



# Research and Development

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

## Prepared for

Office of Radiation and Indoor Air

## Prepared by

National Risk Management  
Research Laboratory  
Research Triangle Park, NC 27711

**TECHNICAL REPORT DATA**  
*(Please read Instructions on the reverse before comp*



PB98-142011

|  |   |  |
|--|---|--|
| 1. REPORT NO.<br><b>EPA-600/R-97-137</b>   |   | 2.   |
| 4. TITLE AND SUBTITLE<br><b>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</b>  |   | 5. REPORT DATE<br><b>December 1997</b>                           |
| 7. AUTHOR(S)<br><b>R. Fortmann and C. Gentry (Acurex), and K. Foarde and D. VanOsdell (RTI)</b>  |   | 6. PERFORMING ORGANIZATION CODE                                  |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br><b>Acurex Environmental Corp., PO Box 13109, RTP, NC 27709; and Research Triangle Institute, PO Box 12194, RTP, NC 27709</b>  |   | 8. PERFORMING ORGANIZATION REPORT NO.                            |
| 12. SPONSORING AGENCY NAME AND ADDRESS<br><b>EPA, Office of Research and Development<br/>Air Pollution Prevention and Control Division<br/>Research Triangle Park, NC 27711</b>  |   | 10. PROGRAM ELEMENT NO.  |
|  |   | 11. CONTRACT/GRANT NO.<br><b>68-D4-0005/2-030 (Acurex)</b>       |
|  |   | 13. TYPE OF REPORT AND PERIOD COVERED<br><b>Final; FY95-FY96</b> |
|  |   | 14. SPONSORING AGENCY CODE<br><b>EPA/600/13</b>                  |
| 15. SUPPLEMENTARY NOTES<br><b>APPCD project officer is Russell M. Kulp, Mail Drop 54, 919/541-7980.</b>  |   |  |
| 16. ABSTRACT<br>The report discusses and gives results of 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) 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 study was conducted at EPA's Indoor Air Quality Test House and eight occupied homes in the Research Triangle Park area of North Carolina. Week-long studies at each home involved background air monitoring and sampling, cleaning of the HAC system, 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 flow, static pressure, temperature, and relative humidity; and environmental parameters indoors and outdoors. Study results are presented on the effectiveness of ADC, its impact on selected indoor air quality parameters, and an assessment of its impact on system performance. Recommendations are provided on future research needs. |   |  |
| 17. KEY WORDS AND DOCUMENT ANALYSIS  |   |  |
| a. DESCRIPTORS   | b. IDENTIFIERS/OPEN ENDED TERMS                         | c. COSATI Field/Group  |
| Pollution<br>Cleaning<br>Ducts<br>Heating<br>Air Conditioning<br>Residential Buildings   | Pollution Control<br>Stationary Sources<br>Indoor Air   | 13B<br>13H<br>13K<br>13A<br><br>13M                              |
| 18. DISTRIBUTION STATEMENT<br><b>Release to Public</b>   | 19. SECURITY CLASS (This Report)<br><b>Unclassified</b> | 21. NO. OF PAGES<br><b>228</b>                                   |
|  | 20. SECURITY CLASS (This page)<br><b>Unclassified</b>   | 22. PRICE  |

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E. Timothy Oppelt, Director  
National Risk Management Research Laboratory

## ABSTRACT

The mechanical cleaning of heating, ventilating, and air conditioning (HVAC) systems, often referred to as air duct cleaning (ADC), involves the physical removal of particulate matter and debris from air distribution systems and air handler components. In recent years there has been a substantial increase in the number of companies offering services for ADC of air conveyance systems in large buildings and in residences. Despite some claims that ADC improves indoor air quality (IAQ) and reduces heating and cooling energy costs, there is little published research data on the effectiveness of HVAC system cleaning or its impact on IAQ and energy use for residential heating and air conditioning (HAC) systems. A research program has been initiated by the U.S. Environmental Protection Agency (EPA) National Risk Management Research Laboratory (NRMRL) Air Pollution Prevention and Control Division (APPCD) in conjunction with the National Air Duct Cleaners Association (NADCA) to evaluate the effectiveness of HAC system cleaning and its impact on IAQ and system performance in residential buildings.

To evaluate the effectiveness of HAC system cleaning in residences and its impact on IAQ and system performance, a pilot field 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. A week-long study was performed at each home. Background air monitoring and sampling were performed for three days, then the systems were professionally cleaned by NADCA. Cleaning of the air distribution ducts and air handler components was performed using methods and equipment 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 the study. Source removal was performed by mechanical cleaning and chemical biocides were not used in the study. Monitoring was performed again for two to four days following cleaning. Pre- and post-cleaning measurements of particulate matter in the ducts was performed to assess duct cleaning effectiveness. Measurements were also performed throughout the study period at each house to assess the impact of cleaning on HAC system performance.

The results of the study demonstrated that the mechanical cleaning methods commonly used in the HVAC system cleaning industry effectively removed particulate and fiber contamination from the system, thus removing one potential source of particulate air contaminants in the study homes. Dust (particulate and fibrous) levels on surfaces in the supply air ducts prior to cleaning ranged from an average of 1.5 to 26.0 g/m<sup>2</sup> at the nine houses. Dust levels were higher in the return air ducts, ranging from an average of 5.3 to 35.1 g/m<sup>2</sup>. Post-cleaning dust levels ranged from 0.06 to 1.97 g/m<sup>2</sup> and the average was 0.43 g/m<sup>2</sup> for 58 samples collected from the surfaces of supply and return ductwork with a medium volume dust sampler developed

specifically for this study. Dust levels measured on duct surfaces with the NADCA Standard 1992-01 vacuum sampler method met the criterion of 1.0 mg/100 cm<sup>2</sup> for demonstrating cleaning effectiveness at all study homes.

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<sup>2</sup> in the supply side and from 5 to 2300 cfu/cm<sup>2</sup> in the return, with a mean of less than 200 cfu/cm<sup>2</sup> 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 on HAC system duct surfaces were generally higher than bacterial levels. Mechanical cleaning without the use of chemical biocides had the most impact on the ducts with the highest levels of fungi and noticeably reduced the level of fungi on ductwork surfaces in most houses.

There was no apparent relationship between levels of dust collected from surfaces of furnishings in the study homes and the levels of dust measured on surfaces of the HAC system ductwork. There was also little correlation between surface microbial loads and dust levels measured in the houses.

Indoor respirable (PM<sub>2.5</sub>) and inhalable (PM<sub>10</sub>) particle mass concentrations were low at the houses, ranging from 4.2 to 32.7 µg/m<sup>3</sup>, consistent with results from past studies in houses without tobacco smoking or other major sources. Differences in airborne concentrations of particle mass in the two size fractions between pre-cleaning and post-cleaning periods were highly variable. There was no trend related to HAC system cleaning. Comparison of indoor and outdoor particle mass concentrations suggested that the outdoor concentrations had a substantial impact on indoor concentrations. Continuous measurements of particle concentrations (particles/m<sup>3</sup>) also demonstrated the strong impact of outdoor concentrations. The study results suggest that although the source of particulate matter in the HAC system was effectively removed, the magnitude of the impact of HAC system cleaning on particle concentrations could not be quantitatively determined due to the presence of other indoor sources, occupant activity, and the impact of outdoor particle sources.

Airborne fiber concentrations were low at all houses, precluding an assessment of the impact of HAC system cleaning on this parameter. Measurements of fibers with a continuous optical monitor suggested that HAC system cleaning reduced airborne fiber concentrations at the EPA IAQ Test House and the house that had the highest levels of fibers in the ductwork based on visual observation. There was no substantial effect on fungal bioaerosol concentrations following the mechanical cleaning of the HAC system without use of chemical biocides.

Measurements of parameters related to performance of the HAC system suggested that cleaning may improve system performance. HAC system cleaning generally resulted in increased air flows in the system. Air flows measured in the house at supply registers and diffusers increased 4 to 32% at eight of the houses. The current to the air handler blower motor increased after cleaning at all houses where the measurement was performed. Using data collected in the study for HAC system parameters, calculations were made to determine the enthalpy across the cooling coil and to estimate the total heat removed by the coil for the two houses that had the largest increase in return air flows. The estimated increase in the amount of heat removed by the cooling coil was 14 and 23%, suggesting that there would be increased overall system efficiency.

Results of the study demonstrated that methods commonly used in the HVAC system cleaning industry effectively removed particulate and fibrous materials from the HAC systems in the study homes. The medium volume dust sampler developed for this study was shown to be an effective tool for quantitatively assessing HAC system cleaning effectiveness. Measurements of HAC system parameters suggest that cleaning should have a positive impact on energy use. But the impact could not be quantified in this study due to the limited number of study homes and short duration of the study at each home. Neither the short-term integrated sampling methods nor the continuous air monitoring methods could be used to assess the impact of HAC system cleaning on airborne particulate or fiber concentrations due to the presence of other indoor air contaminant sources. The results for the assessment of the impact of HAC system on IAQ parameters, therefore, were inconclusive. Additional research using alternative methods would be helpful. Further research would also help to quantify the impact of HAC system cleaning on energy use. The report also suggests research on a number of other HVAC cleaning issues.

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## **ACKNOWLEDGMENTS**

The success of this project was the result of the work and input of a number of people. The authors wish to acknowledge the efforts of all those who contributed to the design, implementation, analysis, and reporting of this study.

Overall project goals were provided by Russell Kulp with the assistance of Marc Menetrez and the Ventilation Research Team of the Air Pollution Prevention and Control Division of the U.S. Environmental Protection Agency (EPA) National Risk Management Research Laboratory.

The project was a joint effort of the EPA and the National Association of Air Duct Cleaners (NADCA) under the Cooperative Research and Development Agreement (CRADA) File Number 0129-96. Robert Krell served as the Project Manager for NADCA.

A number of staff members of Acurex Environmental assisted the authors on the technical activities of the project. Sam Brubaker assisted in preparation and calibration of the instrumentation used in the study. He also played a key role in the field data collection effort. Laura Beach provided support on quality assurance activities.

Staff of Research Triangle Institute were responsible for collection and analysis of the microbiological samples. Eric Meyers was responsible for collecting the field samples.

Representatives of the National Air Duct Cleaners Association were responsible for cleaning the heating and air conditioning air conveyance systems at the nine study homes. Tim Hebert, the Principal Investigator for NADCA, provided the required logistics support and excellent technical input to the study in addition to his efforts on the cleaning of the systems. He was assisted by Charles Cochrane, Bob Krell, Tim Bray, Frank Copeland, Tom Gwaltney, and Tom Yacobellis.

Equipment for cleaning the heating and air conditioning systems in the homes during this study was provided by manufacturers and distributors. Their support was important to the success of the project.

The authors would like to thank all of the homeowners who responded to the request for study participants. We would especially like to thank the eight homeowners who were selected for the study and allowed us to enter their homes numerous times for collection of samples and information. Their participation has enabled us to meet the study objectives and has helped us gain a better understanding of the air conveyance system cleaning and its impact on indoor air quality and system performance.

## **1.0 INTRODUCTION**

Source removal cleaning of heating and air conditioning (HAC) systems, also referred to as air duct cleaning (ADC), involves the physical removal of particulate and fibrous matter and debris from air distribution systems and air handler components. ADC services are offered for all types of buildings, including residences. There is currently little published research data on the effectiveness of air duct cleaning or its impact on indoor air quality (IAQ) and energy use for residential heating and cooling (HAC) systems. A research program has been initiated by the U.S. Environmental Protection Agency (EPA), National Risk Management Research Laboratory (NRMRL), Air Pollution Prevention and Control Division (APPCD) in conjunction with the National Air Duct Cleaners Association to evaluate the effectiveness of HAC system cleaning and its impact on IAQ in residential dwellings.

### **1.1 Background**

In recent years there has been a substantial increase in the number of companies offering ADC services. The services are offered for large heating, ventilating, and air conditioning (HVAC) systems in office buildings, public access buildings, health care facilities, and special use facilities. The services are also being offered for residential HAC systems. Some advertisements claim that air duct cleaning will improve IAQ, reduce allergies, and lower energy costs, and improve system performance. There is little published research data on which to base a decision on when a system should be cleaned or on its effect on either system performance or IAQ.

A recent research project to evaluate ADC involved testing at 33 homes in Montreal, Canada (Fugler and Auger, 1994). Cleaning was performed by commercial companies using (1) portable vacuum cleaners and brushes, (2) portable vacuums and compressed air, (3) truck-mounted vacuum systems, or (4) truck-mounted vacuum and "skipper ball" to dislodge duct dust. Measurements were made of blower fan current and voltage, static pressure, air flow rates, airborne particle concentrations, and airborne bacteria and mold levels. The results of the study were inconclusive. The measurements in the study were of such limited scope that it is difficult to draw conclusions from the study. The authors reported that air flows did not change significantly due to cleaning. But, air flow rates before and after cleaning were measured at a subset of only three supply registers and the authors admit that damper settings may have changed following cleaning. Airborne dust levels measured at supply registers did not change significantly after cleaning. Sampling for airborne particulate was limited to collection of very short-term samples before and after cleaning. Data were only used for samples collected at the ducts. Data were not used on room concentrations because the authors believed occupant movement around the samplers invalidated the test results. The study results indicated a decrease in the concentration of microorganisms (fungi and bacteria) on surfaces of just over 50% of the

ducts sampled. There was also a decrease in airborne concentrations of bacteria and fungi although the decrease was not statistically significant.

Another recent study involved ADC at eight residences (Ahmad et al., 1994). The researchers observed that short-term airborne particles levels increased during cleaning. They observed lower airborne particle levels after cleaning. They also reported that bioaerosol concentrations were lower after cleaning.

In a literature survey presented in the Air Infiltration Review (AIVC, 1993), it was reported that Pejtersen et al. evaluated the effect of cleaning of the HVAC system on occupants' perceptions on indoor air quality and concluded that cleaning tends to improve indoor air quality. The survey also states that Pjnakka and Jyrkiinen reported that particle concentrations in indoor air were three times higher during cleaning than after cleaning. The literature survey includes data showing that the average surface dust mass in supply ducts was 6.8, 10.6 and 18.2 g/m<sup>2</sup> in three studies of schools and office buildings.

With the exception of these studies, little is known about the impact of ADC on IAQ and system performance in residences. This is of particular concern because the typical homeowner may not have adequate knowledge about the HAC system to determine whether cleaning should be performed. As discussed by O'Neil and Kulp (1995), the potential economic and public health reasons are significantly sufficient to warrant research on HAC system cleaning.

## **1.2 Study Objectives**

The objectives of this project included the following:

- 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,
- Evaluate monitoring, sampling, and analysis methods to determine if the methods can be used to quantitatively assess the impact of source removal from HAC systems on airborne particulate and fiber concentrations,
- Collect information on the effectiveness of currently available cleaning methods for removal of dust and debris from air conveyance systems in residences,
- Collect information on the impact of ADC on airborne particulate and fiber concentrations in residences,
- Collect information on the impact of cleaning on the performance of the air conveyance system in residences,
- Evaluate the impact of the type of duct material and duct configuration on HAC system cleaning methods, and

- Collect information that can be used to develop a research strategy for further assessing the effectiveness and impact of HAC system cleaning in residential and non-residential buildings.

### **1.3 Overview of the Study**

To evaluate the effectiveness of HAC system cleaning in residences, a pilot field 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 goal was to obtain eight study homes with a variety of duct material types and configurations. A week-long study was performed at each home. Background monitoring and sampling of airborne particles and fibers were performed for three days, then the air conveyance system was professionally cleaned NADCA. Cleaning of the air distribution ducts and air handler components was performed by source removal practices commonly used in the HVAC system cleaning industry. Cleaning involved use of high volume vacuum (negative air) systems, brushes, forced-air nozzles, and hand vacuuming. Specific cleaning methods varied according to the type of duct materials, duct configurations, and accessibility. Monitoring and air sampling were performed for at least two days following cleaning. Pre- and post-cleaning measurements of particulate matter in the ducts was performed to assess duct cleaning effectiveness. Measurements were also performed to assess the impact of ADC on air handler performance. Prior to the field study, testing was performed at the un-occupied EPA IAQ Test House (TH) in Cary, NC to evaluate the impact of ADC under more controlled conditions and to evaluate the test protocol and methods for the field study.

To accomplish the objectives of this project, the following work activities were performed:

- Participants were recruited for the study and an initial screening questionnaire was completed to collect information for selecting participants,
- An initial screening visit was made at potential study homes to assess the type of duct materials, duct configuration, accessibility for cleaning, relative level of dust and debris in the ducts, and factors related to logistics for participation in the field study,
- Methods and protocols for collection of dust samples from the ducts, for continuous air monitoring, integrated air sampling, and other data collection at the homes were finalized based on results from previous testing in a pilot scale test facility (VanOsdell et al., 1997),
- Instrumentation was calibrated and prepared for the field study,
- Study protocols, test methods, and analysis methods were evaluated during the initial cleaning experiment at the TH,
- The field study was performed at eight occupied homes,
- Sample analysis was performed, and

- Data processing, validation, and analysis were performed for preparation of this final report.

This report presents the results of the field study. The results presented in this report represent an initial effort to obtain a better understanding of HAC system cleaning procedures, their advantages and limitations, cleaning effectiveness, and the impact of system cleaning on selected IAQ parameters (particles, fibers, and bioaerosols) and the performance of heating and cooling systems in residences. The research project was, of necessity, limited in scope. Because of the limited number of homes sampled, statistical analyses could not be performed to determine the significance of the results. However, the results show trends that may be useful in assessing the impact of system cleaning. The results provide information that can be used to formulate and develop future research programs in this area, both as they relate to residential dwellings and large buildings.

## **2.0 SUMMARY AND CONCLUSIONS**

Results of the study are summarized below. Conclusions supported by the study are provided in the following subsection.

### **2.1 Summary**

- The heating and air conditioning system, including the ductwork, air handling unit (AHU), and associated components, were cleaned at the EPA Indoor Air Quality Test House and eight occupied field study homes by professional HVAC system cleaning contractors representing NADCA, Inc. The systems were cleaned by practices commonly used in the HVAC system cleaning industry and accepted by NADCA for this study. No proprietary methods were used. Truck-mounted systems were not used in the study. Source removal involved mechanical cleaning. Chemical biocides were not used in this study.

- Various parameters related to indoor air quality and performance of the HAC system were measured for two to four days prior to cleaning and again during a two to four day period following cleaning. The IAQ parameters measured included particle mass concentrations ( $PM_{2.5}$  and  $PM_{10}$ ), particle concentrations (particles/ $m^3$ ), fiber concentrations, and airborne fungi concentrations. Parameters related to the performance of the 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 the effectiveness of HAC system cleaning, the levels of dust (particulate and fibrous combined) were measured in the supply and return ducts prior to, and following, HAC system cleaning using a medium volume dust sampler (MVDS) developed for this study (Fortmann 1996c). Microbial loading on duct surfaces was evaluated using a vacuum/filter method for collection of samples from a defined area.

- Eight owner-occupied homes were purposefully selected for the study, which was conducted in the Research Triangle Park area of North Carolina during the summer of 1996. Selection of the homes was based on the type of ductwork materials, the configuration of the HAC system, potential complexity of cleaning, and the relative amount of dust and debris in the system. The homes cleaned include single-story, split-level, and two-story homes. The AHU and most of the ductwork were located in a crawl space under the house at six of the eight occupied field study houses. Additionally, monitoring and HAC system cleaning were performed at the unoccupied EPA Indoor Air Quality Test House.

- Dust levels in the ducts prior to HAC system cleaning ranged from a mean concentration in the supply ductwork of 1.48 to 26.03 g/m<sup>2</sup> at the nine houses. The mean dust level in the return air ducts of the nine homes was substantially higher, ranging from 5.26 to 35.11 g/m<sup>2</sup>. Samples of dust were collected from the surface of the cooling coil at some homes, but the vacuum sampler method was not effective for the coil surface. Visual inspection of cooling coils was more useful for assessing the relative amount of material on the surface.

- The equipment, methods, and cleaning practices employed in this study were effective for removing dust and debris from the HAC system. Visual inspection indicated that the dust and debris were effectively removed. Dust samples collected with the MVDS demonstrated that the residual dust after cleaning ranged from 0.06 to 1.97 g/m<sup>2</sup>. For all 58 samples collected in the supply and return air ductwork after cleaning the HAC system at the nine study homes, the mean was 0.43 ± 0.34 g/m<sup>2</sup>.

- Measurements of residual dust on ductwork surfaces after HAC system cleaning with the NADCA Standard 1992-01 vacuum method ranged from 0.01 to 0.36 mg/100 cm<sup>2</sup>, meeting the NADCA criterion that residual dust must be less than 1.0 mg/100 cm<sup>2</sup> to demonstrate that the cleaning was effective. Side-by-side measurements with the NADCA vacuum method and the MVDS, which was developed for this study, showed that the collection efficiency of the MVDS was higher than the NADCA method. If the MVDS is used for post-cleaning dust sampling, the results suggest that the criterion for demonstrating that source removal cleaning is effective should be higher, probably 5 mg/100 cm<sup>2</sup>.

- 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<sup>2</sup> in the supply side and from 5 to 2300 cfu/cm<sup>2</sup> in the return, with a mean of less than 200 cfu/cm<sup>2</sup> 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.

- Mechanical cleaning without the use of chemical biocides had the most impact on fungi levels in surface dust at the homes with the highest fungi concentrations in the dust. HAC system cleaning reduced the levels of fungi in samples collected from HAC system surfaces in most homes, although the magnitude of the impact varied.

- There was little correlation between surface microbial loads and dust levels measured in the houses. This was unexpected because usually dust or dirt and microorganism levels correlate well. It may be that the composition of duct dust in this study had a high level of debris which would effectively dilute the microbial concentrations as measured per surface area.

