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Project Summary

Results of a Pilot Field Study to Evaluate the Effectiveness of Cleaning Residential Heating and Air-Conditioning Systems and the Impact on Indoor Air Quality and System Performance

Roy Fortmann, Cary Gentry, Karin Foarde, and Douglas VanOsdell

The U.S. Environmental Protection Agency (EPA), Air Pollution Prevention and Control Division (APPCD) in conjunction with the National Air Duct Cleaners Association (NADCA) performed a pilot field study to evaluate the effectiveness of air duct cleaning (ADC) as a source removal technique in residential heating and air conditioning (HAC system) systems and its impact on airborne particle, fiber, and bioaerosol concentrations. Data were also collected to assess the potential impact of cleaning on performance of the air handler and cooling system.

The field study was conducted at EPA's Indoor Air Quality (IAQ) Test House and eight occupied homes in the Research Triangle Park area of North Carolina. Week-long studies conducted at each home involved background air monitoring and sampling, cleaning of the HAC system by NADCA, and post-cleaning monitoring and sampling. Measurement parameters included airborne particle, fiber, and fungi concentrations; microbiological and dust deposition sampling in the supply and return air ducts; various system related parameters including air flows, static pressures, temperature, and relative humidity; and environmental parameters indoors and outdoors.

The report discusses the technical approach for the study and the study results. Results are presented on the effectiveness of ADC, its impact on selected IAQ parameters, and an assessment of its impact on system performance. Recommendations are provided in the report on future research needs.

Results of this pilot study will be useful to the EPA for preparing a strategy for further research on heating, ventilating, and air conditioning (HVAC) system cleaning and development of consumer information.

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

HAC system source removal is commonly referred to as air duct cleaning (ADC). It generally involves the physical removal of deposits of dirt, dust, particulate matter, and debris from air distribution systems including system components such as fans, heating and cooling coils, and control devices such as dampers and turning vanes. In recent years there has been a substantial increase in the number of companies offering ADC services both in commercial and residential buildings. Despite some claims that ADC improves IAQ and reduces heating and cooling energy costs, there is little published research data on its effectiveness to meet these claims. A research program has been initiated by the EPA's National Risk Management Research Laboratory (NRMRL) to develop and provide information relevant to these issues. The research is being conducted in conjunction with the NADCA.

The objectives of this project included:

- Evaluate sampling and analysis methods that may be used to quantitatively assess the effectiveness of cleaning (source removal) of non-porous ductwork and components of residential HAC systems.
- Collect information on the effectiveness of currently available cleaning methods for removal of dust and debris from HAC systems in residences.
- Evaluate monitoring, sampling, and analysis methods to determine if they can be used to quantitatively assess the impact of source removal from HAC systems on airborne particulate and fiber concentrations.
- Collect information on the impact of HAC system cleaning on airborne particulate and fiber concentrations in residences.
- Collect information on the impact of cleaning on the performance of the HAC system in residences.
- Collect information that can be used to develop a research strategy for further assessing the effectiveness and impact of HVAC cleaning in residential and non-residential buildings.

Technical Approach

To evaluate ADC effectiveness, a pilot field study was designed and implemented. The study was conducted in the Research Triangle Park area of North Carolina during the summer of 1996. Participants were recruited into the study who had central (whole-house) cooling systems and forced air distribution systems. The study was performed at the unoccupied EPA Indoor Air Quality Test House and eight occupied houses that were purposefully selected. Homes were selected for the study that had a range of "dust" levels in the supply and return ducts of the HAC system, that varied in size and layout (e.g., two-story, single-story, and split-level homes), and that differed with respect to accessibility and complexity of the ductwork. A week-long study was performed at each home. Background air monitoring and sampling were performed for 2 to 4 days, then the system was cleaned by NADCA. The air distribution ducts and air handler components were cleaned using methods commonly used in the ADC industry and accepted for use by NADCA in this study. No proprietary methods or truck-mounted systems were used in this study. Sources were removed by mechanical cleaning. Chemical biocides were not used in this study. Monitoring and sampling were performed for 2 to 4 days following cleaning.

Various parameters related to IAQ and system performance were measured prior to and following cleaning. The IAQ measurements included 24-hr integrated particle mass concentrations ($PM_{2.5}$ and PM_{10}), continuous measurements of particle concentrations (particles/cubic meter) with a two-channel optical monitor, continuous measurements of particle concentrations with a 16-channel spectrometer, integrated and continuous measurements of fiber concentrations, and airborne fungi concentrations. Parameters related to the performance of the air handling unit (AHU) included air flows for the supply and return air, static and differential pressures, coolant line temperatures, AHU blower motor current, supply and return temperature and relative humidity (RH), and system on-time. Additionally, temperature and RH were measured indoors and outdoors. To assess ADC effectiveness, the levels of dust (particulate and fibrous combined) were measured in the supply and return ducts prior to and following, cleaning using a medium volume vacuum sampler with collection on an in-line filter. Microbial loading on duct surfaces was evaluated using a vacuum/filter method for collection of samples from a defined area.

