarily a stiff, abrasive-coated, cylindrical rotary power brush to loosen the dust. The test dust adhered well, and multiple passes were required to clean corners and the stiffening beads in the duct. Following brushing, air washing (configured to move debris through the system toward the main vacuum source) was used to entrain and transport any remaining dislodged dust to the collector.

Cleaning of the fiberglass lined and the duct board ducts was different primarily in that the rotary power brush was constructed of cloth strips to loosen the dust while minimizing damage to the duct material. Frequent inspection was used to prevent over cleaning and consequent damage to the duct. Hand-brushing was used where required.

Results and Discussion

An overview of the sampling conducted during this research is provided in Table 1. The discussion below presents selected results.

Total Duct Dust Sampling

The MVDS brush method worked well on the galvanized steel duct surface. Because there was no concern about dislodging surface materials, it could be used aggressively to obtain maximum collection efficiency. The method also worked well on the FDL used in this study. Although background mass was collected from surfaces of the new FDL prior to loading of the dust into the system, the amount of background mass from “clean” FDL was not substantially higher than that collected from the surface of flexible duct and foil liner in the same system. The amount of mass collected from “clean” FDL surfaces was also similar to that collected from galvanized steel duct surfaces, flexible duct surfaces, and foil liner after ACS cleaning.

The precision of the MVDS/brush sampling method was generally very good for duplicate side-by-side samples in spite of the variability of particle deposition in the ducts. Duplicate samples were obtained in locations similar in apparent dust loading. Over all the sampling in the three duct types and the flexible feeder ducts, the standard deviation of duplicates was between 8 and 40% of the mean mass for the pre-cleaning samples. This level of precision is probably adequate for sampling duct dust from ACS components because the dust loading at different locations in an ACS can be expected to be highly variable.

The NADCA sampling method was used only to collect post-cleaning samples from galvanized steel duct surfaces. This is currently the only application for which the method is recommended. It is not an efficient sampling method.

The average mass collected on the cleaned galvanized steel duct surfaces was 0.26 ± 0.11 g/m^2, while prior to cleaning the average of all samples was 7.0 ± 4.4 g/m^2. On the flexible duct surface, the bottom-of-duct average prior to cleaning was 4.3 ± 4.0 g/m^2 while after cleaning the overall average was 0.27 ± 0.09 g/m^2. The mass on the cleaned foil liner of the air handler was 0.28 g/m^2 in the galvanized duct system. Similar results were observed in the FDL system where the average mass on surfaces after cleaning was 0.39 ± 0.08 g/m^2 on FDL, 0.30 ± 0.06 g/m^2 on flexible duct, and 0.24 g/m^2 for the one foil liner sample. When efficient sampling methods such as the MVDS brush method are used, a more appropriate criterion for cleaning effectiveness is probably residual dust of less than 0.5 g/m^2 based on the results of these tests. The sampling results for the duct board system are inconclusive because all sample contained a large fraction of fibers that confounded efforts to measure removal of deposited dust.

Table 1. *Measurements Conducted*

Parameter	Sampling Method	Instrumentation	Analysis Method	Notes
Dust loading	Manual	EADS - brush	Gravimetric	Primary method
Dust loading	Manual	EADS - nozzle	Gravimetric	For duct board
Dust loading	Manual	NADCA method	Gravimetric	Un-lined galvanized only
Dust loading	Manual	High volume sampler	Gravimetric	Cooling coils only
Microbial loading	Manual	Pipet tip sampler	Plate counting	Applied to all ducts
Bioaerosol concentration	Integrated	Mattson-Garvin slit to agar impactor	Plate counting	1-hr integrated samples
$PM_{2.5}$	Integrated	MS&T impactor/filter and 20 lpm pump	Gravimetric	24-hr integrated samples
PM_{10}	Integrated	MS&T impactor/filter and 20 lpm pump	Gravimetric	24-hr integrated samples
Particles > 0.5µm (counts)	Continuous: 10-min averages	Climet CI-4100	Optical (scattered light)	Recorded with IAQDS and Climet
Particles > 5.0µm (counts)	Continuous: 10-min averages	Climet CI-4100	Optical (scattered light)	Recorded by Climet
Particle count - 16 channel	Continuous: 60-min averages	LAS-X	Laser aerosol spectrometer	Direct download to laptop computer
Fibers	Integrated	Filter/SKC pump	Phase contrast microscopy	NIOSH 7400 method - 24-hr integrated samples
Fibers	Semi-continuous	MIE FAM-1	Optical fiber monitor	PDL-10 data logger