- Indoor respirable ( $PM_{2.5}$ ) and inhalable ( $PM_{10}$ ) mass concentrations in 24-hr integrated samples, were generally low at the houses, ranging from 4.2 to 32.7  $\mu\text{g}/\text{m}^3$ . The concentrations were consistent with data previously reported for homes without smoking or other major indoor particle sources (Wallace, 1996).

- Indoor respirable ( $PM_{2.5}$ ) and inhalable ( $PM_{10}$ ) particle concentrations in air samples collected after HAC system cleaning were not substantially different from the samples collected prior to HAC system cleaning. The ratio of the post-cleaning concentrations to the pre-cleaning concentrations of respirable particles measured indoors was greater than 1.0 at seven of the nine houses. At all but one of these seven houses, the post-/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. 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. They may also have been impacted by occupant activity and other indoor sources.

- Measurements of particle concentrations (particles/ $\text{m}^3$ ) indoors with a two-channel laser particle counter and a 16-channel laser aerosol spectrometer also did not show substantial differences in airborne particle concentrations before and after HAC system cleaning. The mean concentrations of particles in a  $>0.5 \mu\text{m}$  size fraction measured indoors following HAC system 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. At these houses indoor particle concentrations increased on the same days of the week following cleaning, even though AHU operation patterns and occupant activities differed dramatically at the two houses. The data suggest that changes in airborne particle concentrations as a

result of HAC system cleaning may not be measurable with the methods used in this study due to the presence of other sources of particles indoors, including outdoor sources and occupant activity, and temporal variability of particle concentrations.

- Comparison of the level of dust measured in the supply and return ductwork and the airborne particle concentrations and particle mass concentrations prior to HAC system cleaning did not show any substantial relationship.

- Concentrations of airborne fibers were low at all homes, precluding an assessment of the impact of HAC system cleaning on airborne fiber concentrations. Measurements with a continuous optical monitor suggest that HAC system cleaning reduced airborne fiber concentrations at the Test House and at a house that had heavy deposits of fibers visible in the ductwork prior to cleaning. But the data set is insufficient to draw any conclusions.

- Mechanical cleaning of the HAC system 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 samples. Similar to the particulate measurements, the failure to determine a difference in concentrations before and after cleaning may be related to the presence of other sources and the variability of airborne concentrations of fungi.

- Measurements of parameters related to performance of the HAC system suggest that cleaning had a positive impact on system performance. Cleaning of the HAC system generally resulted in increased air flow to the house. Supply air flows increased between 4 to 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 at loose floor boots of supply registers. Return air flows measured at the return air grilles in the house increased 14 and 38% at two houses, but were not substantially different after cleaning at the other seven houses. Because of the small sample size (nine houses), the limited number of measurements, and the short duration of the study period at each house, the magnitude of the impact of HAC system cleaning could not be quantified in this study.

- AHU blower motor current increased after HAC system cleaning 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.

- Example engineering calculations made to estimate the change in heat transfer for the cooling coil following HAC system cleaning suggest that HAC system cleaning may improve system performance. 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.

- Cleaning of the HAC system in the study homes, which had floor areas of 1500 to 2000 ft<sup>2</sup>, was accomplished by two to three workers during an eight to ten hour period. This level of effort was required to adequately clean and inspect all supply and return grills, the air handler components, and the ductwork. To effectively clean all surfaces required a combination of cleaning methods, including hand vacuuming, and routine inspection and re-cleaning, as required.

- A limited scope evaluation of the impact of brushing on HAC system cleaning demonstrated that airwashing alone with the ductwork under negative pressure removed a substantial amount of the dust in the ductwork, but that brushing in conjunction with airwashing was required to clean the ductwork effectively. The data suggest that airwashing alone may not effectively remove contaminants from HAC systems.

- Many of the heating and air conditioning systems at the occupied homes of the study had design and maintenance deficiencies that would be expected to result in significant energy losses, and in some cases, might result in adverse impacts on occupant comfort and indoor air quality. External insulation on ductwork was deteriorated or inadequate in many cases. Duct leakage was substantial at some homes. Loose floor boots and poor ductwork construction were observed at many of the homes. Internal fibrous glass duct liner in the AHU supply plenums and in bullhead plenums were contaminated with fungal growth at some of the homes.

- Most homeowners that participated in the study had limited knowledge about their AHU and ductwork. They could not provide accurate information about the HAC system during participant screening and were unaware of deficiencies in their system. Homeowners whose condensate drain lines were improperly installed or not working properly were either unaware of the problem or not concerned. Homeowners were generally not aware of the significant impact of deteriorating external insulation or duct leakage on energy costs for heating and cooling. They were generally not aware of design deficiencies or obvious maintenance problems.

- Potential participants had difficulty providing accurate information about their air handlers and duct systems during the screening phase of participant recruitment because of a lack of knowledge about their systems. This had an impact on the recruiting and screening effort. They also had little knowledge about HAC system cleaning methods and practices. The results of this study suggest that homeowners will require a substantial amount of educational material related to residential heating and cooling systems and the air conveyance system in addition to material about HAC system cleaning methods in order to make informed

decisions about when to have HAC system systems cleaned, how to select a qualified HAC system cleaning contractor, and how to evaluate the work performed.

## 2.2 Conclusions

- The results of the nine home pilot study demonstrated that mechanical cleaning methods and equipment commonly used by HVAC system cleaning contractors effectively removed particulate and fibrous contamination from the HAC systems, thus removing one source of particulate contamination in the study homes.

- The impact of HAC system cleaning on bacteria levels on surfaces of HAC systems was variable in the study. However, the impact of HAC system cleaning on bacterial contamination on surfaces was not fully evaluated in this study because chemical biocides, which are frequently used by HVAC system cleaning contractors, were not used at the study homes.

- Mechanical cleaning without use of chemical biocides had the greatest impact on fungi concentrations in surface dust samples at the homes with the highest fungal levels in the duct. The levels of fungi in surface samples were lower following HAC system cleaning at most of the homes.

- The impact of HAC system cleaning on airborne particle concentrations, airborne fiber concentrations, and bioaerosols could not be determined in this study. There was no clear trend in the changes in concentrations after HAC system cleaning. The study results suggest that because of the presence of other indoor sources, occupant activity, outdoor contaminant sources, and temporal variability in particle concentrations, it will be difficult to detect changes resulting from HAC system cleaning by air sampling and monitoring methods.

- Measurements of HAC system-related parameters at the study homes suggest that HAC system cleaning may improve HAC system performance. This was indicated by increased air flows and AHU blower motor current. Due to the limited scope of this study, the magnitude of the impact of HAC system cleaning could not be quantified.

- The medium volume dust sampler developed for this study was demonstrated to be an effective tool for quantitatively assessing HAC system cleaning effectiveness.

- The study results demonstrated that neither the short-term integrated air sampling methods nor the continuous air monitoring methods could be used to assess the impact of HAC system cleaning on airborne particulate or fiber concentrations due to the contribution from other contaminant sources and temporal variability of air contaminant concentrations.

### 3.0 RECOMMENDATIONS FOR FUTURE RESEARCH

The results of this study were useful as the first phase for evaluating the impact of HAC system cleaning on selected IAQ parameters and performance of air conveyance systems in homes. Because of the limited scope of the current study, the statistical significance of the results could not be determined. However, the study results will be useful in developing a strategy for future research on HAC system cleaning. Based on the results of this study, the following recommendations are made:

- An alternative approach should be developed for determining the impact of HAC system cleaning on airborne particle, fiber, and bioaerosol concentrations. The results of this study show that changes in airborne concentrations of air contaminants that may result from HAC system cleaning can not be determined by either integrated short-term sampling or continuous monitoring methods used in this study for pre- and post-cleaning measurements of airborne particle mass, particle counts, fiber concentrations, or bioaerosol concentrations. An alternative technical approach may require other instrumentation, long-term monitoring, and more comprehensive measurements. Testing in homes with higher dust levels in the HAC system may make it easier to measure changes in air contaminant concentrations due to HAC system cleaning. Longer term studies are required to distinguish between the impact of cleaning and occupant activities on indoor air contaminant concentrations.

- Testing to assess the impact of HAC system cleaning on indoor air quality parameters should be performed in test facilities where human activity and indoor sources can be controlled and well-documented. Tests should be performed in the new Pilot Scale HAC Test Facility (PSTF) at EPA to determine how HAC system cleaning affects IAQ parameters in the short- and long-term. Tests can also be conducted at the EPA Indoor Air Quality Test House, which provides a realistic test system where indoor sources of particles and fibers can be controlled and documented.

- Additional testing should be performed in the PSTF at EPA to determine the impact of HAC system cleaning on the performance of the HAC system. Improved air handler/condenser efficiency may be the most significant impact of HAC system cleaning. It is important to determine the magnitude of the effect, the potential energy savings, and the pay-back period for HAC system cleaning costs. If significant energy savings can be demonstrated that warrant the costs of cleaning, any coincidental improvement in indoor air quality, even if it can not be demonstrated, may be a no-cost benefit. The new PSTF is ideally suited for this type of testing because the cooling coil can be artificially loaded with varying levels of dirt and fiber and the required parameters can be measured accurately and precisely over extended time periods.

- Research is needed to systematically and quantitatively measure fungal emissions under a variety of environmental conditions to allow informed assessments of the significance of surface microbial measurements. A commonly advertised justification for residential HAC system cleaning is to reduce and

control allergies, many of which are related to fungal contamination. Emissions from fungal HAC system contamination have been shown (Morey and Williams, 1991) to have a direct impact on indoor biocontamination.

- Research should be undertaken to evaluate the short and long-term efficacy of biocides and encapsulants used following HAC system cleaning over a reasonable range of HAC system environmental conditions. HAC system cleaning was found in many cases to significantly reduce the levels of surface microbial contamination in the tested duct systems. The most important issue with regard to HAC system cleaning, however, is the prevention of microbial regrowth on cleaned HAC system surfaces. Biocides and/or encapsulants are sometimes recommended and used on microbially contaminated HAC system systems to contain debris and prevent regrowth.

- Research should be performed to evaluate cleaning of other types of duct surfaces in addition to the galvanized sheet metal surfaces, that were the focus of this study. Many HVAC system cleaning contractors claim to be able to clean duct systems with internal fibrous glass liner. The cleaning methods, effectiveness, the impact of HAC system cleaning on the duct materials, and the impact on indoor air quality, specifically airborne fiber concentrations, should be evaluated.

- A test method needs to be developed to quantitatively measure the mass of dirt and fiber on porous surfaces. Both a research method and a practical field method are required. The method must have a sufficiently high collection efficiency without removing fibers and liner material from surfaces that have been cleaned.

- Research on HAC system cleaning effectiveness and its impact on IAQ and energy use should be expanded to include the systems in large buildings. The impact of HAC system cleaning may be much more significant in large buildings because of the higher cooling loads and energy costs. Many buildings have significant indoor sources of particles and fibers that accumulate in the HAC system. Initial studies should focus on only a few buildings and involve long-term measurements prior to, and following, cleaning to obtain accurate data on IAQ and HAC system performance.

- Additional research is recommended to develop a system for determining when HVAC system cleaning should be performed in various types of buildings and HVAC systems. Criteria need to be developed so that building owners and operators can make an informed decision on when to have the HVAC system cleaned.

- Information needs to be provided to homeowners to assist them in determining when to have their residential HAC system cleaned, how to select a cleaning contractor, and how to evaluate the work that was done. The EPA has already started work on an informational brochure for this purpose. Results of the participant screening process and interaction with the homeowners participating in this study, suggest that homeowners have limited knowledge about heating and cooling systems and ductwork. The informational

brochure should include educational material on the HAC system as well as detailed information about HAC system cleaning methods and the potential benefits.

- Although this study has focused on the effectiveness and impact of HAC system cleaning, a reactive approach to duct contamination problems, research is needed to develop effective strategies for preventing contamination of heating, ventilating, and air conditioning (HVAC) systems with particulate, fibrous, microbiological, and volatile organic contaminants. This research may include studies of various filtration technologies and practices, evaluation of HVAC designs and equipment, research on controlling humidity levels and condensation problems, and developing guidance for building owners and HVAC operators.

#### **4.0 STUDY METHODS**

This section describes the methods used in the field study including participant recruitment, participant selection, the field study protocol, and the sample collection and analysis methods.

##### **4.1 Participant Recruitment and Selection Methods**

The study involved testing at the U.S. EPA Indoor Air Quality Test House located in Cary, NC and eight occupied homes located in the Research Triangle Park area of North Carolina (Raleigh, Cary, Apex, Durham, and Chapel Hill). The eight homes included in the study were purposefully selected; they were not selected at random. The following criteria were used to determine the eligibility of potential study participants:

- The participant must own the home,
- There may not currently be smoking of tobacco products in the home, and
- The home must have a central cooling system with forced air distribution that was expected to be used during the study.

Homes were not used in the study where smoking of tobacco products occurred indoors because the high emissions of particles from environmental tobacco smoke would make it difficult to interpret particle monitoring and sampling data. Because the study was conducted in the summer, homes had to have a central cooling system that the occupants intended to use during the study period.

A number of criteria were considered for selection of the homes, including the following:

##### **Characteristics of the HVAC**

- (1) Type of duct materials
- (2) Level of particulate matter and debris in the ductwork
- (3) Accessibility of the ducts for cleaning (i.e., difficulty of cleaning)

Age of the ductwork and air handler

History of duct cleaning

Type of heating system (heat pump, gas furnace, oil, electric heating coils)

Type of cooling system (central, window/wall, natural ventilation)

Size of system (heating/cooling capacity, fan speed or duct air velocity)

Number of main and branch ducts

Configuration of ducts

Type of particulate filter used in the system

#### Characteristics of the Occupants

Number of adults

Number of children

Number of pets (cats or dogs)

Type of cooking range

Extent of cooking performed (average number of meals/week with range)

Other sources (e.g., hobbies performed indoors)

Ventilation habits - Extensive window openings vs. year-around closed windows

Reported complaints about dust problems

#### Characteristics of the Structure (Home)

Age of the home

Size (ft<sup>2</sup>)

Number of floors

Sub-structure (slab-on-grade, crawl space, or basement)

Location (inner city, suburban, rural)

Type of yard (grass, dirt)

Amount of dust on indoor surfaces

In consultation with the EPA Project Manager, items 1 through 3 listed above were defined as the primary selection criteria. Many of the other parameters listed may have an impact on the first three criteria, particularly with respect to the level of dust and debris in the air conveyance system, but were determined not to be primary criteria for selecting the study homes. The goal was to obtain homes with different types of duct materials, including: (1) un-lined galvanized ducts, (2) internally lined (fibrous glass duct lining), non-microbially contaminated ducts, and (3) flexible ducts. In consultation with the NADCA representatives performing the HAC system cleaning, it was determined that participant homes could have only one air handler. Large homes with two air handlers could not be cleaned in one day, which was essential to meet the requirements of the monitoring and sampling schedule. To the extent possible, homes were selected that had differing amounts of dust and debris in the ducts. The level of dust and debris in the ducts was determined by

visual inspection and by collection of duct dust samples using the MVDS during the initial screening visit. Homes were selected that had varying levels of complexity of duct materials and configurations so that HAC system cleaning effectiveness could be evaluated under a variety of conditions.

Homes with fiberboard duct materials were not included in the study due to the difficulty of cleaning and the potential for damaging internal surfaces of the ducts. Homes with internally-lined (insulated) ducts were to be included in the study if there was no visible indication of fungal contamination or historical information that would indicate potential microbial contamination of the duct liner. These homes were not included in the study because the current EPA recommendations are that microbial-contaminated fibrous glass duct liner be replaced rather than cleaned (U.S. EPA, 1991). Homes with known or suspected microbial contamination of un-lined galvanized ducts were included in the study because there are accepted methods for cleaning them (NADCA, 1992; NADCA, 1995).

Potential candidate homeowners were initially screened by telephone using a 42 question *Participant Screening Questionnaire*. The questionnaire was designed to first determine eligibility, then to collect information on the home, air conditioning system, and the occupants in order to assess their potential suitability for use in the study. Information collected with the screening questionnaire was used to select eight candidates for the second phase of screening, a visit to the house.

Each of the candidate homes was visited to verify eligibility for the study, to determine the type of duct material, to inspect the air handler and ductwork, and to assess the level of dust and debris in the ducts. The Acurex Environmental principal investigator visited all of the homes so that the suitability of the homes could be compared. Responses to the screening questionnaire were verified during the visit and additional information was collected on the characteristics of the heating and cooling system and the ducts in the home. Components of the HAC system were inspected to assess the level of dust and debris in the system. At some homes, samples of dust in the HAC system were collected using the MVDS from the supply and return ducts if access could be obtained through return air grilles, existing access panels, or duct end caps. In most homes, the level of dust was assessed by visual inspection only.

A number of homes were determined to be ineligible or unsuitable for the study during the site visits. When this occurred another home was selected and visited. A total of 19 homes were visited in order to select eight homes for the study. The homes were ranked according to suitability for the study based on the selection criteria. Recommendations were provided to the EPA Project Manager who approved final selection of the homes. A second visit was made to some of the homes selected for the study so that a NADCA representative could inspect the house and the HAC system in order to prepare for cleaning, including selection of cleaning methods and equipment.

#### **4.2 Sample Collection and Analysis Methods**

A number of parameters were measured at each home during the study. Measurements were made using continuous (real-time) monitors for particles, fibers, and environmental parameters; integrated sampling methods for particles, fibers, and bioaerosols; and bulk sampling methods for dust and fungi in the HAC system. The measurement parameters and sampling and analysis methods are summarized in Table 4-1 and described below. The protocol for sampling is described in a following sub-section.

The primary contaminants measured at the study homes were particles, fungi, and fibers. Both real-time monitoring and integrated sampling methods were used for particle measurements.

#### **4.2.1 Measurements of Dust Levels in Ducts**

The level of dust in ducts ( $\text{g}/\text{m}^2$ ) was determined by collection of dust samples at selected locations with the MVDS and the NADCA vacuum method. The MVDS, fitted with a brush, was the primary sampling method for all HAC system surfaces. The NADCA method was used only for collection of post-cleaning samples from galvanized steel surfaces because that is the only application for which it was developed.

##### **4.2.1.1 NADCA Standard Method 1992-01**

The NADCA Standard Method 1992-01 is described in the document entitled, *Mechanical Cleaning of Non-Porous Air Conveyance System Components* (NADCA, 1992). The hardware for the method consists of a vacuum pump operated at 10 L/min, a filter cassette, and a template for sampling. The 37-mm diameter plastic filter cassette is used as the nozzle. The same pump and rotameter as used for the MVDS were used to collect NADCA vacuum method samples. A flow control valve was placed in-line to control the flow to 10 L/min. The purpose of the method is to document the effectiveness of cleaning of non-porous ducts. In this study, the NADCA Standard Method 1992-01 was used only for post-cleaning measurements on galvanized ducts to document cleaning effectiveness; it was not used for pre-cleaning measurements.

Table 4-1. Measurement Parameters and Methods<sup>a</sup>

| Parameter                          | Sampling Method               | Instrumentation                     | Analysis Method            |
|------------------------------------|-------------------------------|-------------------------------------|----------------------------|
| Particle count, > 0.5 µm           | Continuous (10 min avg)       | Climet CI-4100                      | Optical (scattered light)  |
| Particle count, > 5.0 µm           | Continuous (10 min avg)       | Climet CI-4100                      | Optical (scattered light)  |
| Particle counts (16 channels)      | Continuous (60 min avg)       | LAS-X                               | Laser aerosol spectrometer |
| PM <sub>2.5</sub> mass             | Integrated (24 hr)            | Impactor/filter/pump                | Gravimetric                |
| PM <sub>10</sub> mass              | Integrated (24 hr)            | Impactor/filter/pump                | Gravimetric                |
| Fiber count                        | Integrated (24 hr)            | Filter/pump                         | PCM and SEM                |
| Fiber count                        | Semi-continuous (100 min avg) | MIE FAM-1                           | Optical (scattered light)  |
| Bioaerosol (fungi) concentration   | Integrated (60 min)           | Matson-Garvin slit to agar impactor | Culture/microscopy         |
| Temperature                        | Continuous                    | IAQDS                               | Solid state sensor         |
| Relative humidity                  | Continuous                    | IAQDS                               | Thin-film capacitance      |
| Carbon dioxide                     | Continuous                    | IAQDS                               | NDIR                       |
| Air flow rate (HAC system)         | Manual                        | Omega HH-30                         | Vane anemometer            |
| Temperature (HAC system)           | Continuous                    | IAQDS                               | RTD                        |
| Relative humidity (HAC system)     | Continuous                    | IAQDS                               | Thin-film capacitance      |
| Static pressure (HAC system)       | Manual                        | AirData ADM-860                     | Capacitance                |
| Differential pressure (HAC system) | Continuous                    | IAQDS                               | Capacitance sensor         |
| Blower on-time (HAC system)        | Continuous                    | IAQDS                               | Pressure switch            |
| Blower current (HAC system)        | Manual                        | Fluke 32 meter                      | Current measurement        |
| Surface dust                       | Pump/filter                   | MVDS - filter                       | Gravimetric                |
| Duct dust mass                     | Manual                        | MVDS - filter                       | Gravimetric                |
| Duct dust mass                     | Manual                        | NADCA method                        | Gravimetric                |
| Microbial loading                  | Manual                        | Pipet tip sampler, filter, swab     | Plate counting             |

<sup>a</sup> Abbreviations = IAQDS: Indoor Air Quality Data Station; PCM: Phase Contrast Microscopy; SEM: Scanning Electron Microscopy; NDIR: Non-dispersive infrared analyzer; RTD: Resistance Temperature Device; MVDS: Medium volume dust sampler;

#### 4.2.1.2 Medium Volume Dust Sampler (MVDS)

A medium volume vacuum method was developed for this project. The sampler consisted of the following components:

- Thomas Model 2107CA20A dual diaphragm vacuum pump with nominal free air flow of 50 L/min,
- Gelman Model 2220 stainless steel 47 mm diameter in-line low pressure filter holder,
- Whatman EPM 2000, 47 mm, high-volume air sampling filters rated at 99.997% retention for 0.3  $\mu\text{m}$  dioctyl phthalate (DOP),
- Brooks rotameter, 0 - 50 L/min range, placed in-line; calibrated with a wet test meter
- Nozzle with brush - nylon bristle brush, oval shaped, with an opening of approximately 18 mm X 10 mm, with 10 mm long nylon bristles (Source: Enervac Battery-Powered Vacuum Cleaner).