Results and Discussion

The mass of dust (particulate and fibrous) deposited on the bottom surfaces of the supply air ducts prior to cleaning ranged from an average of 1.5 to 26.0 g/m^2 at the nine houses (Table 1). Dust levels were higher on the bottom surfaces of the return air ducts, ranging from an average of 5.3 to 35.1 g/m^2. The HAC system cleaning methods employed in the study effectively removed dust and debris. Post-cleaning dust levels ranged from 0.06 to 1.97 g/m^2 and the average was 0.43 g/m^2 for 58 samples collected from the surfaces of supply and return ductwork during the study.

Measurements of residual dust on ductwork surfaces after cleaning with the NADCA Standard 1992-01 vacuum method ranged from 0.01 to 0.36 mg/100 cm^2, meeting the NADCA criterion that residual dust must be less than 1.0 mg/100 cm^2 to demonstrate that the cleaning was effective. Side-by-side measurements with the NADCA vacuum method and the medium volume dust sampler (MVDS), which was developed for this study, showed that the collection efficiency of the MVDS was higher than the NADCA method. The results suggest that the criterion for demonstrating that ADC is effective should be higher, probably 5 mg/100 cm^2, if the post-cleaning samples are collected with the MVDS.

The impact of mechanical cleaning without the use of chemical biocides on the levels of bacteria in samples collected from the surfaces of the HAC system was highly variable. Bacterial pre-cleaning surface levels in the ducts ranged from 5 to 1100 cfu/cm^2 in the supply side and from 5 to 2300 cfu/cm^2 in the return, with a mean of less than 200 cfu/cm^2 in most homes. Mean concentrations of bacteria in samples collected from surfaces of return ducts were lower after cleaning in six of seven houses with return duct samples. But the bacteria levels were lower in surface samples from the supply ducts in only four of the occupied homes and the pre-cleaning versus post-cleaning difference was generally small.

Fungal levels in samples collected from duct surfaces were generally higher than bacterial levels. Cleaning had the most impact on the ducts with the highest levels of fungi and noticeably reduced the level of fungi in samples collected from ductwork in most houses (Table 2).

There was no correlation between levels of dust collected from surfaces of furnishings in the homes and levels of dust measured in either the supply or return ducts. There was also little correlation between surface microbial loads and the dust levels measured in the houses.

Indoor respirable ($PM_{2.5}$) and inhalable (PM_{10}) particle mass concentrations were low at the houses, ranging from 4.2 to 32.7 μg/m^3 (Table 3), consistent with results from past studies in houses without tobacco smoking or other major sources. The measurements of respirable and inhalable particle mass concentrations indoors and outdoors suggest that, during this study, the indoor concentrations were strongly impacted by outdoor concentrations. The indoor/outdoor ratios for the integrated particle samples were less than 1.0 for all but two of 72 sets of samples collected at the nine study homes. The ratio of the post-cleaning to the pre-cleaning concentrations of respirable particles measured indoors was greater than 1.0 at seven of the nine houses (Table 3). However, at all but one of these seven houses, the post-cleaning/pre-cleaning ratio was also greater than 1.0 for the outdoor respirable particle concentrations. The post-cleaning/pre-cleaning ratios of PM_{10} concentrations indoors and outdoors followed similar, but less clear, trends. Indoor particle mass concentrations may also have been impacted by occupant activity and other indoor sources. The results of the particle mass measurements suggest that,

Table 1. Mean and Maximum Dust Levels Measured on Surfaces of HAC System Ductwork in the Study Homes

House	Summary Statistic	Duct Dust Mass (g/m^2) Supply Pre-Cleaning	Supply Post -Cleaning	Return Pre-Cleaning	Return Post -Cleaning
TH	Mean	2.33	0.74	-[a]	-[a]
	Max	4.66	1.24	-[a]	-[a]
1	Mean	8.62	0.30	19.83	0.58
	Max	26.30	0.41	13.10	0.63
2	Mean	3.37	0.21	24.13	0.44
	Max	5.79	0.30	40.80	0.60
3	Mean	1.91	0.25	7.80	0.28
	Max	3.00	0.35	13.15	0.42
4	Mean	1.48	0.27	7.89	0.12
	Max	1.69	0.34	9.55	0.17
5	Mean	2.28	0.59	11.34	1.11
	Max	2.62	0.87	11.49	1.97
6	Mean	2.30	0.18	5.26	0.15
	Max	2.45	0.18	6.99	0.19
7	Mean	3.34	0.50	12.91	0.32
	Max	5.93	0.69	16.78	0.34
8	Mean	26.03	0.79	35.11	0.39
	Max	36.07	1.13	51.10	0.59

[a] Return air duct replaced; no samples collected.