Microbial Surface Samples

The microbial surface samples showed that duct cleaning significantly reduced the microbial loading (by factors of 10 to 20). However, the loadings were low and not amplification sites, so the results cannot be applied to microbial problem ducts. The nozzle technique gave results comparable to but generally lower than the swab on the galvanized and duct liner system, and higher on the duct board. Overall, the nozzle system was preferable for all systems.

Aerosol Measurements

The aerosol measurements were all conducted as an instrumentation and procedure shakedown study, and were not intended to establish the effect of ACS cleaning on indoor air quality. Integrated $PM_{2.5}$ and PM_{10} samples were collected in the instrument room during pre- and post-cleaning nominal 24-hr periods for each duct system. All concentrations were low (1.8 to 11.8 µg/m³ while the National Ambient Air Quality PM_{10} Annual Primary Standard is 50 µg/m³). The effect of the ACS cleaning was not clear-cut, given the small number of samples and lack of control over the particle content of infiltrating air. Following cleaning of the galvanized duct system, the inhalable particle mass was lower; it was higher for the fibrous glass liner; and about the same for the duct board system. The instrument shakedown that was the study's major purpose was successful, as pump and timer operation and flow stability were verified.

The mean optical particle counter results (an integrated sample) were similarly inconclusive with respect to the effect of duct cleaning but productive as an equipment shakedown test. Post-cleaning particle counts for particles >0.5 and >5.0µm were mostly lower following cleaning, but the differences are probably not significant.

Examination of the particle counter results as a function of time during the tests gave additional information. During most of the 24 hour period, particle counts in the instrument room actually were lower following cleaning of each duct. However, a burst of particles was emitted on start-up that raised the after-cleaning mean. This decrease occurred with both particle size ranges, and was especially clear for the >0.5 µm particles. The optical particle counter results show clearly that particle concentrations change from day to day even in a simple system such as the PACS and that aerosol samples must be taken over several days to make valid comparisons.

Airborne Fiber Measurements

Fibers were generally found to be below detection limits using both the integrated mass sampler and an optical detector.

Bioaerosols

The bioaerosol concentration was low in the instrument room for all tests. Concentrations high enough to allow pre- and post-cleaning comparisons were only reached with the galvanized duct. In this case, the overall culturable fungal concentration rose following AHU start-up (from about 20 cfu/m³ during the background, dirty duct, and during-cleaning samples) to 104 cfu/m^3 in the hour immediately following system startup. However, over 80% of that increase was sampled in the first 15 minutes of the 60-minute sample. After 45 minutes, the fungal concentration was down to about 2 cfu/m^3.

Conclusions and Recommendations

Overall, the PACS was successful as a test bed for sampling method development. That is, dust could be injected and conditioned, and the system cleaned such that the PACS was a reasonable laboratory surrogate for a residential ACS. Operated for only short periods, as was true of this work, it was not suitable for biocontaminant studies because active growth was not present. Conclusions from this research are summarized below:

1. Previously collected duct dust can be dispersed into a duct system and conditioned at high humidity to provide a realistic challenge to conventional ACS cleaning techniques. The dust deposit was clearly artificial but, in the opinion of experienced ACS cleaning practitioners, had reasonable distribution in the duct system and adhesion to the duct.
2. A pilot ventilation system can be used to investigate some aspects of ACS cleaning under controlled conditions and provide results that may be applicable to field ACS cleaning. Additional research is needed to understand all the parameters involved in obtaining a suitable ACS dust deposit, including dust injection and conditioning.
3. The medium volume dust sampler (MVDS), when fitted with a brush on the nozzle, was shown to be suitable for collection of dust from bare galvanized steel, FDL, and foil liner surfaces of ACS components. Collection efficiency of the MVDS with the brush was higher than the MVDS with a slotted nozzle or the NADCA Vacuum Test Method. The MVDS with brush is recommended to sample dust mass deposited on surfaces during the Phase II field study. NADCA Standard 1992-01 should be only used as intended.
4. Neither the MVDS with the slotted nozzle nor that with the brush was suitable for collection of dust from FDB. The brush dislodged a substantial amount of fibrous material from new FDB, while the nozzle did not effectively remove deposited dust on the fibrous surface. Accurate measurements of dust on FDB surfaces can not be made with the vacuum methods used in this study. If FDB cleaning is to be evaluated, a suitable surface sampling method must be developed.
5. The dust loading on bare galvanized steel duct surfaces that were cleaned was less than 0.02 g/m^2 when measured with the NADCA Vacuum Test Method, meeting the NADCA Standard 1992-01 criterion for effective cleaning. Collocated measurements with the MVDS-brush were 0.26, 0.37, and 0.36 g/m^2 at the three locations, demonstrating the low collection efficiency of the NADCA Vacuum Test method.
6. For microbial sampling of dust deposited on the surface of various fibrous glass and galvanized metal surfaces, the vacuum method provided more consistently reliable results than the surface swab technique and should be used in future studies. It was particularly superior on fibrous materials.
7. Both the results of the post-cleaning dust sampling and visual inspection indicated that the ACS components could be cleaned effectively by the methods used in this study. The amount of dust measured on ACS components after cleaning was comparable to those made prior to soiling in the PACS.
8. The impact of ACS cleaning of particle concentration indoors remains unclear because infiltration and filtration effects confounded the results.
9. The importance of collecting multiple integrated samples and the need to measure particle concentrations for extended pre- and post-cleaning periods were evident in the indoor particle data.
10. No evidence was obtained for fiber emission from the cleaned duct systems, but the scope of this research was too limited to allow a definitive conclusion on fiber emissions from FDB.
11. A brief pulse of particles was released when the galvanized ACS was returned to service following cleaning. This phenomenon was detected by both the bioaerosol and optical particle samplers.
12. While not a focus of the study, as the research progressed it became apparent that ACS construction quality was an important variable in both PACS operation and the "cleanability" of an ACS. While poor construction practices did not interfere with this study, which focused on methods development and not measurements, they did affect the performance of the ACS and the ease and thoroughness with which it could be cleaned.

    With regard to the duct itself, the unlined galvanized duct installed in the PACS had no apparent construction flaws. The butt joints between sections in the FDL system had been sprayed with duct liner adhesive but were not sealed with a mastic. A small piece of liner near the return air inlet was found to be loose when inspected prior to cleaning. The cut edges in the FDB system did not appear to be sealed and were not coated. These construction details, while not in accordance with applicable construction standards, were flaws that the duct cleaning professionals considered to be very common.

    In addition to duct quality shortcomings, the air handler, though it was in "as received" condition, was not perfectly sealed, and coil bypass and leaks occurred at several points.
13. The study of biocontamination in an ACS must be conducted over longer time periods than were available to the present research so that active microbial growth can become established in the ACS. Accomplishing this would present some risk of exposure for those working in the vicinity unless the PACS was redesigned for containment to prevent exposure, and may be impractical. Such studies are needed, and use of smaller biocontamination study apparatus is thus recommended.
14. Biocides, encapsulants, and sealants are all used in residential ACS cleaning in attempts to control biocontamination without replacing duct work. The usefulness of these practices and their potential threats to residents have not been determined and should be investigated.

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***Russell N. Kulp** is the EPA Project Officer (see below).*
The complete report, entitled "Phase I Pilot Air Conveyance System Design, Cleaning, and Characterization," (Order No. PB97-189682; Cost: $25.00, subject to change) will be available only from:
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