The sampler was operated at 40 L/min. The brush was used for all sample collection during the study. Previous testing at the RTI pilot scale test facility showed that the use of the brush was essential for acceptable collection efficiency (VanOsdell et al., 1997). The sampler was used with a 10 cm X 10 cm square template. Sampling was performed by making multiple passes across the entire surface of the template in both directions. There was not a standard set of passes made; the surface was brushed until visual observation indicated that no additional dust could be collected.

The performance of the MVDS was evaluated in a previous laboratory study. Using artificially-loaded duct surfaces, the MVDS fitted with the nozzle had a collection efficiency of greater than 90%. Results of the evaluation are included as Appendix A to this report.

#### 4.2.2 Continuous Particle Monitoring Methods

The Climet CI-4100 was used to monitor particle concentrations (particles/ $\text{m}^3$ ) throughout the test period at each house. The instrument was operated with a 10-min averaging time and data were logged with the EPA Indoor Air Quality Data Station (IAQDS) equipped with the Blue Earth data acquisition system. Although the Climet CI-4100 collects data in both a greater than 0.5  $\mu\text{m}$  size fraction and a greater than 5.0  $\mu\text{m}$  size fraction only one channel of data can be output to a data logger. The >0.5  $\mu\text{m}$  size fraction data were recorded with the IAQDS. The Climet has internal data storage capability for both size fractions, but only 200 data sets can be stored in memory. The data for the >0.5  $\mu\text{m}$  size fraction recorded with the IAQDS was the primary data set collected in the field study. However, each time the technician visited a study house to change filter media, he downloaded the data from the Climet. Because visits were made to the houses on two days during each study to change filter media and for the HAC system cleaning, a reasonable amount of data was obtained for the > 5.0  $\mu\text{m}$  size fraction:

Two Climets were placed in the primary living area. One was placed at a representative, well-mixed location in the room at a height between 1 and 2 meters above the floor to monitor airborne particle concentrations. The other monitor was placed within one meter of a supply air diffuser that served the room in an attempt to gain better resolution of changes in concentrations of particulate matter delivered to the room from the HAC system, rather than due to occupant activities in the room. A third Climet was placed in a different room of the house. The sampling locations are described below and are indicated on floor plans included as Appendix B to this report.

The real-time measurements of particle number concentrations were augmented by use of a LAS-X laser aerosol spectrometer. The instrument was collocated with the Climet used to measure room air concentrations. The instrument was used for measuring particle concentrations in the size fraction of 0.1 to 7.5  $\mu\text{m}$  geometric diameter. Data were recorded with a laptop computer via an RS-232 connection.

#### **4.2.3 Integrated Particle Sampling Methods**

In addition to the real-time monitoring, integrated samples of  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  mass were collected during selected time periods, as described below. Samples were collected with size selective impactors developed at Harvard University. The impactors are currently being used in both the EPA Office of Research and Development (ORD) Large Buildings Study (Fortmann et al., 1994; U.S. EPA, 1994) and in the EPA Indoor Environment Division's Building Assessment and Survey Evaluation (BASE) program (Girman et al., 1995; U.S. EPA, 1994). The impactors collect particulate matter in the less than 10  $\mu\text{m}$  diameter and less than 2.5  $\mu\text{m}$  diameter size fractions on Teflon filters. The samples were collected using pumps that operate at 20 L/min, which provided sufficient mass over a 24-hr sampling period for accurate and precise gravimetric measurements. Mass determinations were made on the EPA Cahn microbalance located in the EPA Annex following standard filter conditioning and weighing procedures developed for the EPA Large Building Study. The microbalance has a resolution of 1 ng. Sample collection and analysis followed procedures developed for other indoor air sampling projects and are described in the Standard Operating Procedures for the ORD Large Building Study (Acurex, 1994).

#### **4.2.4 Fiber Monitoring and Sampling Methods**

Fiber concentrations were monitored continuously at one study home each week using the MIE FAM-1 Fibrous Aerosol Monitor. The monitoring principal of the instrument is light scattering. It was placed in the primary living area for measurement of ambient room air concentrations. An integration time of 100 minutes was used providing a detection limit of approximately 0.0005 fiber/ $\text{cm}^3$ . Data from the instrument were output to the MIE PDL-10 data logger for continuous recording.

Integrated samples of airborne fibers were collected according to the NIOSH Method 7400, *Asbestos and Other Fibers by PCM* (NIOSH, 1994). Samples were collected on 25 mm cellulose ester membrane filters (0.8  $\mu\text{m}$  pore diameter) housed in a conductive cowl. A nominal sample volume of 2800 liters was collected over a 24-hour time period. Total fiber concentrations were determined in accordance to the NIOSH Method 7400 B counting rules. The NIOSH method, with analysis by phase contrast microscopy (PCM) measures fibers with a diameter greater than 0.25  $\mu\text{m}$  and length greater than 5.0  $\mu\text{m}$ . The samples were analyzed at the laboratory of the R.J. Lee Group (Manassas, VA). One filter collected prior to cleaning and one collected following cleaning were selected from each house for analysis by scanning electron microscopy (SEM) to identify the composition of the fiber and particles in the samples, particularly the types of fibers (e.g., fiber glass, cellulose fibers, hair).

#### 4.2.5 Fungal Air Sampling Methods

Bioaerosol samples (fungi only) were obtained directly from within supply ducts in the primary and secondary rooms which were sampled for particles in the field test houses. These samples were obtained directly from the ventilation supply ducts to prevent room contamination from affecting the results, as explained below. In addition, a room (not duct) bioaerosol fungal sample was obtained near the optical particle counters. In the houses with secondary supply registers in the ceiling (upstairs), a room sample was taken in place of the supply. Bioaerosol samples were not collected outdoors during the study because outdoor air data were not required to meet study objectives. Because the bioaerosol samples were obtained directly from within the supply ducts before and after cleaning, the impact of HAC system cleaning could be assessed. The one sample collected in the room was intended to identify gross contamination indoors and allow for comparison of samples collected from the ducts with the room air. This sample measured the reservoir of indoor airborne fungal contamination that would be recirculated by the HAC system.

The bioaerosol samples were obtained at each test site with either Mattson-Garvin slit-to-agar samplers operated over 60-minute periods or 1-stage Andersen cascade samplers operated for 10 minutes. Jensen (1992) have shown that the results from a 1-stage Andersen are comparable to those from a Mattson-Garvin. Three samplers were operated simultaneously, two in the ducts and one in the room, or one in the duct and two in the room depending upon the secondary supply. The bioaerosol samplers, as configured for the in-duct sampling, drew air from the supply ducts at 28.3 L/min through a sample probe allowing a broad range of airborne particles to be impacted upon the surface of an agar plate. The sample probe was 108 cm in overall length, with a conical duct sampling nozzle of 3.5 cm internal diameter (ID) at the inlet and tapered to 0.5 cm (Mattson-Garvin) or 0.9 cm (1-stage Andersen) ID tubing in its 5.5 cm length. The duct sampling nozzle was placed vertically about 10 - 15 cm into the supply duct, and the tubing formed a smooth U-shape

from the nozzle to the fixture and adapter on the sampler inlet. It was placed into the supply duct to reduce mixing with room air during the brief blower shutdowns described below. The duct sampling nozzle inlet diameter provided a sampling velocity of 0.51 m/s (100 ft/min). The poor flow development at air duct supply diffusers (usually close to duct elbows), the need to keep sample lines short, and the fact that unsteady-state flow (blower on/off, as described below) was inherently non-isokinetic limited the value of isokinetic sampling. Thus the same nozzle was used at all sites. Additional details of the sampling method can be found in *Field Microbiological Investigation of Ventilation System Cleaning: Project Work/QA Plan* (RTI, 1996). When configured for room air samples, the sample probe was not used and air was drawn directly into the slit from the room.

Routine microbiological emissions from undisturbed HVAC systems are normally low because the emissions are usually caused by disturbances. Thus duct sampling in a period of fully established flow might give low values that did not represent the overall emissions rate. On the other hand, tapping the duct generally provides very high bioaerosol counts that are also not representative. The normal disturbances in an HVAC system are the blower coming on and off and the consequent flow changes and duct movement.

Thermal and humidity changes can also change emission rates, but cannot be simulated in the short time period available. To measure the emissions under conditions representative of normal operation (without actively disturbing the microorganisms) while obtaining enough emission to potentially detect the effect of HAC system cleaning, the blower was cycled on and off four times during the 60 min sampling period.

The supply duct sampling procedure was predicated on the use of a central forced-air ventilation system, set in air conditioning (AC) mode, and using a conventional thermostat. The procedure was as follows:

- 1) Prepare the bioaerosol sampler to begin sampling, but do not start the system.
- 2) Five minutes before starting to sample, put the HVAC system in manual mode with the thermostat set to a high enough temperature to prevent the AC from operating. The blower will be on most of the time with brief shutdowns.
- 3) Remove the supply duct diffuser and position the microbiological sampler nozzle approximately 10 - 15 cm into the supply duct, facing into the air, and centered in the air flow.
- 4) Start sampling with the HVAC blower having been on (and the cooling coil off) for at least 5 minutes. All three samplers were started within 30 s of each other. Record the start time and run a stopwatch during the period.

- 5) After 5 sampling minutes and with the sampler remaining on, turn the blower off. Continue sampling. After about 30 seconds, turn the blower back on. This will cause the system to shift slightly as the pressure changes, and may dislodge some particles.
- 6) After 20 sampling minutes, repeat the shut-off cycle (Step 4).
- 7) After 35 sampling minutes, repeat the shut-off cycle (Step 4).
- 8) After 50 sampling minutes, repeat the shut-off cycle (Step 4) for the fourth and last time.
- 9) Stop sampling after 60 minutes, turning the samplers off in the same order they were turned on.
- 10) Return the HVAC system to its normal operating mode.

The pre-cleaning bioaerosol samples were obtained before any portion of the air handler had been disturbed except by normal operation, usually the day before duct cleaning. The post-cleaning bioaerosol samples were collected at least 24 hours following the duct cleaning. Samples were not collected during HAC system cleaning because the activity in the home and duct agitation were expected to generate a microbial aerosol that would not be indicative of actual conditions.

#### ***4.2.6 Microbial Surface Sampling Methods***

The primary microbial measurement was of the culturable microbial surface loading, expressed as colony forming units (CFU) per cm<sup>2</sup>. Samples of deposited materials within a template defined area of 10 cm<sup>2</sup> were obtained by two techniques:

- 1) Suctioned at 10 L/min through a sterile pipet tip nozzle directly into a filter cassette, from which they were eluted, and plated onto Trypticase Soy Agar (TSA) and Sabourauds Dextrose Agar (SDA) for analysis.
- 2) Collected with a sterile swab that had been wetted in a saline solution. The sample was then eluted into a saline solution and plated onto TSA and SDA for analysis.

For both methods, the samples plated onto SDA were evaluated for fungal growth and the TSA plates for bacterial growth. The methods are described in *Air Conveyance System Cleaning Pilot System Development, Characterization, and Operation: Project Work and QA Plan* (RTI, 1995) and *Field Microbiological Investigation of Ventilation System Cleaning: Project Work/QA Plan* (RTI, 1996).

These measurements were conducted near where the dust mass loading measurements were made to permit evaluation of the correlation between dust mass and microbial populations. Duplicate vacuum and swab samples were collected in most cases to allow comparison of the two methods. A sample was considered a duplicate when collected using the same access port, near the primary sample, and visually similar in loading.

While the use of swabs to obtain surface samples is a traditional technique for non-porous surfaces, its use on rough-surfaced or porous materials cannot be quantitative because contact between the swab and the surface is imperfect. The vacuum technique was developed for improved efficiency on porous materials. During operation of the HAC system pilot unit (VanOsdell et al., 1997), the vacuum technique was found to be more generally applicable on duct liners.

Because duct dust deposits vary non-uniformly in the relatively small residential ducts, duplicate tests provide a measure of dust non-uniformity as much or more than of measurement variability.

#### ***4.2.7 Interior Surface Dust Sampling Method***

In an attempt to assess the level of dust on surfaces in the home, a possible factor that may be related to dust levels in the ducts, samples of dust were collected from two locations in the home. The samples were collected from surfaces such as the top of book shelves, kitchen cabinets, etc. The sample was collected from a 100 cm<sup>2</sup> area using a template and the MVDS. Samples were collected on filters and the mass weighed. Filters were weighed using the EPA balance with a resolution of 0.1 mg located in the controlled environment weighing facility.

#### ***4.2.8 Measurements in the Air Conveyance System***

A number of measurements were made in the air conveyance system to assess the impact of HAC system cleaning on the performance of the system. The measurement parameters selected for this study may serve as indicators of the impact of HAC system cleaning. The technical approach for this study was to perform measurements prior to and following cleaning of the system to determine relative differences between pre- and post-cleaning periods. During design of the field protocol, it was determined that quantitative measurements of changes in energy usage due to HAC system cleaning could not be accomplished within the scope of this study. Such measurements are complex, costly, and require extended measurement periods. Measurements of the impact of HAC system cleaning on energy usage in a controlled test environment may provide more accurate results than field measurements.

Temperature and relative humidity were measured in the main supply duct and the return duct by inserting probes into the ducts at locations downstream of the coil where the air was expected to be relatively well-mixed. The temperature and RH sensors were interfaced to an IAQDS that was placed in the basement, crawl space, or other appropriate location near the air handler and ducts. A 10-min averaging time was used for recording the data.

Differential pressure across the coil was measured throughout the study. Pitot tubes were installed upstream and downstream of the coil and connected to a sensor. Data were output to the IAQDS for continuous logging. Static pressures in the supply and return ducts were measured manually with an AirData micromanometer on two days prior to cleaning and again following cleaning.

The amount of time that the air conditioning systems operated during the monitoring period was determined by installing a sail switch into the duct. Percent on-time was logged with the IAQDS.

AC current for the air handler fan motor was measured manually pre- and post-cleaning using a Fluke 32 digital (clamp-on) meter. Measurements were to be made twice before and twice after cleaning of the HAC system. In some cases, the measurements could not be made because of the configuration of the wiring harness or access problems.

The temperatures of the coolant lines were measured as an indicator of the performance of the cooling system. Solid state temperature sensors were attached to the coolant lines at a location as close as possible to the coil and wrapped with foam insulation. Temperatures were logged throughout the study period with the IAQDS.

To assess the impact of HAC system cleaning on air flow rates in the system, volumetric air flows were measured at all air supply registers and return registers in the home. Measurements of air velocity were made with an Omega HH-30 digital meter/vane anemometer and the registers were measured to calculate volumetric air flows. To perform the measurements of the supply air flows the vane anemometer was placed on the front of supply diffusers. Measurements were made at two to four locations on each register to obtain an average air flow rate. On return air grilles, measurements were made at twelve to 16 locations. The exact number of locations was determined by the register size and air flow characteristics.

#### ***4.2.9 Temperature, Relative Humidity, and Carbon Dioxide Measurements***

Temperature, relative humidity, and carbon dioxide concentrations were monitored continuously at one location in the primary living area of the home and at an outdoor location. The parameters were monitored with a solid state temperature sensor and a thin film capacitance relative humidity sensor. Data were logged continuously with the IAQDS; ten minute average readings were recorded. These were not considered to be critical parameters, but were collected to aid in the interpretation of the data, if required.

### **4.3 Survey Instruments and Data Collection Tools**

Two survey instruments were used during the study at each home to collect information about the home, the heating and cooling system, and occupant activities. The first survey instrument was the *EPA/Acurex*

*Environmental Air Duct Cleaning Field Research Study - Study Home and Heating and Air Conditioning System Documentation Log.* This survey included three sections:

- Characteristics of the Home,
- Characteristics of the Heating and Cooling Systems, and
- Occupant Activities and Air Contaminant Sources in the Home

Detailed information was collected on the air conditioning system(s) in the home and the air conveyance system, including system age, manufacturer, size, etc.. Information about the home and occupant activities was fairly detailed in an attempt to identify factors that may be related to dust levels in the ducts.

The second survey instrument was the *Participant Daily Activity Log*. This survey instrument was used by study participants to document activities in and around the home during the monitoring week that may have impacted particle and fiber levels in the home. The activity log was designed to be as simple to complete as possible to maximize the response rate and the accuracy of the entries. The Log was set-up in a daily log format that included activities such as opening of windows, number of people in the home during 1-hour blocks, presence of pets in the home, cooking, hobbies, etc.

#### **4.4 Field Protocol**

The protocol for the field study involved week-long study periods at each home. In some cases, the study period was extended beyond one week to collect additional data with the continuous particle monitors. Monitoring and sampling occurred outdoors and at multiple locations indoors.

##### **4.4.1 Sampling Locations**

There were four primary locations for sample collection at each home. The primary sampling location was a primary living area in the home, which may have been a living room, family room, dining room, TV room, or den. Samplers were placed at a location in the room expected to provide representative measurement results. The exact location was determined by the available space for placing the instruments. The monitors and sampling ports were placed at a height between 1 and 2 meters above the floor and were at least 0.5 m from a wall whenever possible. Integrated samples for particles and fibers were performed in the same room at a location near the continuous monitors.

A Climet was placed in a second room in the house for continuous measurement of particle concentrations. Integrated samples of particles and fibers were also collected at this location. In a two-story home, the “second room” was on a different floor than the primary sampling location if it was feasible to route the Climet output signal cable to that location from the primary monitoring area. In a single-story home, the second room was a room that was not used extensively. Monitoring was not performed in the kitchen,

bathrooms, closets, or other rooms that may have atypical or sporadic particle sources. The indoor sampling locations are indicated on floor plans included as Appendix B to the report.

The third monitoring location was outdoors. Temperature and relative humidity were recorded outdoors. Integrated particle and fiber samples were collected outdoors simultaneously with the collection of indoor air samples. Meteorological data were not collected at the houses.

The fourth monitoring location was the air conveyance system. Locations of the measurements were described above.

#### ***4.4.2 Protocol for Data Collection at Each Home***

The schedule for performing the monitoring study at each home and the list of technician activities are summarized in Table 4-2. The table summarizes the activities for a home set up on a Saturday. Week-long studies were performed at two houses each week. The schedule for the second home was staggered by one day. Homes were always cleaned on Tuesday and Wednesday. HAC system cleaning was always completed in one day. With the exception of the continuous fiber monitor, sufficient instrumentation was available for measurement of all parameters at the two houses. The original protocol involved instrument set-up and retrieval on Saturdays and Sundays. This approach was taken to improve access to the study homes. However, it was not necessary to set up and retrieve instrumentation at all homes on the weekends. When possible, these activities were performed during the week and the study period was extended at the homes. The initial testing at the EPA IAQ Test House was performed in May, 1996. The field studies at the eight occupied homes were performed during the June to August, 1996 period, the period of peak cooling requirements in North Carolina.

#### **4.5 Initial Testing at the EPA Indoor Air Quality Test House**

The first house studied was the EPA Indoor Air Quality Test House in Cary, NC. The study at the Test House was a pre-test of the technical approach and methods to be used for the eight occupied homes. The procedures were similar to those described above, except that a larger number of samples were collected and continuous monitoring was performed for a longer period. The modifications to the protocol for the Test House was as follows:

- Real-time (continuous) monitoring was performed for 5 days prior to and 5 days following cleaning of the HAC system.
- Three sequential 24-hour integrated samples of  $PM_{2.5}$ ,  $PM_{10}$ , and fibers were collected prior to and following cleaning (compared to two samples pre- and post-cleaning in the field study).

The results of the study at the Test House were analyzed and evaluated to determine if changes should be made in the technical approach or the methods for monitoring and sampling.

Table 4-2. Protocol for Week-long Studies at Each Home

| Day/Time         | Activity  |
|------------------|---|
| <b>Saturday</b>  |   |
| 0900 - 1600      | Set up instrumentation at house in living area, outdoors, and HAC system; set up integrated samplers and program to start Sunday at 0900; collect room surface dust samples; measure supply and return air flow rates; measure static pressures and other HAC system parameters |
| <b>Sunday</b>    |   |
|                  | No technician activities at house; automated fiber and particle samplers run  |
| <b>Monday</b>    |   |
| 0800 - 1200      | Retrieve filter media; start second set of integrated samples; download IAQDS and Climet data; repeat manual measurements of HAC system parameters (air flows, static pressure, fan current); collect microbiological samples   |
| <b>Tuesday</b>   |   |
| 0800             | Retrieve integrated particle and fiber samples;   |
| 0800             | Coordinate with NADCA on duct dust sampling locations and cleaning protocol   |
| 0900             | Collect pre-cleaning duct dust and microbiological samples from supply and return   |
| 1000 - 1600      | Perform duct cleaning   |
| 1630             | Collect post-cleaning duct dust and microbiological samples from supply and return  |
| 1730             | Set up particle and fiber samplers to start on Wednesday at 0900  |
| <b>Wednesday</b> |   |
|                  | No technician activities at house; automated fiber and particle samplers run; HAC system cleaning being performed at other house studied that week  |
| <b>Thursday</b>  |   |
| 0800 - 1200      | Retrieve filter samples; replace filter media; start second set of integrated samples; download IAQDS and Climet data; perform manual measurements of HAC system parameters; collect microbiological samples  |
| <b>Friday</b>    |   |
|                  | No technician activity at house   |
| <b>Saturday</b>  |   |
| 0800 - 1200      | Download IAQDS and Climet data; retrieve filters; perform manual measurements of HAC system parameters; take down instrumentation   |

#### **4.6 HAC System Cleaning Methods**

The air conveyance systems at the EPA Indoor Air Quality Test House and the eight field study homes were all cleaned by representatives of NADCA. The principal investigator for the NADCA team was present for the HAC system cleaning at all houses and was responsible for scheduling and on-site coordination of the cleaning activities. Cleaning team consisted of two to four NADCA representatives. During the study, six different NADCA representatives assisted in cleaning at various houses.