Table 2. Results of Surface Samples of Fungi in the Supply and Return Ducts

House	Summary Statistic	Cfu/cm^2 Supply Pre-Cleaning	Supply Post-Cleaning	Return Pre-Cleaning	Return Post-Cleaning
1	Mean	35700	1206	2650	-[a]
	Max	250000	4700	4800	-[a]
2	Mean	9217	138	280	153
	Max	19000	640	320	260
3	Mean	4604	740	22333	147
	Max	8300	1700	26000	190
4	Mean	73400	15890	850	617
	Max	160000	36000	1200	1000
5	Mean	35	46	58	71
	Max	110	120	90	140
6	Mean	113	61	613	7
	Max	250	130	2600	15
7	Mean	1089	49	2200	23
	Max	3900	150	2400	40
8	Mean	63	7	196	10
	Max	170	15	320	15

[a] No sample collected

Table 3. Impact of ADC on Airborne $PM_{2.5}$ and PM_{10} Concentrations

		$PM_{2.5}$			PM_{10}		
		µg/m³		Ratio	µg/m³		Ratio
House	Location[a]	Pre-Cleaning[b]	Post-Cleaning[b]	Post/Pre	Pre-Cleaning[b]	Post-Cleaning[b]	Post/Pre
TH	Outdoor	23.3	20.4	0.88	28.1	26.1	0.93
	Primary	7.5	10.3	1.37	11.1	29.0	2.61
	Secondary	7.8	10.8	1.38	9.5	14.2	1.49
1	Outdoor	8.6	28.1	3.27	14.4	33.8	2.35
	Primary	6.5	15.3	2.36	10.7	22.1	2.08
	Secondary	6.3	16.0	2.56	8.6	18.7	2.17
2	Outdoor	11.6	29.3	2.53	18.7	32.8	1.75
	Primary	11.8	16.9	1.43	15.2	19.2	1.26
	Secondary	10.5	16.8	1.60	12.1	13.1	1.08
3	Outdoor	35.0	25.3	0.72	42.1	28.5	0.68
	Primary	16.5	13.3	0.80	17.7	17.4	0.98
	Secondary	16.7	12.3	0.74	18.9	16.2	0.86
4	Outdoor	24.6	33.8	1.37	28.8	41.5	1.44
	Primary	11.8	25.7	2.17	15.6	33.6	2.15
	Secondary	10.8	21.9	2.03	12.6	11.0	0.87
5	Outdoor	14.4	22.8	1.59	19.0	30.3	1.59
	Primary	5.7	10.3	1.81	10.0	13.6	1.36
	Secondary	5.2	10.7	2.05	8.7	13.8	1.59
6	Outdoor	14.8	21.6	1.46	23.4	20.6	0.88
	Primary	6.5	6.8	1.05	10.3	9.7	0.94
	Secondary	8.3	8.3	1.01	9.7	8.4	0.87
7	Outdoor	21.3	12.5	0.59	26.2	21.0	0.80
	Primary	11.7	8.5	0.73	14.3	11.4	0.79
	Secondary	11.3	7.7	0.68	13.2	11.3	0.86
8	Outdoor	13.7	17.4	1.27	26.2	22.1	0.84
	Primary	11.3	13.2	1.17	10.9	12.7	1.17
	Secondary	7.7	10.9	1.42	15.7	13.7	0.87

[a] Measurements were performed at an outdoor location and in two rooms in the home, generally a family room (primary) and a secondary, lesser used room.
[B] Mean for two days prior to and two days following ADC.