HAC system cleaning was performed practices and equipment commonly used in the HVAC cleaning industry. No proprietary equipment or methods were used in the study. All homes were cleaned using portable equipment. Vacuum trucks were not used in the study. Specific equipment used at each house varied according to the type and configuration of the HAC system and is described in Section 5.3 The following equipment was used in the study:

##### Vacuum Collection

- Advance Containment Systems, 2801 Unit
- Meyer Machine & Equipment, General Collector Vacuum
- Nikro Industries, 15-gal wet/dry HEPA vacuum

##### Agitation

- Vac Systems Industries, VIS 15, 20, and 25 feet RSBS cable-drive rotary brush system
- Meyer Machine & Equipment, Viper pneumatic air whip system
- Abatement Industries forward and reverse skipper snakes
- Portable pressure washer, 1100 psi, 0.75 gallon/min
- Pressurized air source (minimum of 135 psi @ 10 cfm)

##### Wet Cleaning

- Acti-Kleen used for cooling coils
- Simple Green and power washer used for registers, diffusers, and grilles

##### Inspection

- UEMSI Chaser CCTV Video Inspection System
- Inspection mirrors and flashlights

## 5.0 RESULTS AND DISCUSSION

This section describes the results of the field study. It includes a discussion of the participant selection process and the results of the screening process used to select the eight occupied homes for the study. The characteristics of the EPA Indoor Air Quality Test House and the eight occupied homes studied in the project are described in the second subsection. Results of the measurements performed in the field study are described in the following subsections. The final subsections include an evaluation of the sampling and analysis methods used in this pilot study and observations made during the study related to the HAC system cleaning methods, the condition of HAC system components in the study homes, and other factors that may have impacted the research results.

### 5.1 Participant Recruitment and Screening Results

The participant recruitment and selection procedures generally were effective in identifying potential participants and recruiting them into the program. Solicitation of participants from the research organizations involved in the study - Acurex Environmental Corp. and the Research Triangle Institute - worked well, resulting in a set of participants who were highly cooperative and provided a high level of access to their homes. There was some difficulty identifying the type of materials used for the ductwork in homes of people that responded to the solicitation for participants. This was because most homeowners were not knowledgeable about their heating and cooling systems and the HAC system. They had difficulty describing the type of ductwork and were usually not aware of what type of HAC system components that they had. This resulted in a slight increase in the screening effort in the form of follow-up telephone calls and a greater number of initial visits to potential participant homes than initially planned.

As described in Section 4.0, participants were recruited into the study by placing a "call for participants" on the Acurex Environmental office E-mail system and in the weekly newsletter published by the Research Triangle Institute. This approach was used because it was the most cost-effective method to obtain potential participants. It was also felt that employees of the two research institutions were likely to provide a higher level of cooperation and access to their homes because of their understanding of the technical aspects of this research project and the logistics associated with field monitoring studies. However, the study was not limited only to employees of the two organizations. Employees of the two organizations were encouraged to have their friends, family, and neighbors respond to the advertisement.

The first step in the participant recruiting process was to have the potential participant provide responses to a screening questionnaire. The Participant Screening Questionnaire, published in the Project Test Plan (Fortmann, 1996a), included three questions to establish eligibility for the study and 39 questions to collect information on the *Characteristics of the Home*, *Characteristics of the Heating and Cooling System*, and

*Characteristics of the Occupants and Activities.* Participants that called the Acurex Environmental office in response to the advertisement provided responses to the screening questionnaire which was completed by an Acurex Environmental staff member.

The screening questionnaire provided critical information for selection of study homes. There was no difficulty establishing eligibility for the study; respondents provided the information needed to establish that the participant owned the home, that there was no smoking of tobacco products in the home at the time, and that they had a central air conditioning system that they intended to use during the study period. Respondents could also provide responses to the seven questions on the *Characteristics of the Home*, including size of the home, number of floors, age of the home, etc.. Respondents could also provide accurate answers to questions in the section on *Characteristics of the Occupants and Activities*. The section included questions about the number of occupants, pets, cooking activities, use of windows for ventilation, and perceptions about dust levels in the home. The section of the screening questionnaire that respondents had difficulty providing answers was *Characteristics of the Heating and Cooling System*. This section contained 18 questions about the heating and cooling system that were critical for the initial selection of homes for the study. It included questions related to the age and type of heating and cooling systems, age of the ductwork and the materials of construction of the ducts, type of filters in the system, location of supply diffusers and return air grilles, and other HAC system-related questions. Many of the respondents knew the type of heating system (gas, heat pump, etc.) and the approximate age of the heating and cooling system. They also could provide reasonably accurate information on the location and type of filter used in the system. Information was also generally adequate on the locations of supply diffusers, return air grilles, and the air handler. The two areas in which the respondents generally could not provide accurate information was on the type of ducts installed in the home and an assessment of how dirty the system was. It was not surprising that respondents did not know the extent of dust in the system. Most respondents did not have the expertise to make this assessment. Furthermore, the fact that the potential participants responded to the advertisement suggested that they thought their HAC system needed cleaning. In general the respondents thought they had moderate, heavy, or excessive dirt and debris in their ducts.

Potential participants had the most difficulty responding to the question “Do you know what type of ducts are installed in the house?” The options included, *galvanized metal ducts, galvanized metal ducts with flexible ducts to the rooms, galvanized metal ducts lined with insulation on the inside, duct board (also known as fiberboard, i.e. not metal), and other*. Many respondents did not know what types of ducts were in the home. Some knew that the main ducts were galvanized metal, but were not sure what type of ducts went to the room supply diffusers. Practically none of the 65 respondents knew whether they had ducts internally lined with fibrous glass duct liner. Generally, respondents did not know what duct liner was. The

failure to be able to collect accurate information on the type of ducts in the home resulted in a large number of follow-up calls and more initial screening visits to the homes than planned. It is anticipated that in any study of this type it would be difficult to obtain accurate information about the types of ducts because most people are not knowledgeable about duct materials. Furthermore, in the area where the study was performed, most ductwork is in a crawl space under the home. The average homeowner avoids entering the crawl space and is not familiar with the HAC system components. Slightly better information might have been obtained if an additional question had been included that asked if the ducts in the crawl space were insulated on the outside. This may have helped identify systems with internally-lined ducts.

Sixty-five people responded to the call for participants. Of those, five were determined to be ineligible due to smoking or not being homeowners. Of the remaining 60 homes, nine were large homes with two air handlers. As described in Section 4, homes with two air handlers were excluded from the study because it was not feasible to clean the entire HAC system in one day, a requirement for the field monitoring schedule. Four homes had ducts internally-lined with fibrous glass duct liner, but three of the homes had two air handlers and could not be used in the study. One home had a single air handler with internally-lined ducts, but inspection of the ducts indicated that there was substantial fungal contamination in the system, making it ineligible for the study. Three homes had HAC system' with components constructed of fibrous duct board. These homes were not included in the study.

The second phase of the participant selection process was a review of the screening questionnaires and selection of eight candidate homes that appeared to fit the selection criteria and that provided a range of duct types and configurations. Because respondents generally did not know the type of ducts in their home it was first necessary to make follow-up telephone calls or E-mail inquiries to nearly half of the respondents in an attempt to collect better information on the duct materials. Based on that information, eight candidate homes were selected for site visits. When the plan for recruitment of participants was developed, it was anticipated that visits would need to be made to 12 to 16 homes in order to identify eight for the study. A total of 19 site visits were performed for the study.

The initial visit to the house was performed by the principal investigator of the project. The objectives of the initial visits were to verify the eligibility of the participant, inspect the HAC system to determine if it met study requirements, and assess the level of dust in the system. Eligibility of the home was easily verified. Responses to the screening questionnaire were verified during the visit and additional information was collected related to the air handler and air conveyance system. Information collection during the visit confirmed that responses to the questionnaire about the home, the occupants, and occupant activities were generally accurate. But the information provided by the potential participant about the HAC system during the screening interview was frequently not accurate.

During the initial site visit, the air handler and ducts were inspected to assess the relative level of dust in the system. This was generally accomplished using an inspection mirror or fiberscope. The return ducts were inspected at the return air grilles in the home and at the air handler. Supply ducts were inspected from the supply diffusers, via existing access panels, by removing end caps from ducts, and in some cases by disconnecting feeder ducts from the main supply trunks. This approach generally was adequate to obtain a qualitative assessment of duct dust levels. No access holes were cut into the ducts during the initial visit. Where access to the ducts permitted, samples of duct dust were collected with the MVDS for a quantitative assessment. This information was useful, but was not a primary determinant in the final selection of homes for the study. The qualitative information from visual inspections was sufficient to rank homes based on the relative amounts of dirt and debris in the HAC system.

Following the initial visits, the homes were ranked according to suitability for the study based on the selection criteria. Recommendations were made to the EPA project officer, who made a final decision on the homes to be used in the study. Following selection of the homes, return visits were made to most of the homes with representatives of NADCA who evaluated the duct configuration and materials in order to prepare for the cleaning.

## **5.2 Characteristics of the Nine Study Homes**

The characteristics of the study homes are summarized in Table 5-1. The first home studied in the project was the EPA Indoor Air Quality Test House located in Cary, NC. This small ranch-style house is unoccupied and unfurnished. It is used by the EPA to study a wide range of indoor air quality issues. The use of the home in the study provided an opportunity to perform a pre-test of the field measurement protocols and a location to evaluate the monitoring and sampling instrumentation in a semi-controlled environment. The house also provided an opportunity to evaluate cleaning methods for fibrous glass duct liner (FGDL). The duct system in the house consists of a single internally-lined galvanized steel supply trunk that extends 19 feet (5.8 m) in one direction from the air handler and 12 feet (3.7 m) in the other direction. Eleven flexible feeder ducts connect to the main supply trunk. Due to previous condensate drainage problems, the FGDL was contaminated with fungal growth. The fungal contamination was present at the time of cleaning.

Table 5-1. Characteristics of the Nine Study Homes

| No. | City        | House Age       | Duct Age        | AH Age          | Duct Materials                 | House Size (ft <sup>2</sup> ) | No. of Floors | No. of Adults | No. of Children | Pets             | Notes  |
|-----|-------------|-----------------|-----------------|-----------------|--------------------------------|-------------------------------|---------------|---------------|-----------------|------------------|--|
| TH  | Cary        | 20 <sup>a</sup> | 20 <sup>a</sup> | 20 <sup>a</sup> | Fibrous duct liner and flex    | 1305                          | 1             | 0             | 0               | 0                | Unoccupied EPA Indoor Air Quality Test House; AH in crawl space  |
| 1   | Raleigh     | 22              | 22              | 22              | All galvanized                 | 1520                          | 1             | 2             | 2               | 1 cat            | Air handler (AH) in crawl space; condensate drain plugged  |
| 2   | Raleigh     | 18              | 18              | 0.5             | Galvanized supply; flex return | 1450                          | 1             | 2             | 0               | 0                | Ranch style home; new air handler installed in Feb, 96; AH in crawl space; homeowner planned to get ducts cleaned      |
| 3   | Apex        | 10              | 10              | 10              | All flex                       | 1980                          | 2             | 2             | 2               | 0                | All flexible ducts with distribution plenum boxes with fibrous glass duct; AH in low crawl space                       |
| 4   | Apex        | 9               | 9               | 9               | All flex                       | 2000                          | 2             | 2             | 2               | 2 dogs           | All flexible ducts with distribution plenum boxes with fibrous glass duct; AH in crawl space                           |
| 5   | Cary        | 28              | - <sup>a</sup>  | - <sup>a</sup>  | All galvanized                 | 1955                          | 1.5           | 2             | 2               | 1 cat            | Split level house; AH in crawl space; condensate drain improperly installed; not draining; dryer vented to crawl space |
| 6   | Durham      | 25              | 25              | - <sup>a</sup>  | Galvanized and flex            | 1000                          | 1.5           | 3             | 0               | 2 dogs<br>2 cats | Split level; mix of un-lined galvanized and flex ducts; AH in unoccupied basement; easy cleaning access                |
| 7   | Chapel Hill | 26              | 26              | 26              | All galvanized                 | 2000                          | 2             | 2             | 2               | 0                | Complaints of dust from supply; AH in crawl space  |
| 8   | Durham      | 35              | 35              | - <sup>a</sup>  | All galvanized                 | 1500                          | 2             | 2             | 2               | 1 cat            | AH in full unheated basement   |

<sup>a</sup> Accurate information unavailable. Age of Test House believed to be 15 to 20 years. In cases where information was unavailable, inspection of the ductwork suggests that ducts are same age as house, but age of air handler is unknown.

The other eight homes in the study were occupied by the owners at the time of the study. All homes were occupied by two adults, except House No. 6 which was occupied by three adults. The number of occupants was not a selection criterion and it turned out that six of the eight houses were occupied by two adults and two children. Cats and/or dogs were present in five of eight homes.

As shown in Table 5-1, the homes ranged in size from 1000 to 2000 ft<sup>2</sup> (93 to 186 m<sup>2</sup>). The homes were 9 to 28 years old. Two houses were single level ranch-style homes with a crawl space under the entire house and two were split-level homes. House No. 5 had a crawl space under approximately half of the house. Some of the ducts in the house were in the crawl space and some were in the ceiling of the lower level of the house. House No. 6 was a split level house in which a previous owner had converted the original crawl space to an unfinished basement in which the air handler was located. In this house some ducts were in the unfinished basement and others were in the ceiling of the finished lower level. Four houses were two stories with ducts for the first floor in the crawl space and ducts for the second floor located in the attic. In all homes, except House No. 2, the ducts appeared to be the original installed at the time of construction. At House No. 2, the air handler and return air ducts had been replaced approximately six months before the study. The HAC system in House Nos. 3 and 4, which were located in the same development and were similar in construction, were all flexible ducts. The supply ducts were connected via internally-lined (FGDL) distribution boxes. House No. 6 had a combination of galvanized steel ducts and flexible ducts. All other houses had all galvanized duct systems, consisting of externally-insulated rectangular supply ducts with round galvanized steel feeder ducts to the rooms. Additional description of the houses is included in the following subsection.

### **5.3 Description of the HAC System and the HAC System Cleaning Methods**

During the field study, each of the houses was visited by the Acurex Environmental project director, the field technicians, staff from EPA, and two to four NADCA representatives responsible for performing the HAC system cleaning. During the visits, a number of observations were made relating to the design, construction, operation, and maintenance of the air conveyance system at the house. On the day that cleaning was performed, the HAC system components were inspected as part of the cleaning process. During the study, numerous instances of poor design and poor maintenance of the HAC system were observed. At house 1, for example, the condensate drain was plugged, resulting in intrusion of water into the air handler. This had apparently been a problem for an extended period of time because the air handler frame was rusty and badly corroded. At House 5, the condensate drain line was not installed properly and had insufficient vertical drop for use as a gravity drain system. As a result, the water was not draining. Installation of a drain pump would be required to correct the problem. During the first visit to House 7, the principal investigator found that one of the branch feeder ducts had broken away from the main supply trunk; the branch trunk was on the

floor of the crawl space and air was blowing out of the supply trunk. At House 5, there was a large gap in the supply trunk where it connected to the air handler plenum box, resulting in large energy losses to the crawl space. This unit also had an access plate on the supply duct that was originally taped onto the side of the duct, but had fallen off. A number of the deficiencies in the systems would impact the performance of the HAC system and the energy use, as described above. Some deficiencies might adversely impact indoor air quality and occupant comfort and health. At House 3, mice had eaten through the flexible duct. There were large pieces of fiberglass insulation that the mice had collected as nesting material. Some of it had blown to the floor registers. In this system, there were mice feces and seed shells throughout the system, including deposits on ceiling diffusers on the second floor. At House 7, condensate drain problems resulted in water damage to the fibrous glass liner in the air handler plenum box. Upon opening the box, the fibrous glass liner was found to be contaminated with fungal growth. Other deficiencies impacted the effectiveness of the HAC system cleaning. There were numerous cases of panned return air plenums. The wood, gypsum board, and other surfaces were more difficult to clean than sheet metal duct. At Houses 5 and 6, the stairwell served as the return plenum. Not only was the design conducive to heavy dust and debris deposits in the return because there were no filters on the grilles, but the plenums were difficult to clean. In general, the homeowners were not aware of design deficiencies or maintenance problems. They were usually not aware of the significant impact that duct leakage and deteriorating insulation would have on energy costs for operating the system. This was normally the result of a lack of knowledge about residential heating and cooling systems and not a lack of concern.

The HAC system was cleaned by representatives of NADCA with methods and commercially-available equipment commonly used in the HVAC cleaning industry. No proprietary equipment or methods were employed during this study. The vacuum collectors were portable units; vacuum trucks were not used in the study. Cleaning of the HAC system at the study homes generally involved work by two to four cleaning personnel during a six to ten hour period. The cleaning involved removal of all supply registers and diffusers and return air grilles. The floor boots were hand vacuumed at all homes. The panned return air plenums were also hand vacuumed. The systems were zoned as required for cleaning. A substantial effort was expended on cleaning of the AHU components. The blower was removed from the AHU for cleaning at all houses. Cooling coils were wet-cleaned in place. During cleaning there was a high level of visual inspection to insure that the components of the system were cleaned effectively. Visual inspection was normally performed with mirrors and flashlights. Use of a remote video camera provided improved inspection capabilities particularly in systems with long ducts and extensive bends and transitions.

The following sub-sections contain a brief summary of the characteristics of the air conveyance system and the methods used for cleaning the HAC system at the study homes. To the extent possible, deficiencies

in the systems that may have impacted energy use, indoor air quality, or HAC system cleaning effectiveness are highlighted. Ratings of characteristics such as duct integrity are subjective.

### 5.3.1 EPA Indoor Air Quality Test House

**Date Cleaned:** May 21, 1996  
**NADCA Personnel:** TH, BK, CC  
**House Design:** Single story ranch

#### HAC System Description:

##### **Air Handling Unit:**

**Location:** Hallway closet  
**Type:** Vertically-mounted; DX cooling; gas heating; blow-through fan  
**Cooling Coils:** Visible dust  
**Blower:** Coating of dust on fan blades  
**Drain pan:** Standing water; not draining completely; on-going problems with condensate in the supply plenum at the time of cleaning; pan was not fitting properly on one end; fan was blowing water out of pan into the supply duct  
**Drain Line:** Working properly  
**Humidifier:** None  
**Contamination:** Water damaged fibrous glass insulation was contaminated with mold growth; insulation was removed, discarded, and replaced with new insulation

##### **Supply Ductwork:**

**Location:** Ducts in crawl space; floor registers; panned in supply air (S/A) plenum in kitchen and bathrooms  
**Duct Type:** Galvanized sheet metal, rectangle trunk duct, internal fibrous glass liner; flexible ducts to room diffusers  
**Integrity:** Some rust in areas with previous water damage from condensate drain problem; insulation at bottom of S/A plenum was saturated with water from condensate drain pan  
**Contamination:** Visible debris at floor boots, assorted debris; internal fibrous glass duct liner heavily contaminated with fungal growth throughout supply trunk; fungal contamination in flexible ducts

**Return Ductwork:**

**Location:** Ductwork in attic; return grille in hall ceiling adjacent to air handling unit  
**Duct Type:** Flexible duct  
**Integrity:** Acceptable condition  
**Filter:** Located in ceiling return grille; standard low-efficiency; clean  
**Contamination:** Visible dust; visible fungal contamination

**Environmental Observations:**

**Crawl Space -** Polyethylene sheet on dirt floor; mold odor

**House Interior Conditions -** House unfurnished; all carpeted; carpet requires cleaning; mold odor

**HAC System Cleaning Methods:**

Due to the degraded and contaminated condition of the fibrous glass ductliner, NADCA personnel recommended either replacing the duct or re-surfacing the duct liner to prevent further degradation. However, this was not done so that the contaminated duct could be used for additional research in the future. The fibrous glass duct liner was power brushed with nylon brushes, air washed, and visually inspected while kept under negative pressure from an Advanced Containment Systems (ACS) 2801 collector vacuum with HEPA filtration. Parts of fibrous glass liner were hand brushed and hand vacuumed. Flexible return air duct removed, discarded, and replaced with new duct. All flexible ducts to room supplies were removed and replaced with new ducts because of extensive mold contamination in the HAC system which made them uncleanable. AHU plenum hand vacuumed with attachments on a portable HEPA-filtered canister vacuum. AC coil was wet cleaned with Acti-Kleen. Visual inspection performed with fiber scope.

**5.3.2 House Number 1**

**Date Cleaned:** June 11, 1996  
**NADCA Personnel:** TH, BK, TY  
**House Design:** Single story ranch

**HAC System Description:**

**Air Handling Unit:**

**Location:** Crawl space  
**Type:** Horizontally-mounted; DX cooling; electric heating; draw-through fan  
**Cooling Coils:** Visible debris  
**Blower:** Coating of dust on fan blades, along with some oil from motor shaft  
**Drain pan:** Standing water with debris and slime

**Drain Line:** Not draining; plugged, although AHU equipped with condensate pump that was working; condensate draining out of supply plenum onto crawl space floor

**Contamination:** One-fourth inch of wet dirt in the supply plenum; mole crickets and bugs impaled on heating coil; dead bugs throughout AHU

**Humidifier:** None

**Supply Ductwork:**

**Location:** Ducts in crawl space; floor supply registers, except two sidewall registers in sunken living area

**Duct Type:** Galvanized sheet metal, rectangle trunk duct; round branch ducts to rooms; externally insulated

**Integrity:** Limited amount of rust/corrosion at floor boots, otherwise acceptable condition; external insulation deteriorated and needed replacement

**Contamination:** Crusty coatings at floor boots, assorted debris including toys, crayons, hair, etc.; overall the system was considered to be very dirty

**Return Ductwork:**

**Location:** (1) Kitchen wall; (2) hallway ceiling

**Duct Type:** (1) Wall board/sheetmetal to flexible duct; (2) flexible duct

**Integrity:** Normal

**Filter:** Located in return air grilles; high-efficiency, washable; moderately dusty

**Contamination:** Dust and hair coating throughout return system

**Environmental Observations:**

**Crawl Space -** Loose dirt on crawl space floor; no polyethylene covering on crawl space dirt floor

**House Interior Conditions -** Below average housekeeping; carpet heavily soiled; surfaces of furnishings dusty

**HAC System Cleaning Methods:**

Metá ductwork was power brushed with silica-carbide brushes, air washed, and visually inspected while kept under negative pressure from a Meyers General collector vacuum without HEPA filtration. Return air boxes and AHU plenum were hand vacuumed with attachments on a portable HEPA-filtered canister vacuum. AC coil was wet cleaned and condensate drain line was blown free of debris with pressurized air. Meyers General vacuum located near crawl space door.

### 5.3.3 House Number 2

Date Cleaned: June 12, 1996  
NADCA Personnel: TH, BK, TY  
House Design: Single story ranch

#### HAC System Description:

##### Air Handling Unit:

**Location:** Crawl space  
**Type:** Horizontally-mounted; DX cooling; electric heating; draw-through fan  
**Cooling Coils:** Light debris, new coil (less than one year old)  
**Blower:** Light coating of dust on fan blades  
**Drain pan:** Moderate standing water  
**Drain Line:** Working properly  
**Contamination:** AHU less than one year old; moderate dust present  
**Humidifier:** None

##### Supply Ductwork:

**Location:** Ducts in crawl space; floor supply registers  
**Duct Type:** Galvanized sheet metal, rectangle trunk duct; round ducts to room diffusers  
**Integrity:** Acceptable condition  
**Contamination:** Moderate surface contamination at floor boots and trunk duct

##### Return Ductwork:

**Location:** Two return grilles: (1) in entry hallway, (2) in main hallway; both R/A were panned  
**Duct Type:** Galvanized sheet metal and flexible duct  
**Integrity:** Normal  
**Filter:** In return air grilles; high-efficiency panel type media filters; moderate dust  
**Contamination:** Coating of dust throughout the return system

#### Environmental Observations:

Crawl Space - Loose dirt on crawl space floor; no polyethylene covering on crawl space dirt floor  
House Interior Conditions - Housekeeping above average; mostly wall-to-wall carpeting

#### HAC System Cleaning Methods:

Metal ductwork was power brushed with silica-carbide brushes, air washed, and visually inspected while kept under negative pressure from a Meyers General collector vacuum without HEPA filtration. Meyers General located behind house at crawl space door. Panned in R/A plenums and AHU were hand vacuumed

with attachments on a portable HEPA-filtered canister vacuum. Flexible return duct was contact-vacuumed. Cooling coil was wet cleaned with Acti-Kleen. Simple Green used to clean registers and grilles.

#### 5.3.4 House Number 3

Date Cleaned: June 25, 1996

NADCA Personnel: TH, BK

House Design: Two-story

#### HAC System Description:

##### Air Handling Unit:

**Location:** Crawl space

**Type:** Horizontally-mounted; DX cooling; gas heating; blow-through fan; internal insulation poorly installed

**Cooling Coils:** Visible debris

**Blower:** Moderate coating of dust on fan blades, along with some oil from motor shaft

**Drain pan:** Some standing water

**Drain Line:** Working properly

**Contamination:** Substantial amount of loose fiberglass, rodent feces, sunflower seed hulls, peanuts hulls, and other debris from mice that had inhabited system

**Humidifier:** Add-on unit located in supply plenum; severe mineral build-up; assorted slime and debris in unit

##### Supply Ductwork:

**Location:** First floor ducts in crawl space; floor supply registers on first floor; ceiling diffusers on second floor; ducts in attic

**Duct Type:** All flexible duct with bullhead plenums, internally-lined; volume dampers for balancing

**Integrity:** NADCA personnel recommended replacement of the entire duct system due to poor design and installation. There was substantial deterioration of portions of round flexible duct material which needed replacement; volume dampers inoperable because of poor design and installation; bullhead plenums had significant air leakage.

**Contamination:** Excessive contamination throughout the system including rodent droppings, rodent's nesting material consisting of the fiberglass insulation, and sunflower seed hulls. Also construction material was left in the ductwork, dust accumulation, and other debris. Insulated round ducts had visible condensation and mold growth on the outside.

**Return Ductwork:**

**Location:** Two R/A grilles: (1) living room wall on first floor; (2) hallway wall on second floor

**Duct Type:** Flexible duct

**Integrity:** NADCA personnel recommended replacement of the entire return duct system due to the poor condition and poor installation. Duct was severely degraded at connection to air handler

**Filters:** In return air grilles; washable, high-efficiency, panel type; moderate dust level

**Contamination:** Heavy dust coating throughout the return air system.

**Environmental Observations:**

Crawl Space - Loose dirt on crawl space floor; no polyethylene covering over dirt floor of crawl space

House Interior Conditions - Above average housekeeping

**HAC System Cleaning Methods:**

Flexible ductwork was power brushed with nylon brushes and air washed while kept under negative pressure from a Meyers General collector vacuum without HEPA filtration. Meyers General vacuum collector located outside at the crawl space access door. Return air plenums and AHU were hand vacuumed with attachments on a portable HEPA-filtered canister vacuum. Cooling coil and humidifier unit were wet cleaned using Acti-Kleen.

**5.3.5 House Number 4**

**Date Cleaned:** June 26, 1996

**NADCA Personnel:** TH, BK

**House Design:** Two-story

**HAC System Description:**

**Air Handling Unit:**

**Location:** Crawl space

Type: Horizontally-mounted; DX cooling; gas heating; blow-through fan; insulation poorly installed

Cooling Coils: Visible debris

Blower: Coating of dust on fan blades, along with some oil from motor shaft

Drain pan: Some standing water

Drain Line: Operational, but not completely draining the pan

Contamination: Moderate dust; some mold growth on internal insulation at supply plenum

Humidifier: None

**Supply Ductwork:**

Location: First floor ducts in crawl space; floor supply registers on first floor; ceiling diffusers on second floor; ducts in attic

Duct Type: All flexible duct with bullhead plenums, internally-lined; volume dampers for balancing

Integrity: Poor design and installation; deterioration of portions of round flexible duct material which needed replacement in both attic and crawl space; volume dampers inoperable because of poor design and installation; bullhead plenums had significant air leakage; NADCA personnel recommended replacement of parts of the duct system

Contamination: Visible dirt and dust throughout the system including pet hair and debris

**Return Ductwork:**

Location: Two return air grilles: (1) Living room wall on first floor; (2) ceiling on second floor

Duct Type: Flexible duct

Integrity: NADCA personnel recommended partial replacement of the duct system

Filter: In return air grilles; standard low-efficiency fiberglass panel type; heavy dust loading on both filters; upstairs filter did not fit

Contamination: Dirt and dust coating throughout return system

**Environmental Observations:**

Crawl Space - No polyethylene covering of loose dirt on crawl space floor

House Interior Conditions - Average housekeeping; two dogs kept in house

**HAC System Cleaning Methods:**

Flexible ductwork was power brushed with nylon brushes and air washed while kept under negative pressure from a Meyers General collector vacuum without HEPA filtration. Meyers General located outside

near crawl space access door. Return air plenums and AHU were hand vacuumed with attachments on a portable HEPA-filtered canister vacuum. Cooling coil and humidifier unit were wet cleaned.

### 5.3.6 House Number 5

Date Cleaned: July 16, 1996

NADCA Personnel: TH, BK, CC, FC

House Design: Split-level ranch

#### HAC System Description:

##### **Air Handling Unit:**

**Location:** Crawl space

**Type:** Horizontally-mounted; DX cooling; gas heating; blow-through fan

**Cooling Coils:** Visible debris

**Blower:** Heavy coating of dust on fan blades

**Drain pan:** Over one inch of standing water; water carry over into supply plenum

**Drain Line:** Improper design; not working; condensate drain improperly routed (inadequate drop for gravity drain); requires installation of a condensate drain pump

**Contamination:** Heavy deposits of dust and fibers in system

**Humidifier:** None

##### **Supply Ductwork:**

**Location:** Floor registers on main level and upstairs; ceiling diffusers in lower level rooms; ducts in crawl space and in ceiling of lower level rooms

**Duct Type:** Galvanized sheet metal; rectangular trunk duct; round branches to rooms; deteriorated external insulation

**Integrity:** Duct design had excessive right angle turns/transitions throughout system; one main supply trunk had large separation at connection to supply plenum of air handler resulting in large losses of air from system

**Contamination:** Moderate surface contamination throughout system; considerable debris in trunk duct

##### **Return Ductwork:**

**Location:** Two return air plenums: (1) In stairwell from entry to first level; (2) in stairwell from first level to second level; grilles in all stair risers; no filters at grilles; stairwell serves as panned R/A plenum

**Duct Type:** Galvanized sheet metal

**Integrity:** Access difficult under stairwell; return not well sealed; not insulated

Filter: In air handler at blower; old, low-efficiency fiber mat filter; heavily-loaded with dirt; poor fit  
Contamination: Dust and debris coating throughout return system

Environmental Observations:

Crawl Space - No polyethylene covering over loose dirt on crawl space floor.

House Interior Conditions - Average housekeeping; downstairs lower level den with visible dust on surfaces; dryer was venting into the crawl space near the return duct; strong odor detected at the AHU, but source was not identified

HAC System Cleaning Methods:

Metal ductwork was power brushed with silica-carbide brushes, air washed, and visually monitored via a UEMSI portable cctv video inspection system while kept under negative pressure from a Meyers General collector vacuum without HEPA filtration. Meyers General vacuum collector located outside near crawl space access door. Return air plenum and AHU were hand vacuumed with attachments on a portable HEPA-filtered canister vacuum. Cooling coil was wet cleaned using Acti-Kleen.

**5.3.7 House Number 6**

Date Cleaned: July 17, 1996  
NADCA Personnel: TH, BK, CC, FC  
House Design: Split-level ranch with original crawl space under entry level excavated and converted to an unfinished basement

HAC System Description:

Air Handling Unit:

Location: In unfinished basement  
Type: Vertically-mounted; DX cooling; gas heating; blow-through fan  
Cooling Coils: Visible debris, slime  
Blower: Moderate coating of dust on fan blades  
Drain pan: Standing water; water carry over into supply plenum; visible microbial contamination; excessive condensation on exterior of supply plenum ductwork  
Drain Line: Not working properly; standing water  
Contamination: Moderate levels of dust and fibers in system; slime in drain pan

**Humidifier:** Humidifier was not working; had heavy mineral deposits and microbial contamination; removed and not replaced

**Supply Ductwork:**

**Location:** Floor registers on main level and upstairs; ceiling diffusers in lower level rooms; ducts in crawl space and in ceiling of lower level rooms

**Duct Type:** Predominantly galvanized sheet metal; rectangular trunk duct; round branches to rooms; some flexible branch ducts

**Integrity:** Acceptable; insulation not complete on all exposed components (e.g., at transitions)

**Contamination:** Moderate surface contamination throughout system

**Return Ductwork:**

**Location:** Two return air plenums: (1) In stairwell from first level to second level; grilles in stair risers; no filters at grilles; panned stairwell R/A plenum; (2) in sidewall in lower level bedroom

**Duct Type:** Galvanized sheet metal

**Integrity:** Acceptable

**Filter:** One in return air grille in lower level bedroom was standard low-efficiency fiberglass with heavy dust loading; second one in air handler near blower that owner did not know was present and had excessive dirt loading on it

**Contamination:** Dust and debris coating throughout return air system

**Environmental Observations:**

House Interior Conditions - Housekeeping below average; visible dust on surfaces; heavy fungal contamination on walls in upstairs bathroom

**HAC System Cleaning Methods:**

Metal ductwork was power brushed with silica-carbide brushes, air washed, and visually monitored via a UEMSI portable cctv video inspection system while kept under negative pressure from a Advanced Containment Systems 2801 collector vacuum with HEPA filtration located in unfinished basement. Return air plenums and AHU were hand vacuumed with attachments on a portable HEPA-filtered canister vacuum. Cooling coil was wet cleaned.

**5.3.8 House Number 7**

Date Cleaned: July 30, 1996

NADCA Personnel: TH, BK, TB, TG

House Design: Two-story

HAC System Description:

**Air Handling Unit:**

**Location:** Crawl space  
**Type:** Horizontally-mounted; DX cooling; gas heating; draw-through fan  
**Cooling Coils:** Visible debris  
**Blower:** Moderate coating of dust on fan blades  
**Drain pan:** Standing water; water carry over into supply plenum; internal fibrous glass liner in supply plenum box contaminated with fungal growth  
**Drain Line:** Not working properly; standing water  
**Contamination:** Moderate levels of dust and fibers in system; internal liner of supply plenum contaminated with mold growth  
**Humidifier:** None

**Supply Ductwork**

**Location:** Floor registers on main level; ceiling diffusers on second level  
**Duct Type:** Galvanized sheet metal; rectangular trunk duct; round branches to rooms; supply plenum box with internal fibrous glass liner  
**Integrity:** One supply branch duct had disconnected from the main trunk and fallen off; system very leaky; external insulation that was deteriorated; fibrous glass duct liner in supply plenum box contaminated with fungal growth  
**Contamination:** Moderate surface contamination throughout system; limited construction debris; contaminated fibrous glass liner in supply plenum box

**Return Ductwork:**

**Location:** One grille in wall hallway under stairs near entry; R/A plenum was panned in; no return from second floor  
**Duct Type:** Galvanized sheet metal  
**Integrity:** Panned in R/A plenum; return not well sealed  
**Filter:** Located in return air grille; standard low-efficiency fiberglass; moderate dust  
**Contamination:** Dust and debris coating throughout return system

Environmental Observations:

Crawl space - No polyethylene covering on loose dirt in crawl space floor

House Interior Conditions - Housekeeping average to above average HAC System Cleaning Methods:

Metal ductwork was power brushed with silica-carbide brushes, air washed, and visually inspected while kept under negative pressure from a Meyers General collector vacuum without HEPA filtration. Meyers General vacuum collector located outside near access door for crawl space. Return air plenums and AHU were hand vacuumed with attachments on a portable HEPA-filtered canister vacuum. Cooling coil was wet cleaned with Acti-Kleen. Supply plenum liner was removed and replaced with new insulation after cleaning.

**5.3.9 House Number 8**

Date Cleaned: July 31, 1996

NADCA Personnel: TH, BK, TB, TG

House Design: Two-story with full, partially-finished basement

HAC System Description:

Air Handling Unit:

Location: Basement

Type: Vertically-mounted; DX cooling; oil-fired heating; blow-through fan

Cooling Coils: Heavy accumulation of dust and debris; significant blockage; cooling coil was "A" coil; cooling coil was add-on to the AHU

Blower: Moderate coating of dust on fan blades

Drain pan: Standing water; some debris; slime in drain pan; poor access

Drain Line: Working, but not completely draining pan; drain line routed to basement floor drain

Contamination: Heavy deposits of dust and fibers in system; coil very dirty; slime in drain pan

Humidifier: None

Supply Ductwork:

Location: Floor registers on both levels; ducts exposed in basement; some ducts in finished ceiling of basement; all ducts went up exterior walls to second floor

Duct Type: Galvanized sheet metal; rectangular trunk duct; round branches to rooms

Integrity: Generally good; two supply diffuser boots pulling away from basement ceiling (nails loose)

Contamination: Heavy surface contamination (dirt, dust, hair) throughout system; substantial amount of fibers, probably cat hair, visible in ducts

**Return Ductwork:**

- Location:** (1) Sidewall floor grille in dining room; (2) sidewall floor grille in living room; no return from second floor
- Duct Type:** Galvanized sheet metal; undersized
- Integrity:** Moderate leakage, but in finished, conditioned basement
- Filter:** Located in air handler at blower; low-efficiency fiberglass; poor fit
- Contamination:** Heavy accumulation of dust in return system; highest dust levels in return of the eight field study homes

**Environmental Observations:**

House Interior Conditions - Housekeeping average; visible mold growth on floor joists in basement

**HAC System Cleaning Methods:**

Metal ductwork was power brushed with silica-carbide brushes, air washed, and visually inspected while kept under negative pressure from a Meyers General collector vacuum without HEPA filtration. Meyers General located outside near basement door. Return air plenums and AHU were hand vacuumed with attachments on a portable HEPA-filtered canister vacuum. Cooling coil was wet cleaned.

**5.4 Duct Dust and Microbial Surface Loading Measurements**

The amount of dust in the supply and return ducts was measured at each home by collection of dust samples with the MVDS. Dust was defined as the material that could be collected with the MVDS and includes both particulate matter and fibers. Large pieces of debris, such as pencils, construction debris, and parts of toys, were not collected with the MVDS. Obtaining access to the ducts was the most difficult aspect of sample collection. In general, samples were collected only where easy access could be obtained without disrupting the dust deposits in the ducts. Samples were collected in the return ducts near the return air grilles and near the air handler. At the return air grilles, the technician reached into the duct as far as possible to collect the sample. At the air handler, the access panel was removed for the blower and samples were collected from the return air duct as far away from the access panel as possible. In both cases, the duct was visually inspected with a mirror and flashlight in an attempt to identify a sampling location with representative deposits of duct dust. In the supply side, access was gained in three ways. End caps were removed from the main trunk duct or at distribution boxes. In some cases, feeder ducts were disconnected from the main trunk in order to collect samples from the main trunk or from the feeder duct. The feeder ducts were also disconnected near the supply register at some homes in order to collect samples. The third, and least preferred method, was to cut access panels into the supply trunks to gain access for sampling. The problem associated with this approach was that the process of cutting the galvanized steel metal resulted in

metal shavings in the duct. These could be easily observed with proper lighting, but it was necessary to reach into the duct to access sampling locations without metal shavings. In one home, a short section of a main supply trunk was removed to facilitate sampling.

A limited number of dust samples were collected with the NADCA method in the homes that had galvanized steel ducts. Samples were collected only after HAC system cleaning to verify cleaning effectiveness, as recommended in NADCA Standard 1992-01.

Samples were also collected in the ducts for determination of the culturable microbial surface loading in the supply and return ducts. Samples were collected using the same access method as the dust samples, as described in Section 4.0.

#### **5.4.1 Duct Dust Mass Measurements Pre- and Post-Cleaning**

The results of the duct dust measurements with the MVDS at the nine homes are summarized in Table 5-2. The complete data set is included in Appendix C. The mean and standard deviation are presented for the total number of samples (indicated as N) collected in the supply and all samples collected in the return. The minimum and maximum duct dust concentrations are also included in the table to show the range of concentrations. A limited number of samples collected from the foil liner of the air handler and the cooling coil are also included in the table.

The mean dust mass in the supply ducts of the nine homes prior to HAC system cleaning ranged from 1.48 g/m<sup>2</sup> at House 4 to 26.03 g/m<sup>2</sup> at House 8. The second highest mean dust mass in the supply ducts was 8.62 g/m<sup>2</sup> at House 1. The mean was less than 3.4 g/m<sup>2</sup> at the other six houses. As shown in the table, the maximum dust mass concentrations and the standard deviations were highest for Houses 1 and 8. The high dust mass levels at House 8 were consistent with visual observations; House 8 was considered to have the “dirtiest” ducts by all staff who inspected the ducts at the study homes.

Pre-cleaning dust levels were substantially higher in the return ducts than in the supply ducts. The mean duct dust levels in the returns ranged from 5.26 to 35.11 g/m<sup>2</sup>. The maximum mass measured was 51.1 g/m<sup>2</sup> in the return duct immediately upstream of the filter located adjacent to the air handler blower in House 8.