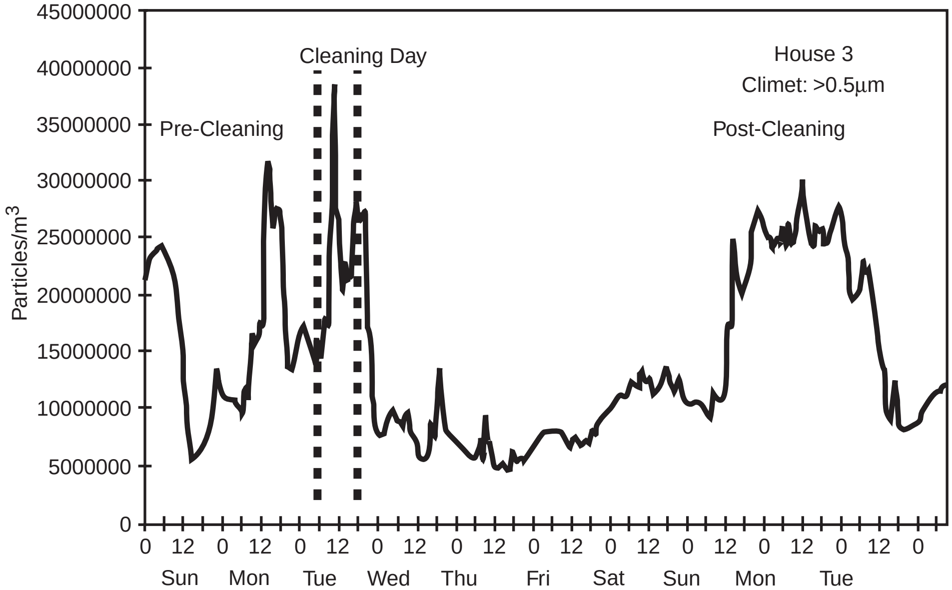
although the HAC system cleaning very effectively removed one source of particulate matter in the study homes, the airborne concentrations before and after cleaning were not substantially different in the study homes due to the impact of outdoor particle sources and other indoor sources, such as occupant activity, cooking, and pets.

Measurements of particle concentrations (particles/cubic meter) indoors with a two-channel optical particle counter and a 16-channel laser aerosol spectrometer also did not show substantial differences in airborne particle concentrations before and after cleaning. The mean concentrations of particles in a >0.5 µm size fraction measured indoors following cleaning were lower only at the Test House and at two of the eight field study houses. The post-cleaning/pre-cleaning ratio was near 1.0 at two houses, but higher than 1.0 at the other four occupied field study homes. Measurement results at two houses that were cleaned on the same week and located across the street from each other suggest that the outdoor particle levels had a strong impact on indoor particle concentrations (Figure 1). At both houses, indoor particle concentrations increased on Sunday and Monday following cleaning, even though the houses were cleaned on different days, the HAC system operation patterns differed, and occupant activities differed dramatically at the two houses. The occupants of House 4 were not in the home most of the Saturday through Monday period.

Mechanical cleaning without the use of chemical biocides did not appear to impact fungal bioaerosol concentrations at the nine study homes. With the exception of one house, there was no substantial difference between the pre-cleaning and post-cleaning bioaerosol concentrations.

Measurements of parameters related to system performance suggest that cleaning had a positive impact on system performance. Because of the small sample size (nine study homes) and the limited duration of measurements, it was not possible to quantitatively determine the significance of ADC on system performance and energy use. ADC generally resulted in increased air flow to the house. Supply air flows increased between 4 and 32% at eight houses based on measurements at the floor registers and diffusers in the house. Some of this increase in supply air flow rates may have been attributable to minor repairs of leaks in the ducts and loose floor boots of supply registers. . Return air flows measured at the return air grilles increased 14 and 38% at two houses, but were not substantially different after cleaning at the other seven houses.

AHU blower motor current increased after ADC at the four field study houses where measurements were performed. Static pressure increased in the return air ductwork at the six houses with complete measurements. The increase in blower motor current and increase in static pressure in the return ducts suggest improved system performance. There was no clear trend for changes in static pressure in the supply ducts or the differential pressures across the coil. Coolant line surface temperatures did not provide useful information.