Samples collected from the foil liner of the air handler or the cooling coil were in the same range as samples collected in the supply ducts. The number of samples collected from the air handler foil liner and cooling coils was lower than planned. In some cases, access was limited, precluding easy collection of samples. There were also logistical difficulties as three technicians and up to three NADCA staff worked

Table 5-2. Dust Levels Measured with the MVDS in the HAC System of Study Homes

| House | Summary<br>Statistic | Duct Dust Mass (g/m <sup>2</sup> ) |       |              |              |                          |                   |
|-------|----------------------|------------------------------------|-------|--------------|--------------|--------------------------|-------------------|
|       |                      | Supply                             |       | Return       |              | Air Handler <sup>a</sup> |                   |
|       |                      | Pre-                               | Post- | Pre-         | Post-        | Pre-                     | Post-             |
| TH    | Mean                 | 2.33                               | 0.74  | <sup>b</sup> | <sup>b</sup> | NS                       | NS                |
|       | Std. Dev             | 1.61                               | 0.37  | -            | -            |                          |                   |
|       | Min                  | 0.80                               | 0.27  | -            | -            |                          |                   |
|       | Max                  | 4.66                               | 1.24  | -            | -            |                          |                   |
|       | N                    | 6                                  | 6     | -            | -            |                          |                   |
| 1     | Mean                 | 8.62                               | 0.30  | 19.83        | 0.58         | 1.7                      | NS                |
|       | Std. Dev             | 10.60                              | 0.09  | 6.60         | 0.06         | 2.35 <sup>c</sup>        | 0.29 <sup>c</sup> |
|       | Min                  | 0.51                               | 0.24  | 26.30        | 0.54         |                          |                   |
|       | Max                  | 26.30                              | 0.41  | 13.10        | 0.63         |                          |                   |
|       | N                    | 5                                  | 5     | 3            | 2            |                          |                   |
| 2     | Mean                 | 3.37                               | 0.21  | 24.13        | 0.44         | NS                       | 0.18 <sup>c</sup> |
|       | Std. Dev             | 2.09                               | 0.08  | 23.52        | 0.23         |                          |                   |
|       | Min                  | 2.12                               | 0.16  | 7.50         | 0.28         |                          |                   |
|       | Max                  | 5.79                               | 0.30  | 40.80        | 0.60         |                          |                   |
|       | N                    | 3                                  | 3     | 2            | 2            |                          |                   |
| 3     | Mean                 | 1.91                               | 0.25  | 7.80         | 0.28         | 1.57                     | 0.19              |
|       | Std. Dev             | 1.05                               | 0.09  | 5.30         | 0.12         | 0.72 <sup>c</sup>        | <sup>d</sup>      |
|       | Min                  | 0.54                               | 0.16  | 2.62         | 0.19         |                          |                   |
|       | Max                  | 3.00                               | 0.35  | 13.15        | 0.42         |                          |                   |
|       | N                    | 4                                  | 3     | 3            | 3            |                          |                   |
| 4     | Mean                 | 1.48                               | 0.27  | 7.89         | 0.12         | 0.46                     | 0.10              |
|       | Std. Dev             | 0.29                               | 0.11  | 2.35         | 0.08         | 1.81 <sup>c</sup>        | 0.12 <sup>c</sup> |
|       | Min                  | 1.27                               | 0.19  | 6.22         | 0.06         |                          |                   |
|       | Max                  | 1.69                               | 0.34  | 9.55         | 0.17         |                          |                   |
|       | N                    | 2                                  | 2     | 2            | 2            |                          |                   |
| 5     | Mean                 | 2.28                               | 0.59  | 11.34        | 1.11         | 2.24 <sup>c</sup>        | 0.13 <sup>c</sup> |
|       | Std. Dev             | 0.48                               | 0.39  | 0.21         | 1.22         |                          |                   |
|       | Min                  | 1.94                               | 0.32  | 11.19        | 0.25         |                          |                   |
|       | Max                  | 2.62                               | 0.87  | 11.49        | 1.97         |                          |                   |
|       | N                    | 2                                  | 2     | 2            | 2            |                          |                   |
| 6     | Mean                 | 2.30                               | 0.18  | 5.26         | 0.15         | NS                       | NS                |
|       | Std. Dev             | 0.26                               | 0.00  | 1.69         | 0.04         |                          |                   |
|       | Min                  | 2.00                               | 0.18  | 3.62         | 0.12         |                          |                   |
|       | Max                  | 2.45                               | 0.18  | 6.99         | 0.19         |                          |                   |
|       | N                    | 3                                  | 2     | 3            | 3            |                          |                   |
| 7     | Mean                 | 3.34                               | 0.50  | 12.91        | 0.32         | 6.18                     | 0.25              |
|       | Std. Dev             | 1.79                               | 0.17  | 5.48         | 0.03         | 2.38 <sup>c</sup>        | <sup>d</sup>      |
|       | Min                  | 1.24                               | 0.37  | 9.03         | 0.30         |                          |                   |
|       | Max                  | 5.93                               | 0.69  | 16.78        | 0.34         |                          |                   |
|       | N                    | 6                                  | 3     | 2            | 2            |                          |                   |
| 8     | Mean                 | 26.03                              | 0.79  | 35.11        | 0.39         | 5.48 <sup>c</sup>        | <sup>d</sup>      |
|       | Std. Dev             | 8.41                               | 0.35  | 13.85        | 0.28         |                          |                   |
|       | Min                  | 16.39                              | 0.44  | 26.59        | 0.19         |                          |                   |
|       | Max                  | 36.07                              | 1.13  | 51.10        | 0.59         |                          |                   |
|       | N                    | 4                                  | 3     | 3            | 2            |                          |                   |

<sup>a</sup> Single samples were collected from the foil liner or cooling coil (not mean of replicates)

<sup>b</sup> Return air duct replaced; no samples collected

<sup>c</sup> Coiling coil samples <sup>d</sup> Coiling coil could not be sampled post-cleaning because it was wet

NS: No sample collected due to logistical or access problems

on the system. However, the samples from the foil liner were not considered to be critical because the dust deposit on the air handler liner was generally not representative of the rest of the ductwork. Dust samples were not collected from all cooling coils prior to cleaning. But this was not critical to interpretation of the results. During the study, it was observed that dust could not be efficiently collected from the cooling coils with the MVDS prior to cleaning. Dust and fibers impacted on the coil and in the coil “fins” remained after sampling. This was especially obvious at House 8, where the cooling coil was very dirty. Post-cleaning samples could not be collected at every home because the cooling coil was still wet following cleaning. Results of this study suggest that quantitative measurements of dust on coils will be difficult to perform both prior to, and following, HAC system cleaning. The performance of the MVDS has not been evaluated for sampling from coils and is not likely to be highly efficient. Visual observation of dust and fibers on coils is probably adequate for comparisons between houses.

The post-cleaning measurement results presented in Table 5-2 show that the cleaning methods were generally very effective for removing dust from the HAC system components. The mean residual dust measured with the MVDS from supply ducts after HAC system cleaning ranged from 0.18 to 0.79 g/m<sup>2</sup>. In the return ducts the mean residual dust mass following cleaning ranged from 0.15 to 1.11 g/m<sup>2</sup>. For all post-cleaning samples collected at the nine homes, the dust mass ranged from 0.06 to 1.97 g/m<sup>2</sup>. The reader is cautioned that interpretation of the mean results should be made considering the limited number of samples used to calculate the mean. Only two or three samples each were collected from the supply and return following cleaning, as indicated by “N” in the table. For example, the highest mean levels of residual dust were measured in the return and supply ducts at House 5. However, as shown by the Minimum and Maximum values presented in the Table, for both the supply and return, one sample was less than 0.32 g/m<sup>2</sup>, but the other sample was substantially higher. Post-cleaning measurements for samples from the air handler foil liner and cooling coils were in the same range as those collected from supply and return duct surfaces.

Samples of duct dust were also collected with the NADCA vacuum method following cleaning of the HAC system. Collocated samples were collected with the NADCA and the MVDS methods in order to compare the two methods under field conditions. Results of the comparison are presented in Table 5-3. The NADCA standard units of mg/100 cm<sup>2</sup> are used in the table. The NADCA results ranged from 0.01 mg/100 cm<sup>2</sup> to 0.36 mg/100 cm<sup>2</sup> (0.001 to 0.036 g/m<sup>2</sup>). In all cases, the samples met the NADCA criterion of 1.0 mg/100 cm<sup>2</sup> as a verification that the surfaces were effectively cleaned. Collocated measurements with the MVDS ranged from 1.6 to 11.3 mg/100 cm<sup>2</sup> (0.16 to 1.13 g/m<sup>2</sup>).

Table 5-3. Comparison of Residual Duct Dust Mass Measurements With the MVDS and the NADCA Vacuum Methods Following HAC System Cleaning

| House | Location                         | mg/100 cm <sup>2</sup> |      |
|-------|----------------------------------|------------------------|------|
|       |                                  | NADCA                  | MVDS |
| TH    |                                  | - <sup>a</sup>         | -    |
| 1     | Main Supply Trunk                | - <sup>b</sup>         | 2.4  |
|       | Main Supply Trunk - Site 2       | 0.12                   | 4.1  |
| 2     | Main Supply Trunk                | 0.36                   | 1.8  |
|       | Main Supply Trunk - Duplicate    | 0.34                   | 1.6  |
| 3     |                                  | - <sup>a</sup>         | -    |
| 4     |                                  | - <sup>a</sup>         | -    |
| 5     | Main Supply Trunk                | 0.30                   | 3.2  |
|       | Main Supply Trunk - Duplicate    | 0.32                   | 3.2  |
|       | Return Duct                      | 0.35                   | 2.5  |
| 6     | Main Supply Trunk                | 0.27                   | 1.8  |
|       | Main Supply Trunk - Duplicate    | 0.24                   | 2.3  |
|       | Return Duct                      | 0.27                   | 1.9  |
| 7     | Main Supply Trunk - Left         | 0.08                   | 6.9  |
|       | Main Supply Trunk - Right        | 0.13                   | 4.4  |
|       | Main Supply Trunk - Right - Dup. | 0.13                   | 8.0  |
|       | Return Duct at Grille            | 0.01                   | 3.4  |
| 8     | Main Trunk-Right                 | 0.07                   | 11.3 |
|       | Main Trunk-Right - Duplicate     | 0.06                   | 6.3  |
|       | Main Supply Trunk Near End Cap   | 0.03                   | 4.4  |
|       | Return Duct                      | 0.05                   | 1.9  |

<sup>a</sup> No samples; ducts internally lined or flexible duct

<sup>b</sup> Invalid sample

Although both visual observations and MVDS measurements indicated that the cleaning methods effectively removed particulate and fibrous material from the surfaces of HAC system components, there was always residual dust that could be collected with the MVDS method following cleaning. As shown in Table 5-2, the residual dust measurements in the supply and return ducts ranged from 0.06 to 1.97 g/m<sup>2</sup>. A total of 37 post-cleaning samples were collected from surfaces in the supply ductwork at the nine homes in the study. The mean “residual dust” after cleaning for the 37 samples was 0.448 ± 0.030 g/m<sup>2</sup>. For the 21 post-cleaning samples collected in the return ducts, the mean was 0.401 ± 0.400 g/m<sup>2</sup>. The mean for all 58 post-cleaning samples was 0.431 ± 0.337 g/m<sup>2</sup> (4.3 mg/100 cm<sup>2</sup>). The MVDS was specially developed for this study and

has a higher collection efficiency due to the higher air flow rate and use of a brush on the nozzle. The data from this study demonstrate that the NADCA Standard 1992-01 criterion of 1.0 mg/100 cm<sup>2</sup> to document the effectiveness of cleaning should only be applied to samples collected with the Standard 1992-01 vacuum test method. The criterion of 1.0 mg/100 cm<sup>2</sup> is not appropriate for samples collected with the MVDS sampling method. Results from this study and from measurements performed in the Pilot Air Conveyance System tests performed prior to the field study (VanOsdell et al., 1997), suggest that a criterion approximately 5 mg/100 cm<sup>2</sup> (0.5 g/m<sup>2</sup>) may be more appropriate for samples collected with the MVDS.

Duplicate measurements were collected at a number of locations with both the NADCA vacuum method and the MVDS. Results for the NADCA method are presented above in Table 5-3. As shown in the Table, the precision of the method was very good. Results of duplicate measurements with the MVDS are presented in Table 5-4. The table includes duplicates for pre-cleaning samples, listed first for each house and having concentrations generally above 0.5 g/m<sup>2</sup>, and post-cleaning samples. Twenty-one of the 28 sets of collocated samples have a relative standard deviation below 25 percent. Five sets of duplicates with a RSD greater than 25% were post-cleaning samples.

At Houses 6, 7, and 8, additional duct dust samples were collected to evaluate the effect of brushing versus airwashing only. After collecting the initial pre-cleaning sample, the vacuum system was attached to place the duct section under negative air pressure, then the section of duct was cleaned by high pressure air washing only with pressure ranging from 135 to 165 pounds per square inch (psi) and without mechanical brushing. An "after air-washing" sample was then collected. The duct was then cleaned with a rotary brush and airwashed again to remove the loosened dust. A final post-cleaning sample was then collected. The results of these tests are summarized in Table 5-5. At all three houses, the airwashing procedure removed a substantial amount of loose dust from the surface of the duct as indicated by the difference between the Initial sample and the After Airwash sample. Brushing followed by airwashing removed substantially more; brushing was necessary to effectively clean the surface. Although the testing was limited in scope, it clearly indicates the importance of brushing for cleaning duct surfaces.

Table 5-4. Results of Duplicate Duct Dust Measurements With The MVDS

| House | Location                | g/m <sup>2</sup> |           |       |       | %RSD |
|-------|-------------------------|------------------|-----------|-------|-------|------|
|       |                         | Primary          | Duplicate | Mean  | S.D   |      |
| TH    | Supply <sup>a</sup>     | 0.80             | 1.09      | 0.94  | 0.20  | 22   |
| 1     | Supply <sup>b</sup>     | 10.80            | 11.89     | 11.85 | 0.06  | 1    |
|       | Supply <sup>b</sup>     | 26.28            | 100.72    | 63.65 | 52.64 | 83   |
|       | Return <sup>a</sup>     | 0.24             | 0.25      | 0.25  | 0.007 | 3    |
| 2     | Supply <sup>b</sup>     | 2.22             | 2.73      | 2.48  | 0.36  | 15   |
|       | Supply <sup>a</sup>     | 0.18             | 0.16      | 0.17  | 0.01  | 1    |
| 3     | Return <sup>b</sup>     | 13.15            | 16.54     | 14.85 | 2.40  | 16   |
|       | Supply <sup>a</sup>     | 0.54             | 0.34      | 0.44  | 0.14  | 32   |
|       | Supply <sup>a</sup>     | 0.19             | 0.26      | 0.23  | 0.05  | 22   |
|       | Return <sup>a</sup>     | 0.42             | 0.37      | 0.40  | 0.04  | 9    |
| 4     | Supply <sup>a</sup>     | 1.27             | 1.47      | 1.37  | 0.14  | 10   |
|       | Return <sup>b</sup>     | 6.22             | 5.11      | 5.67  | 0.78  | 14   |
|       | Duct Liner <sup>a</sup> | 1.62             | 1.55      | 1.59  | 0.05  | 3    |
|       | Supply <sup>a</sup>     | 0.34             | 0.12      | 0.23  | 0.16  | 80   |
| 5     | Supply <sup>b</sup>     | 2.62             | 2.52      | 2.57  | 0.07  | 3    |
|       | Return <sup>b</sup>     | 11.49            | 10.47     | 10.98 | 0.72  | 7    |
|       | Supply <sup>a</sup>     | 0.32             | 0.23      | 0.28  | 0.06  | 23   |
|       | Return <sup>a</sup>     | 1.97             | 0.59      | 1.28  | 0.98  | 76   |
| 6     | Supply <sup>b</sup>     | 2.00             | 2.03      | 2.02  | 0.2   | 1    |
|       | Return <sup>b</sup>     | 3.62             | 6.52      | 5.07  | 2.05  | 40   |
|       | Return <sup>a</sup>     | 0.18             | 0.23      | 0.21  | .04   | 17   |
| 7     | Supply <sup>b</sup>     | 4.22             | 5.07      | 4.65  | 0.60  | 13   |
|       | Return <sup>b</sup>     | 9.03             | 11.66     | 10.35 | 1.86  | 18   |
|       | Supply <sup>a</sup>     | 0.44             | 0.80      | 0.62  | 0.25  | 41   |
| 8     | Supply <sup>b</sup>     | 36.07            | 45.98     | 41.03 | 7.01  | 17   |
|       | Supply <sup>a</sup>     | 1.13             | 0.63      | 0.88  | 0.35  | 40   |
|       | Supply <sup>a</sup>     | 0.80             | 0.65      | 0.73  | 0.11  | 15   |
|       | Return <sup>a</sup>     | 0.19             | 0.26      | 0.23  | 0.05  | 22   |

<sup>a</sup> Post-cleaning surface dust samples

<sup>b</sup> Pre-cleaning surface dust samples

Table 5-5. Results of the Evaluation of Brushing Versus Air Washing

| House | Location                  | g/m <sup>2</sup> |               |       |
|-------|---------------------------|------------------|---------------|-------|
|       |                           | Initial*         | After Airwash | Final |
| 6     | Main Trunk Near End Cap   | 2.00             | 0.73          | 0.18  |
|       | Main Trunk Near Middle    | 2.45             | 1.17          | 0.18  |
|       | Return Duct Near AH       | 24.11            | 1.10          | 0.13  |
| 7     | Main Supply Trunk         | 5.93             | 3.23          | 0.69  |
| 8     | Main Supply Trunk - Right | 36.07            | 2.09          | 0.63  |
|       | Main Supply Trunk - Left  | 28.85            | 4.09          | 0.65  |

\* Initial = Prior to cleaning; After Airwash = After airwashing, but prior to brushing; Final = After brushing followed by airwashing

#### 5.4.2 Microbial Surface Loading Measurement Results

The results of the microbial surface sampling are summarized in Tables 5-6, 5-7, and 5-8. The tables present the mean concentration measured at multiple locations in the ducts. Samples were generally collected from the bottom surface of the ducts. The number of locations at which samples were collected is indicated as "N" in the table and the minimum and maximum concentrations are also presented. Results are presented for both the supply side and return ducts prior to, and following, HAC cleaning. The complete data set is included in Appendix D. Table 5-6 shows results of the bacterial sampling in Houses 1 through 8. The results of the surface fungal sampling in the eight field study houses are presented in Table 5-7. The data from the EPA Indoor Air Quality Test House, presented in Table 8, have been separated from the field study homes because the ducts at the test house were lined with fibrous glass duct liner, while the other eight houses had galvanized steel or flexible ducts. As discussed in Section 4.2.6, two different methods were used to collect surface samples from the ducts, a vacuum method and a swab method. The development and use of these two methods was discussed in depth in the *Air Conveyance System Cleaning Pilot System Development, Characterization, and Operation: Project Work and QA Plan* (RTI, 1995) and *Field Microbiological Investigation of Ventilation System Cleaning: Project Work/QA Plan* (RTI, 1996). For the hard surface galvanized steel, little difference was anticipated between the results of these two methods; therefore, the data from both the swab and the vacuum methods have been combined. However, differences are anticipated in the results using the two methods for the porous materials. Therefore, only the vacuum results are summarized from the test house.

As can be seen in Table 5-6, the bacteria levels in samples collected from the duct surfaces prior to HAC system cleaning were generally low. No unusual or unexpected bacteria were isolated from any of the samples. The highest levels of bacteria were isolated from House 4 in the pre-cleaning return duct samples. As indicated by the standard deviation and minimum and maximum values in the tables, the concentrations of bacteria in the surface samples were also highly variable.

The impact of mechanical cleaning of the HAC system without use of chemical biocides on ductwork surfaces following cleaning was variable and the results are inconclusive. There were some differences between the pre-cleaning and post-cleaning samples in both the supply and return ducts. However, there was no clear trend. Although the mean bacteria concentrations decreased following cleaning of the supply ducts at four homes, there were high concentrations of bacteria in the post-cleaning supply duct samples at the other four homes. For samples collected from the return ducts, the post-cleaning concentrations were lower at seven of eight homes. At the three homes with the highest pre-cleaning mean concentration (houses 2, 4, and 6,) the post-cleaning concentrations were substantially lower. It is not evident why the impact of cleaning on return ducts would differ from that on supply ducts. The results, therefore, are generally inconclusive with regarding to evaluating the impact of mechanical cleaning on bacterial surface loading. Chemical biocides are frequently applied to surfaces following mechanical cleaning. But because chemical biocides were not used in this study, evaluation of the practice of applying biocides following cleaning could not be evaluated.

Table 5-6. Results of Surface Samples of Bacteria in the Supply and Return Ducts

| House | Summary Statistic | Cfu/cm <sup>2</sup> |            |           |                |
|-------|-------------------|---------------------|------------|-----------|----------------|
|       |                   | SUPPLY              |            | RETURN    |                |
|       |                   | Pre-clean           | Post-clean | Pre-clean | Post-clean     |
| 1     | Mean              | 166                 | 266        | 20        | - <sup>a</sup> |
|       | Std Dev           | 379                 | 311        | 21        | - <sup>a</sup> |
|       | Min               | 5                   | 5          | 5         | - <sup>a</sup> |
|       | Max               | 1100                | 760        | 35        | - <sup>a</sup> |
|       | N                 | 8                   | 8          | 2         | - <sup>a</sup> |
| 2     | Mean              | 36                  | 28         | 235       | 20             |
|       | Std Dev           | 17                  | 37         | 134       | 7              |
|       | Min               | 10                  | 5          | 140       | 15             |
|       | Max               | 55                  | 95         | 330       | 25             |
|       | N                 | 6                   | 6          | 2         | 2              |
| 3     | Mean              | 11                  | 14         | 78        | 8              |
|       | Std Dev           | 9                   | 8          | 10        | 6              |
|       | Min               | 5                   | 5          | 70        | 5              |
|       | Max               | 25                  | 20         | 90        | 15             |
|       | N                 | 4                   | 4          | 2         | 2              |
| 4     | Mean              | 120                 | 365        | 1233      | 33             |
|       | Std Dev           | 134                 | 482        | 1007      | 14             |
|       | Min               | 25                  | 25         | 300       | 25             |
|       | Max               | 350                 | 1200       | 2300      | 50             |
|       | N                 | 4                   | 4          | 2         | 2              |
| 5     | Mean              | 81                  | 20         | 26        | 13             |
|       | Std Dev           | 146                 | 27         | 25        | 12             |
|       | Min               | 5                   | 5          | 5         | 5              |
|       | Max               | 300                 | 60         | 60        | 30             |
|       | N                 | 4                   | 4          | 4         | 4              |
| 6     | Mean              | 14                  | 73         | 143       | 8              |
|       | Std Dev           | 11                  | 63         | 100       | 6              |
|       | Min               | 5                   | 5          | 5         | 5              |
|       | Max               | 30                  | 140        | 270       | 20             |
|       | N                 | 6                   | 6          | 6         | 6              |
| 7     | Mean              | 404                 | 85         | 128       | 278            |
|       | Std Dev           | 341                 | 112        | 103       | 385            |
|       | Min               | 25                  | 5          | 55        | 5              |
|       | Max               | 800                 | 250        | 200       | 550            |
|       | N                 | 4                   | 4          | 2         | 2              |
| 8     | Mean              | 64                  | 53         | 83        | 53             |
|       | Std Dev           | 69                  | 75         | 60        | 55             |
|       | Min               | 5                   | 5          | 5         | 5              |
|       | Max               | 150                 | 200        | 150       | 100            |
|       | N                 | 6                   | 6          | 4         | 4              |

<sup>a</sup> No sample collected

Table 5-7. Results of Surface Samples of Fungi in the Supply and Return Ducts

| House | Summary Statistic | Cfu/cm <sup>2</sup> |            |           |                |
|-------|-------------------|---------------------|------------|-----------|----------------|
|       |                   | SUPPLY              |            | RETURN    |                |
|       |                   | Pre-clean           | Post-clean | Pre-clean | Post-clean     |
| 1     | Mean              | 35700               | 1206       | 2650      | - <sup>a</sup> |
|       | Std Dev           | 86642               | 1546       | 3041      | - <sup>a</sup> |
|       | Min               | 1900                | 25         | 500       | - <sup>a</sup> |
|       | Max               | 250000              | 4700       | 4800      | - <sup>a</sup> |
|       | N                 | 8                   | 8          | 2         | - <sup>a</sup> |
| 2     | Mean              | 9217                | 138        | 280       | 153            |
|       | Std Dev           | 6367                | 248        | 57        | 152            |
|       | Min               | 1200                | 10         | 240       | 45             |
|       | Max               | 19000               | 640        | 320       | 260            |
|       | N                 | 6                   | 6          | 2         | 2              |
| 3     | Mean              | 4604                | 740        | 22333     | 147            |
|       | Std Dev           | 3423                | 750        | 5508      | 51             |
|       | Min               | 20                  | 100        | 16000     | 90             |
|       | Max               | 8300                | 1700       | 26000     | 190            |
|       | N                 | 4                   | 4          | 2         | 2              |
| 4     | Mean              | 73400               | 15890      | 850       | 617            |
|       | Std Dev           | 69366               | 15935      | 304       | 375            |
|       | Min               | 500                 | 950        | 650       | 250            |
|       | Max               | 160000              | 36000      | 1200      | 1000           |
|       | N                 | 4                   | 4          | 2         | 2              |
| 5     | Mean              | 35                  | 46         | 58        | 71             |
|       | Std Dev           | 50                  | 52         | 35        | 53             |
|       | Min               | 5                   | 5          | 25        | 15             |
|       | Max               | 110                 | 120        | 90        | 140            |
|       | N                 | 4                   | 4          | 4         | 4              |
| 6     | Mean              | 113                 | 61         | 613       | 7              |
|       | Std Dev           | 89                  | 59         | 998       | 4              |
|       | Min               | 15                  | 5          | 20        | 5              |
|       | Max               | 250                 | 130        | 2600      | 15             |
|       | N                 | 6                   | 6          | 6         | 6              |
| 7     | Mean              | 1089                | 49         | 2200      | 23             |
|       | Std Dev           | 1879                | 68         | 283       | 25             |
|       | Min               | 15                  | 10         | 2000      | 5              |
|       | Max               | 3900                | 150        | 2400      | 40             |
|       | N                 | 4                   | 4          | 2         | 2              |
| 8     | Mean              | 63                  | 7          | 196       | 10             |
|       | Std Dev           | 56                  | 4          | 101       | 6              |
|       | Min               | 25                  | 5          | 75        | 5              |
|       | Max               | 170                 | 15         | 320       | 15             |
|       | N                 | 6                   | 6          | 4         | 4              |

<sup>a</sup> No sample collected

Table 5-8. Results of Surface Samples at the IAQ Test House

|          |                   | Cfu/cm <sup>2</sup> |            |                     |            |
|----------|-------------------|---------------------|------------|---------------------|------------|
|          |                   | SUPPLY              |            | RETURN <sup>a</sup> |            |
| Organism | Summary Statistic | Pre-clean           | Post-clean | Pre-clean           | Post-clean |
| FUNGI    | Mean              | 81250               | 4853       | -                   | -          |
|          | Std Dev           | 112964              | 2743       | -                   | -          |
|          | Min               | 13000               | 810        | -                   | -          |
|          | Max               | 250000              | 6900       | -                   | -          |
|          | N                 | 4                   | 4          | -                   | -          |
| BACTERIA | Mean              | 37                  | 295        | -                   | -          |
|          | Std Dev           | 55                  | 593        | -                   | -          |
|          | Min               | 5                   | 5          | -                   | -          |
|          | Max               | 100                 | 1500       | -                   | -          |
|          | N                 | 4                   | 7          | -                   | -          |

<sup>a</sup> Return duct was removed and replaced with new duct; no samples collected

A summary of the results of the surface fungi sampling is presented in Table 5-7. The mean colony forming units (cfus) of fungi isolated per cm<sup>2</sup> in the pre-cleaning supply samples ranged from 35 to 73,400; while in the return, they ranged from 58 to 22,300. In Houses 1, 2, and 4, considerably higher numbers of fungi were isolated from the supply side samples, while in House 3, more fungi were isolated from the return. For the rest of the houses, the levels were similar and demonstrated considerable overlap in the minimum and maximum numbers of cfus isolated. Mechanical cleaning without use of chemical biocides resulted in a reduction of fungi in the surface samples at all houses except House 5, which had low levels of fungi in the surface samples. There was a large change in concentrations between the pre-cleaning and post-cleaning samples at some of the study homes. But the variability of the fungi surface sample concentrations was large, as indicated in Table 5-7 by the standard deviation, making it difficult to assess the significance of the impact of mechanical cleaning of the HAC system on fungi levels on the surfaces. As noted above, chemical biocides, although frequently used by HVAC system cleaning contractors, were not used or evaluated in this study.

The results of the surface sampling in the EPA IAQ Test House are summarized in Table 5-8. When interpreting the results of measurements at the test house, it should be noted that the cleaning procedures employed at the house were probably not typical of what would be used by HVAC system cleaning contractors faced with the situation at the house. The supply duct at the Test House was internally-lined with fibrous glass duct liner that had become heavily contaminated with fungal growth due to previous problems with the condensate drain pan and intrusion of water into the supply duct. Pre-cleaning sampling showed

that fungal levels on the supply duct liner were high (Table 5-8). No return microbiological samples were collected; the flexible return duct in the house was removed and replaced as part of the HAC system cleaning process. There were large variations in fungal cfu/cm<sup>2</sup> between sample locations as indicated by the large standard deviation for the four samples collected. Following mechanical cleaning of the internally-lined supply ducts, the level of fungi isolated from the surface samples was substantially less than in the pre-cleaning samples. However, there were still high levels of organisms in the post-cleaning surface samples, relative to the levels observed in the galvanized and flexible ducts in most of the other study homes (Table 5-7). The predominant fungi isolated from the pre-cleaning samples were yeasts; while few were isolated from the post-cleaning samples. The samples of bacteria collected after cleaning were highly variable, as indicated by the standard deviation. The levels after cleaning were higher than prior to cleaning.

The typical practices for cleaning and remediation of internally-lined ducts with fungal contamination would be to either (1) remove and replace the entire fibrous glass duct liner or (2) to apply an encapsulant, generally one containing a biocide, to the surface of the duct liner. Because of the research nature of this study and the desire to use the Test House facility for further HAC system cleaning research, neither practice was implemented during this study. Testing of encapsulants and biocides is planned as part of future testing. Therefore, the results of measurements from the Test House should not be used to evaluate the impact of HAC system cleaning on fungal or bacterial contamination on duct surfaces.

#### **5.4.3 Surface Dust Samples**

On the day that the sampling and monitoring instrumentation was set up at each house, two dust samples were collected with the MVDS from surfaces of furnishings in the home. The objective of collecting these samples was to assess whether there was a relationship between surface dust samples and levels of dust in the HAC system. Results of the surface dust sample measurements are presented in Table 5-9. Surface dust levels were generally below 0.5 g/m<sup>2</sup>. The levels were above 1.0 g/m<sup>2</sup> only at House No. 5. There was no apparent relationship between the levels of dust on the surfaces of furnishings and the amount of dust measured in either the supply or the return ducts of the HAC system. The surface dust levels were lowest at House No. 8, which had the highest dust levels in the HAC system.

#### **5.5 Measurement Results for Selected Indoor Air Quality Parameters**

Air monitoring and sampling were performed at each study home prior to, and following, HAC system cleaning in an attempt to determine whether the cleaning had short-term impacts on IAQ parameters. The parameters measured included particles, fibers, and fungi. Measurements were made using continuous monitoring instrumentation for particles and by collection of integrated samples. The results are described and discussed in the following sub-sections.

Table 5-9. Results of Measurements of Surface Dust on Furnishings

| House | g/m <sup>2</sup> |        |                 |        |
|-------|------------------|--------|-----------------|--------|
|       | Surface Dust     |        | Duct Dust (Avg) |        |
|       | Site 1           | Site 2 | Supply          | Return |
| TH    | 0.44             | 0.15   | 2.33            | -      |
| 1     | 0.53             | 0.37   | 8.62            | 19.83  |
| 2     | 0.45             | 0.26   | 3.37            | 24.13  |
| 3     | 0.38             | 0.39   | 1.91            | 7.80   |
| 4     | 0.65             | 0.44   | 1.48            | 7.89   |
| 5     | 1.30             | 1.70   | 2.28            | 11.34  |
| 6     | 0.51             | 0.18   | 2.30            | 5.26   |
| 7     | 0.13             | 0.08   | 3.34            | 12.91  |
| 8     | ND               | 0.05   | 26.03           | 35.11  |

\* ND: Not detected above detection limit

### 5.5.1 Respirable and Inhalable Particle Mass Concentrations

Respirable particles, defined as particles with a mean diameter less than 2.5  $\mu\text{m}$  ( $\text{PM}_{2.5}$ ), and inhalable particles, defined as particles with a mean diameter less than 10  $\mu\text{m}$  ( $\text{PM}_{10}$ ), were collected using size-selective impactors. Two sequential 24-hr samples were collected prior to HAC system cleaning and two 24-hr samples were collected following cleaning. The post-cleaning samples were started on the morning of the day following HAC system cleaning to avoid the impact of the activities on the day of cleaning which may have affected particle concentrations due to opening of windows and doors, as well as high human activity in the home. The objective was to determine if HAC system cleaning had a short-term impact on particle levels in the home. Samples were also collected outdoors for comparison.

Concentrations of  $\text{PM}_{2.5}$  are presented in Table 5-10 for pre- and post-cleaning samples. Concentrations of  $\text{PM}_{10}$  are presented in Table 5-11. In both tables, data are presented for outdoors and for the two indoor locations (primary and secondary). The concentrations of both  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  indoors are low and are typical of concentrations measured indoors if there is no tobacco smoking (Wallace, 1996).

Table 5-10. PM<sub>2.5</sub> Measurement Results

| House | Location  | µg/m <sup>3</sup> |             |                   |                 |               |             |      |      | Post/<br>Pre |
|-------|-----------|-------------------|-------------|-------------------|-----------------|---------------|-------------|------|------|--------------|
|       |           | Pre-Cleaning      |             |                   |                 | Post-Cleaning |             |      |      |              |
|       |           | Sample<br>1       | Sample<br>2 | Mean <sup>a</sup> | SD <sup>a</sup> | Sample<br>1   | Sample<br>2 | Mean | SD   |              |
| TH    | Outdoor   | 23.4              | 23.1        | 23.3              | 0.2             | 18.4          | 22.5        | 20.4 | 2.9  | 0.88         |
|       | Primary   | 7.7               | 7.3         | 7.5               | 0.3             | 10.4          | 10.3        | 10.3 | 0.1  | 1.37         |
|       | Secondary | 6.9               | 8.6         | 7.8               | 1.2             | 10.4          | 11.1        | 10.8 | 0.5  | 1.38         |
| 1     | Outdoor   | 5.0               | 12.2        | 8.6               | 5.1             | <sup>b</sup>  | 28.1        | 28.1 | -    | 3.27         |
|       | Primary   | 5.4               | 7.5         | 6.5               | 1.5             | 12.6          | 17.9        | 15.3 | 3.7  | 2.36         |
|       | Secondary | 5.2               | 7.3         | 6.3               | 1.5             | 13.6          | 18.4        | 16.0 | 3.4  | 2.56         |
| 2     | Outdoor   | 11.7              | 11.5        | 11.6              | 0.1             | 25.4          | 33.2        | 29.3 | 5.5  | 2.53         |
|       | Primary   | 7.0               | 16.5        | 11.8              | 6.7             | 13.6          | 20.1        | 16.9 | 4.6  | 1.43         |
|       | Secondary | 6.6               | 14.3        | 10.5              | 5.4             | 14.7          | 18.8        | 16.8 | 2.9  | 1.60         |
| 3     | Outdoor   | 36.4              | 33.6        | 35.0              | 2.0             | 21.6          | 28.9        | 25.3 | 5.2  | 0.72         |
|       | Primary   | 17.2              | 15.8        | 16.5              | 1.0             | 11.0          | 15.5        | 13.3 | 3.2  | 0.80         |
|       | Secondary | 17.1              | 16.2        | 16.7              | 0.6             | 10.2          | 14.4        | 12.3 | 3.0  | 0.74         |
| 4     | Outdoor   | 25.8              | 23.4        | 24.6              | 1.7             | 26.7          | 40.9        | 33.8 | 10.0 | 1.37         |
|       | Primary   | 12.2              | 11.4        | 11.8              | 0.6             | 19.2          | 32.1        | 25.7 | 9.1  | 2.17         |
|       | Secondary | 10.1              | 11.4        | 10.8              | 0.9             | 14.4          | 29.3        | 21.9 | 10.5 | 2.03         |
| 5     | Outdoor   | 18.3              | 10.4        | 14.4              | 5.6             | 22.6          | 23          | 22.8 | 0.3  | 1.59         |
|       | Primary   | 6.6               | 4.7         | 5.7               | 1.3             | 10.3          | 10.2        | 10.3 | 0.0  | 1.81         |
|       | Secondary | 5.2               | 5.2         | 5.2               | 0.0             | 9.8           | 11.5        | 10.7 | 1.2  | 2.05         |
| 6     | Outdoor   | 11                | 18.5        | 14.8              | 5.3             | 24.2          | 19          | 21.6 | 3.7  | 1.46         |
|       | Primary   | 7.3               | 5.6         | 6.5               | 1.2             | 8.7           | 4.9         | 6.8  | 2.7  | 1.05         |
|       | Secondary | 10.4              | 6.1         | 8.3               | 3.0             | 8.9           | 7.7         | 8.3  | 0.8  | 1.01         |
| 7     | Outdoor   | <sup>b</sup>      | 21.3        | 21.3              | -               | 8.5           | 16.5        | 12.5 | 5.7  | 0.59         |
|       | Primary   | 11.2              | 12.1        | 11.7              | 0.6             | 8.2           | 8.8         | 8.5  | 0.4  | 0.73         |
|       | Secondary | 11.4              | 11.1        | 11.3              | 0.2             | 6.6           | 8.7         | 7.7  | 1.5  | 0.68         |
| 8     | Outdoor   | <sup>b</sup>      | 13.7        | 13.7              | -               | 14.7          | 20.1        | 17.4 | 3.8  | 1.27         |
|       | Primary   | 17.3              | 5.3         | 11.3              | 8.5             | <sup>c</sup>  | 13.2        | 13.2 | -    | 1.17         |
|       | Secondary | 10.6              | 4.7         | 7.7               | 4.2             | 8.2           | 13.6        | 10.9 | 3.8  | 1.42         |

<sup>a</sup> Mean and Standard Deviation for two samples

<sup>b</sup> Sample lost due to power failure

<sup>c</sup> Sample not valid

Table 5-11. PM<sub>10</sub> Measurement Results

| House | Location  | µg/m <sup>3</sup> |             |                   |                 |                |             |      |      | Post/<br>Pre |
|-------|-----------|-------------------|-------------|-------------------|-----------------|----------------|-------------|------|------|--------------|
|       |           | Pre-Cleaning      |             |                   |                 | Post-Cleaning  |             |      |      |              |
|       |           | Sample<br>1       | Sample<br>2 | Mean <sup>a</sup> | SD <sup>a</sup> | Sample<br>1    | Sample<br>2 | Mean | SD   |              |
| TH    | Outdoor   | 28.3              | 27.9        | 28.1              | 0.3             | 23.3           | 28.8        | 26.1 | 3.9  | 0.93         |
|       | Primary   | 13.1              | 9.1         | 11.1              | 2.8             | 24.4           | 33.7        | 29.0 | 6.6  | 2.61         |
|       | Secondary | 9.5               | 9.5         | 9.5               | 0.0             | 9.3            | 19.1        | 14.2 | 6.9  | 1.49         |
| 1     | Outdoor   | 11.7              | 17.1        | 14.4              | 3.8             | - <sup>b</sup> | 33.8        | 33.8 | -    | 2.35         |
|       | Primary   | 10.7              | 10.6        | 10.7              | 0.0             | 21.3           | 22.9        | 22.1 | 1.1  | 2.08         |
|       | Secondary | 8.0               | 9.2         | 8.6               | 0.8             | 17.0           | 20.3        | 18.7 | 2.3  | 2.17         |
| 2     | Outdoor   | 15.5              | 21.9        | 18.7              | 4.5             | 29.5           | 36.1        | 32.8 | 4.7  | 1.75         |
|       | Primary   | 8.1               | 22.3        | 15.2              | 10.0            | 15.8           | 22.6        | 19.2 | 4.8  | 1.26         |
|       | Secondary | 7.6               | 16.6        | 12.1              | 6.4             | 7.9            | 18.2        | 13.1 | 7.3  | 1.08         |
| 3     | Outdoor   | 41.8              | 42.4        | 42.1              | 0.4             | 22.3           | 34.7        | 28.5 | 8.8  | 0.68         |
|       | Primary   | 16.5              | 18.8        | 17.7              | 1.6             | 16.1           | 18.6        | 17.4 | 1.8  | 0.98         |
|       | Secondary | 17.9              | 19.8        | 18.9              | 1.3             | 13.4           | 18.9        | 16.2 | 3.9  | 0.86         |
| 4     | Outdoor   | 29.9              | 27.6        | 28.8              | 1.6             | 34.1           | 48.9        | 41.5 | 10.5 | 1.44         |
|       | Primary   | 14.7              | 16.5        | 15.6              | 1.3             | 26.9           | 40.2        | 33.6 | 9.4  | 2.15         |
|       | Secondary | 13.6              | 11.6        | 12.6              | 1.4             | 11.9           | 10.1        | 11.0 | 1.3  | 0.87         |
| 5     | Outdoor   | 20.2              | 17.8        | 19.0              | 1.7             | 26.8           | 33.7        | 30.3 | 4.9  | 1.59         |
|       | Primary   | 7.2               | 12.8        | 10.0              | 4.0             | 14.2           | 13          | 13.6 | 0.8  | 1.36         |
|       | Secondary | 6.8               | 10.6        | 8.7               | 2.7             | 14.4           | 13.2        | 13.8 | 0.8  | 1.59         |
| 6     | Outdoor   | 17.4              | 29.3        | 23.4              | 8.4             | 16.3           | 24.9        | 20.6 | 6.1  | 0.88         |
|       | Primary   | 11.6              | 9           | 10.3              | 1.8             | 12.6           | 6.7         | 9.7  | 4.2  | 0.94         |
|       | Secondary | - <sup>b</sup>    | 9.7         | 9.7               | -               | - <sup>b</sup> | 8.4         | 8.4  | -    | 0.87         |
| 7     | Outdoor   | - <sup>b</sup>    | 26.2        | 26.2              | -               | 19.0           | 23.0        | 21.0 | 2.8  | 0.80         |
|       | Primary   | 13.1              | 15.5        | 14.3              | 1.7             | 11.0           | 11.7        | 11.4 | 0.5  | 0.79         |
|       | Secondary | 12.5              | 13.8        | 13.2              | 0.9             | 11.3           | 11.3        | 11.3 | 0.0  | 0.86         |
| 8     | Outdoor   | - <sup>b</sup>    | 26.2        | 26.2              | -               | 19.0           | 25.1        | 22.1 | 4.3  | 0.84         |
|       | Primary   | 14.6              | 7.1         | 10.9              | 5.3             | 8.0            | 17.4        | 12.7 | 6.6  | 1.17         |
|       | Secondary | 13.7              | 17.7        | 15.7              | 2.8             | 10.4           | 16.9        | 13.7 | 4.6  | 0.87         |

<sup>a</sup> Mean and Standard Deviation for two samples

<sup>b</sup> Sample lost due to power failure

Indoor concentrations of  $PM_{2.5}$  were in the range from 5.2 to 32.1  $\mu\text{g}/\text{m}^3$ .  $PM_{10}$  concentrations ranged from 6.7 to 40.2  $\mu\text{g}/\text{m}^3$ . The highest indoor concentrations were measured at House No. 4 in the post-cleaning samples. The outdoor air concentrations measured at the house were also the highest during the study. As shown in Table 5-10, the concentrations of  $PM_{2.5}$  were similar at the primary and secondary locations indoors for both pre-cleaning and post-cleaning samples. The concentrations were more variable for the two indoor locations for  $PM_{10}$ . For example, at House No. 4, the concentrations of  $PM_{10}$  in post-cleaning samples were three to four times higher in the secondary location than in the primary location. This was an upstairs location near the bedrooms of the two children whose activity may have impacted airborne levels of the larger particles.

Interpretation of the  $PM_{2.5}$  and  $PM_{10}$  results is difficult because the concentrations of  $PM_{10}$  and  $PM_{2.5}$  outdoors will have an impact on indoor concentrations. Because the outdoor concentrations varied over the course of the week-long study, it is difficult to determine if changes in indoor concentrations after cleaning are the result of HAC system cleaning or due to changes in outdoor concentrations or changes in occupant activities. In Tables 5-10 and 5-11, the final column is the ratio of the mean post-cleaning concentration divided by the mean pre-cleaning concentration at each sampling location at each house. If the indoor ratio is less than one, it may mean that HAC system cleaning resulted in lower airborne particle concentrations. However, interpretation of the data is complicated if the outdoor concentration also went down during the post-cleaning period. The post/pre-cleaning change is depicted qualitatively in Table 5-12 to show the trends. For example, at House 1, the higher indoor post-cleaning concentrations were coincident with higher concentrations outdoors. But at House 3, despite the fact that the outdoor concentrations of  $PM_{2.5}$  and  $PM_{10}$  were lower in the post-cleaning period, the indoor concentrations were similar during the pre- and post-cleaning periods.