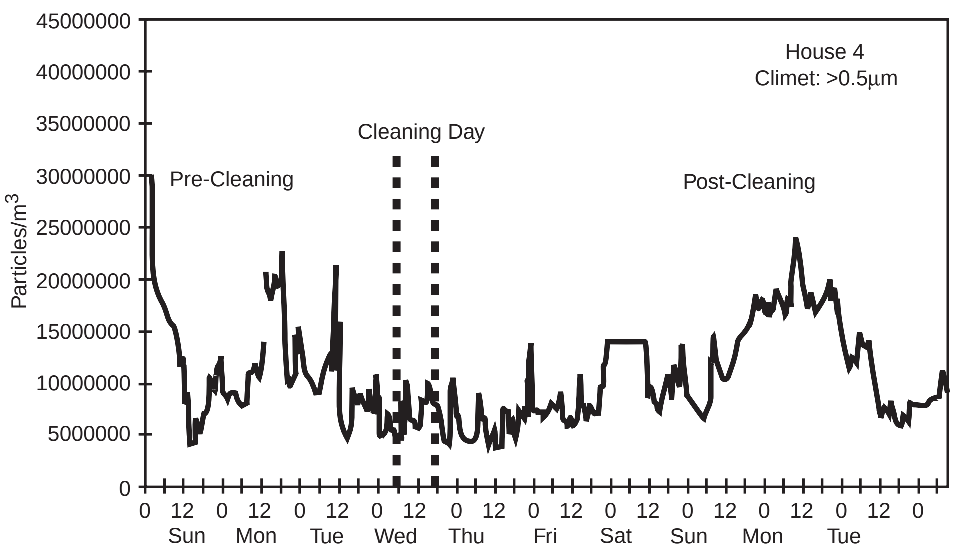


Figure 1. Concentrations of particles in the >0.5µm size fraction measured at two houses during the same week of the study.

Example engineering calculations made to estimate the change in heat transfer for the cooling coil following cleaning suggests that the systems performance improved. Using data for House 5, which had a 38% increase in return air flow, and House 6, which had a 14% increase in return air flow, the estimated increase in heat transfer for the cooling coils was 14% at House 5 and 23% at House 6. Changes of this magnitude would likely result in improved overall system efficiency. However, the data from this study are inadequate to calculate overall system efficiency.

The evaluation of the methods and protocols in this study will provide valuable information that can be used to develop and refine EPA's research strategy in the area of ADC. Results of this study demonstrated that the medium volume dust sampler method developed for this study could be used to quantitatively assess the effectiveness of source removal cleaning by collection of dust samples from surfaces. The methods and protocol for measurements of airborne particles, fibers, and bioaersols, however, were shown not to be useful for quantitatively determining the impact of ADC on these IAQ parameters. Although cleaning effectively removed one potential source of particulate and fibrous matter in the study homes, neither integrated sampling nor continuous monitoring methods could detect a change in airborne concentrations of the IAQ parameters. The study results suggest that physical measurements of IAQ parameters may not be useful for assessing ADC impact IAQ parameters in occupied homes because of the multiple sources of air contaminants, including outdoor sources and occupant activities, and because temporal variability of air contaminant concentrations makes it difficult to discern an effect on IAQ parameters.

Conclusions and Recommendations

The results of the nine home field study have demonstrated that mechanical cleaning methods and equipment commonly used by ADC cleaning contractors for source removal cleaning of HAC systems effectively removed particulate and fibrous contamination, thus removing a potential source of particulate and fiber contamination. The impact of ADC on levels of bacteria and fungi on surfaces of the ductwork could not be fully evaluated because chemical biocides were not used in this study. The medium volume dust sampler developed for this study was shown to be appropriate for quantitatively assessing the effectiveness of ADC. Results of measurements of system-related parameters indicate a positive impact on HAC system performance, although the impact could not be quantified in this study due to the small study population (nine homes) and the short monitoring duration. The short-term air monitoring and sampling methods and protocols, however, were not adequate for assessing the impact of ADC on airborne particle and fiber concentrations. Due to the multiple sources of air contaminants in the homes and temporal variability in airborne concentrations, differences in these IAQ parameters could not be determined between the pre-cleaning and post-cleaning periods.

Results of this pilot study indicate the need for further research on ADC in a number of areas. Additional research, using alternative methods, will be required to quantitatively determine the impact of ADC on IAQ parameters. Research would also help quantify the impact of ADC on energy use for residential systems. That research may be most effectively performed in EPA's pilot scale test facility where environmental conditions can be controlled and long-term tests can be performed. Additional areas of potential research include: evaluation of methods for cleaning porous duct materials, the use of biocides during cleaning, effectiveness and durability of encapsulants applied to porous duct materials, and methods for reducing contamination in HVAC systems. Research could also include large HVAC systems in office and public access buildings where the impact on IAQ and energy use may be greater.

Roy Fortmann and Cary Gentry are with Acurex Environmental Corporation, Research Triangle Park, NC 27709; and Karin Foarde and Douglas VanOsdell are with Research Triangle Institute, Research Triangle Park, NC 27709.
***Russell M. Kulp** is the EPA Project Officer (see below).*
The complete report, entitled "Results of a Pilot Field Study to Evaluate the Effectiveness of Cleaning Residential Heating and Air Conditioning Systems and the Impact on Indoor Air Quality and System Performance," (Order No. PB98-142 011; Cost: $51.00, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Air Pollution Prevention and Control Division
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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