Another way to evaluate the relationship between indoor and outdoor concentrations is to compare the indoor/outdoor ratios (I/O), also presented in Table 5-12. Interpretation of the indoor/outdoor ratios is complex. If the I/O ratio is lower in the post-cleaning sample, this would suggest that the HAC system cleaning resulted in lower airborne particle concentrations if the infiltration of particles into the home from outdoors occurred at the same rate during the post-cleaning period as in the pre-cleaning period. This assumption may be valid for  $PM_{2.5}$ . To fully evaluate the I/O, the following cases need to be examined:

- If the concentration of particles in the indoor air is reduced due to HAC system cleaning and the outdoor concentration and infiltration rate are the same before and after cleaning, then the I/O should be lower in the post-cleaning period. House 6 represents the only case where this occurred, and only for  $PM_{2.5}$ .

Table 5-12. Trends in Particle Concentrations and Indoor/Outdoor Ratios

| House | Location  | Concentration Change <sup>a</sup> |                  | Indoor/Outdoor Ratio |      |                  |      |
|-------|-----------|-----------------------------------|------------------|----------------------|------|------------------|------|
|       |           | PM <sub>2.5</sub>                 | PM <sub>10</sub> | PM <sub>2.5</sub>    |      | PM <sub>10</sub> |      |
|       |           |                                   |                  | Pre                  | Post | Pre              | Post |
| TH    | Outdoor   | =                                 | =                |                      |      |                  |      |
|       | Primary   | H                                 | H                | 0.32                 | 0.51 | 0.40             | 1.12 |
|       | Secondary | H                                 | H                | 0.33                 | 0.53 | 0.34             | 0.55 |
| 1     | Outdoor   | H                                 | H                |                      |      |                  |      |
|       | Primary   | H                                 | H                | 0.75                 | 0.54 | 0.74             | 0.65 |
|       | Secondary | H                                 | H                | 0.73                 | 0.57 | 0.60             | 0.55 |
| 2     | Outdoor   | H                                 | H                |                      |      |                  |      |
|       | Primary   | H                                 | =                | 1.01                 | 0.58 | 0.81             | 0.59 |
|       | Secondary | H                                 | =                | 0.90                 | 0.57 | 0.65             | 0.40 |
| 3     | Outdoor   | L                                 | L                |                      |      |                  |      |
|       | Primary   | =                                 | =                | 0.47                 | 0.52 | 0.42             | 0.61 |
|       | Secondary | =                                 | =                | 0.48                 | 0.49 | 0.45             | 0.57 |
| 4     | Outdoor   | H                                 | H                |                      |      |                  |      |
|       | Primary   | H                                 | H                | 0.48                 | 0.76 | 0.54             | 0.81 |
|       | Secondary | H                                 | =                | 0.44                 | 0.65 | 0.44             | 0.27 |
| 5     | Outdoor   | H                                 | H                |                      |      |                  |      |
|       | Primary   | H                                 | H                | 0.39                 | 0.45 | 0.53             | 0.45 |
|       | Secondary | H                                 | H                | 0.36                 | 0.47 | 0.46             | 0.46 |
| 6     | Outdoor   | =                                 | =                |                      |      |                  |      |
|       | Primary   | =                                 | =                | 0.44                 | 0.31 | 0.44             | 0.47 |
|       | Secondary | =                                 | =                | 0.56                 | 0.38 | 0.42             | 0.41 |
| 7     | Outdoor   | L                                 | L                |                      |      |                  |      |
|       | Primary   | L                                 | L                | 0.55                 | 0.68 | 0.55             | 0.54 |
|       | Secondary | L                                 | L                | 0.53                 | 0.61 | 0.50             | 0.54 |
| 8     | Outdoor   | H                                 | L                |                      |      |                  |      |
|       | Primary   | =                                 | H                | 0.82                 | 0.76 | 0.41             | 0.58 |
|       | Secondary | =                                 | L                | 0.56                 | 0.63 | 0.60             | 0.62 |

<sup>a</sup> Change in mean concentration between pre- and post-cleaning periods: H = higher post-cleaning; L = lower concentration in post cleaning period; = not substantially different between pre- and post-cleaning periods

- If the outdoor concentration is higher in the post-cleaning period, an I/O of greater than 1.0 may result from the increased infiltration of particles from outdoors, masking a reduction of particles due to HAC system cleaning. If the I/O ratio was equal or less than 1.0, there may have been an impact of HAC system cleaning on particle concentrations, but the magnitude of the effect can not be determined because the contribution from outdoors can not be quantified. At Houses 1 and 2 the post-cleaning ratios are somewhat lower than the pre-cleaning ratios, which may indicate an effect of HAC system cleaning, if one assumes that the particle infiltration rate was the same in both the pre- and post-cleaning periods. At Houses 4 and 5, the higher outdoor concentration in the post-cleaning period did not result in a substantial lowering of the I/O ratio indoors in the post-cleaning period.

- If the outdoor concentration of particles is less in the post-cleaning period, a I/O greater than one suggests that there was not a substantial effect of HAC system cleaning on particle concentrations. But I/O ratios less than one do not necessarily mean there was an effect. At House 7, for example, the post-cleaning ratio was 0.68 at the primary location. This was higher than the pre-cleaning ratio, suggesting no effect from HAC system cleaning.

Results of the  $PM_{2.5}$  and  $PM_{10}$  data collected by the integrated sampling method are inconclusive with respect to the impact of HAC system cleaning on indoor air particle mass concentrations. It appears that the integrated particle mass data are not useful to assess whether HAC system cleaning has an impact on respirable and inhalable particle concentrations. Not only is there no clear trend, but there is insufficient data to determine what is a significant difference when comparing I/O ratios. It appears that the impact of outdoor particle concentrations and occupant activity on indoor particle mass concentrations may be so substantial that, even though the source of particles in the HAC system is effectively removed, changes in airborne particle mass concentrations due to HAC system cleaning can not be detected because of the other particle sources and temporal variability of particle concentrations.

The impact of HAC system cleaning on airborne particle concentrations is further evaluated in the following subsection.

### **5.5.2 Particle Concentrations Measured With Real-Time Monitors**

Particle concentrations were measured during the entire study period at each house with Climet CI-4100 Laser Particle Counters and a LAS-X Laser Spectrometer. The results of the measurements are described in this section.

### 5.5.2.1 Results of Climet Measurements

Climets were located in a primary living area of the house and a secondary, lesser used room. Additionally, a Climet was placed near a supply diffuser in the primary living area in an attempt to gain better resolution of the particle concentrations related to the HAC system operation as compared to that in the room where occupant activity may have had a significant impact on airborne concentrations. Particles were measured in the  $>0.5 \mu\text{m}$  diameter size range and in the  $>5.0 \mu\text{m}$  size range.

The differences in the concentration of particles in the size fraction greater than  $0.5 \mu\text{m}$  between pre- and post-cleaning periods are summarized in Table 5-13. The table presents the mean concentration and the standard deviation for the entire period prior to HAC system cleaning compared to the mean for the entire period following HAC system cleaning. The duration of the periods were not necessarily the same. The ratio of the post-cleaning to pre-cleaning periods is presented in the last column of the table. Results are presented for measurements in the primary monitoring location at 1.1 m above the floor, for the Climet located next to a supply diffuser in that room, and for the secondary monitoring location in the house. The data do not include the measurements on the day of cleaning because particle concentrations on that day would be atypical due to the high level of activity and open doors and windows.

Mean particle concentrations at the nine homes of the study ranged from 0.49 to 22.88 million particles per  $\text{m}^3$ . The concentrations were generally similar for the three monitoring locations in each home. At House 3 and 6, the concentrations were somewhat higher for the monitor placed at the supply diffuser. It should be noted that the concentrations of particles were highly variable during both the pre- and post-cleaning periods, as indicated by the large standard deviation. The concentrations of particles  $>0.5 \mu\text{m}$  were lower during the period following HAC system cleaning at the test house and at two of the field study homes (Houses 3 and 8). At Houses 4 and 7, the concentrations were nearly the same in the pre- and post-cleaning periods. At houses 1, 2, 5, and 6 the average particle concentrations were higher in the post-cleaning period.

In Table 5-13, the houses are separated by double lines, indicating that two houses were studied each week, beginning with houses 1 and 2. There is a clear trend evident in Table 5-13 for the Post/Pre-cleaning ratio. Houses that were studied on the same week showed similar changes in concentration between pre- and post-cleaning periods. The Post/Pre-cleaning ratio was higher at both houses 1 and 2, cleaned on the same week. Houses 7 and 8, cleaned on a different week, had a ratio of less than 1.0. Although this could be strictly coincidence, the trend suggests that the indoor concentration changes during the study week were a function of the outdoor concentrations. Particle concentrations were not measured continuously outdoors. The data for the integrated samples of  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  can be used to assess differences in indoor and outdoor particle concentrations and differences between pre- and post-cleaning periods. Tables 5-10 and 5-11 in Section 5.5.1 show the results of integrated samples. For the  $\text{PM}_{2.5}$  size fraction, outdoor particle mass was higher in the post-cleaning period than in the pre-cleaning period at houses 1, 2, 4, 5, 6, and 8. Houses 1, 2, 5, and 6 are the same houses that had higher particle concentrations measured with the Climet in the post-cleaning period.

Table 5-13. Mean Concentrations of Particles Greater Than 0.5µm Pre- and Post-HAC System Cleaning

| House | Location         | Particles X 10 <sup>6</sup> /m <sup>3</sup> |                 |                            |       |                           |
|-------|------------------|---|-----------------|----------------------------|-------|---------------------------|
|       |                  | Pre-Cleaning <sup>a</sup>                   |                 | Post-Cleaning <sup>b</sup> |       | Post/<br>Pre <sup>d</sup> |
|       |                  | Mean <sup>c</sup>                           | SD <sup>c</sup> | Mean                       | SD    |                           |
| TH    | Primary          | 6.97  | 4.06            | 4.68                       | 4.25  | 0.67                      |
|       | Primary - Supply | - <sup>e</sup>                              | -               | 4.15                       | 3.41  | - <sup>e</sup>            |
|       | Secondary        | 5.90  | 3.66            | 4.51                       | 2.11  | 0.77                      |
| 1     | Primary          | 5.60  | 2.75            | 9.87                       | 3.59  | 1.76                      |
|       | Primary - Supply | 3.48  | 2.52            | 8.48                       | 3.22  | 2.44                      |
|       | Secondary        | 2.07  | 2.03            | 7.52                       | 3.22  | 3.63                      |
| 2     | Primary          | 7.21  | 3.68            | 14.02                      | 0.49  | 1.94                      |
|       | Primary - Supply | 8.90  | 1.78            | 13.92                      | 0.41  | 1.56                      |
|       | Secondary        | 9.03  | 3.13            | 14.18                      | 6.91  | 1.57                      |
| 3     | Primary          | 16.01                                       | 6.61            | 13.08                      | 7.16  | 0.82                      |
|       | Primary - Supply | 22.88                                       | 8.60            | 19.14                      | 10.69 | 0.84                      |
|       | Secondary        | 17.05                                       | 5.26            | 12.22                      | 5.52  | 0.72                      |
| 4     | Primary          | 10.98                                       | 4.70            | 11.27                      | 4.54  | 1.03                      |
|       | Primary - Supply | 10.41                                       | 5.64            | 11.61                      | 4.20  | 1.12                      |
|       | Secondary        | 8.32  | 4.46            | 6.92                       | 1.46  | 0.83                      |
| 5     | Primary          | 3.52  | 2.56            | 6.80                       | 3.98  | 1.93                      |
|       | Primary - Supply | 3.53  | 1.61            | 6.31                       | 3.52  | 1.79                      |
|       | Secondary        | 3.97  | 1.35            | 6.60                       | 2.97  | 1.66                      |
| 6     | Primary          | 5.06  | 4.86            | 7.11                       | 4.88  | 1.41                      |
|       | Primary - Supply | 7.39  | 5.30            | 9.66                       | 4.85  | 1.31                      |
|       | Secondary        | 4.85  | 4.81            | 3.94                       | 2.61  | 0.81                      |
| 7     | Primary          | 8.07  | 6.57            | 7.78                       | 3.62  | 0.97                      |
|       | Primary - Supply | 7.45  | 5.99            | 7.21                       | 3.32  | 0.97                      |
|       | Secondary        | 6.32  | 5.55            | 6.40                       | 3.32  | 1.01                      |
| 8     | Primary          | 20.15                                       | 8.77            | 16.35                      | 9.11  | 0.81                      |
|       | Primary - Supply | - <sup>f</sup>                              | -               | 21.17                      | 10.69 | - <sup>f</sup>            |
|       | Secondary        | 15.09                                       | 6.70            | 12.84                      | 6.90  | 0.85                      |

<sup>a</sup> Mean of concentration for entire period prior to 6:00 a.m. on day of cleaning

<sup>b</sup> Mean of concentration for entire period from 6:00 a.m. on day following cleaning to end of study period

<sup>c</sup> Mean and standard deviation for entire period

<sup>d</sup> Ratio of the means

<sup>e</sup> Data lost due data logger problem

<sup>f</sup> Data lost due to power failure

At house 8, the first pre-cleaning  $PM_{2.5}$  sample was lost due to a power failure so the basis for comparing pre- and post-cleaning periods is poor. It should also be noted from Table 5-10 that at all houses, except the Test House, when outdoor  $PM_{2.5}$  was higher outdoors in the post-cleaning period, it was also higher indoors in the post-cleaning period.  $PM_{10}$  mass was also measured outdoors during the study. As shown in Table 5-11,  $PM_{10}$  was higher outdoors in the post-cleaning period at Houses 1, 2, 4, and 5. Houses 1, 2, and 5 were houses with higher particle concentrations measured with the Climet in the post-cleaning period. As was the case for  $PM_{2.5}$ , when outdoor  $PM_{10}$  was higher in the post-cleaning period, the indoor  $PM_{10}$  was also higher in the post-cleaning period. The only exception was in the secondary room at House 4.

The results of the measurements of particles  $>0.5 \mu m$  with the Climets are inconclusive with respect to determining the impact of HAC system cleaning on indoor air particle concentrations for this size fraction. The data suggest that the impact of the outdoor particle concentrations may be so substantial that the impact of HAC system cleaning on airborne particle concentrations can not be detected. The impact of outdoor particles on indoor concentrations is substantial according to calculations performed by Wallace (1996) in his review of indoor particles. In his evaluation of the impact of outdoor particles on indoor particle mass concentrations, he estimated that for a home with no indoor sources and a typical air exchange rate of approximately  $0.75 h^{-1}$ , the fine particle mass concentration indoors would be about 65% of the outdoor value at equilibrium while coarse particles would be about 43% of the outdoor value. However, he noted that the indoor concentrations are rarely this low because there are indoor sources. Referring back to Table 5-8, which has the Indoor/Outdoor ratios for the particle mass measurements, it can be seen that indoor/outdoor ratios of  $PM_{2.5}$  were less than 0.65 for many of the samples. The significance of this observation is not obvious.

Data from the Climet for the greater than  $5.0 \mu m$  size fraction were downloaded from the Climet's internal storage whenever the technician visited a house. Because of the frequency of the visits, a relatively complete data set was obtained. Mean concentrations of particles  $>5.0 \mu m$  were also calculated for pre- and post-cleaning periods and are presented in Table 5-14.

The mean concentrations of particles  $>5.0 \mu m$  ranged from 0.006 to 0.346 million per  $m^3$  (6,000 to 346,000/ $m^3$ ). As shown by the standard deviation, the concentrations varied substantially during the periods. The concentrations measured at the three monitoring locations at each home did not differ substantially, except at House 5, where the concentration in the second room was substantially higher both pre- and post-HAC system cleaning. There was no clear trend in the change between pre- and post-cleaning, as indicated by the Post/Pre-cleaning ratios. Of the six field study houses with data for the  $>5.0 \mu m$  fraction, three had lower post cleaning concentrations, one was nearly the same, and the other two were higher. Comparison of the data for the  $> 5.0 \mu m$  size fraction and the  $> 0.5 \mu m$  size fraction shows no apparent relationship between the Post/Pre ratios for the two size fractions.

Table 5-14. Mean Concentrations of Particles Greater Than 5.0µm Pre- and Post-HAC System Cleaning

| House | Location         | Particles X 10 <sup>6</sup> /m <sup>3</sup> |                 |                            |       |                           |
|-------|------------------|---|-----------------|----------------------------|-------|---------------------------|
|       |                  | Pre-Cleaning <sup>a</sup>                   |                 | Post-Cleaning <sup>b</sup> |       | Post/<br>Pre <sup>d</sup> |
|       |                  | Mean <sup>c</sup>                           | SD <sup>c</sup> | Mean                       | SD    |                           |
| TH    | Primary          | 0.044                                       | 0.123           | 0.058                      | 0.207 | 1.30                      |
|       | Primary - Supply | - <sup>e</sup>                              | -               | 0.080                      | 0.240 | - <sup>e</sup>            |
|       | Secondary        | 0.037                                       | 0.093           | 0.023                      | 0.073 | 0.62                      |
| 1     | Primary          | - <sup>e</sup>                              | -               | - <sup>e</sup>             | -     | - <sup>e</sup>            |
|       | Primary - Supply | - <sup>e</sup>                              | -               | - <sup>e</sup>             | -     | - <sup>e</sup>            |
|       | Secondary        | - <sup>e</sup>                              | -               | - <sup>e</sup>             | -     | - <sup>e</sup>            |
| 2     | Primary          | - <sup>e</sup>                              | -               | - <sup>e</sup>             | -     | -                         |
|       | Primary - Supply | - <sup>e</sup>                              | -               | - <sup>e</sup>             | -     | - <sup>e</sup>            |
|       | Secondary        | - <sup>e</sup>                              | -               | - <sup>e</sup>             | -     | - <sup>e</sup>            |
| 3     | Primary          | 0.011                                       | 0.023           | 0.016                      | 0.020 | 1.50                      |
|       | Primary - Supply | 0.014                                       | 0.020           | 0.020                      | 0.024 | 1.39                      |
|       | Secondary        | 0.015                                       | 0.018           | 0.013                      | 0.021 | 0.85                      |
| 4     | Primary          | 0.020                                       | 0.051           | 0.016                      | 0.029 | 0.82                      |
|       | Primary - Supply | 0.014                                       | 0.037           | 0.010                      | 0.018 | 0.69                      |
|       | Secondary        | 0.017                                       | 0.024           | 0.029                      | 0.025 | 1.76                      |
| 5     | Primary          | - <sup>f</sup>                              | -               | 0.019                      | 0.031 | - <sup>f</sup>            |
|       | Primary - Supply | 0.017                                       | 0.031           | 0.013                      | 0.025 | 0.76                      |
|       | Secondary        | 0.346                                       | 0.051           | 0.303                      | 0.033 | 0.88                      |
| 6     | Primary          | 0.025                                       | 0.066           | 0.027                      | 0.049 | 1.09                      |
|       | Primary - Supply | 0.028                                       | 0.078           | 0.030                      | 0.047 | 1.08                      |
|       | Secondary        | 0.023                                       | 0.071           | 0.031                      | 0.051 | 1.31                      |
| 7     | Primary          | 0.010                                       | 0.019           | 0.010                      | 0.014 | 0.94                      |
|       | Primary - Supply | 0.006                                       | 0.010           | 0.005                      | 0.007 | 0.93                      |
|       | Secondary        | 0.008                                       | 0.018           | 0.008                      | 0.011 | 0.92                      |
| 8     | Primary          | 0.008                                       | 0.024           | 0.016                      | 0.040 | 2.19                      |
|       | Primary - Supply | - <sup>f</sup>                              | -               | 0.028                      | 0.053 | - <sup>f</sup>            |
|       | Secondary        | 0.013                                       | 0.074           | 0.018                      | 0.059 | 1.40                      |

<sup>a</sup> Mean concentration for entire period prior to 6:00 a.m. on day of cleaning

<sup>b</sup> Mean concentration for entire period from 6:00 a.m. on day following cleaning to end of study period

<sup>c</sup> Mean and standard deviation

<sup>d</sup> Ratio of the means

<sup>e</sup> Insufficient data available; not downloaded with sufficient frequency

<sup>f</sup> Data lost due to downloading error

Comparing the particle concentration data based solely on the mean and standard deviation for the pre- and post-cleaning periods does not present the entire picture. The time variations in the particle concentrations should be assessed to determine if there are activities or conditions in the home during the study that may have impacted the particle concentrations. Figures 5-1 through 5-9 depict the variation in the concentrations of particles in the  $>0.5 \mu\text{m}$  size fraction measured with the Climet in the primary living area in each home during the study. In the following figures, it should be noted that there are periods when the particle concentrations exceed the full-scale output capability of the Climet. These periods are indicated in the figures by flat peaks. This was a limitation of the analog output of the Climet. To the extent possible, data that was over-range was replaced with data that was directly downloaded from the Climet's internal data logger. However, this was not possible in all cases. The patterns of the particle concentrations in these figures can be summarized as follows:

- Test House - High concentrations were observed on the Saturday before cleaning due to technician activity in the house, but concentrations were lower on Sunday and Monday even though there was also technician activity in the house in the morning on those days. Although particle concentrations were elevated during the period of cleaning due to the high level of activity and open doors, the concentrations dropped rapidly after the air handler was turned on. There was no indication of elevated particle concentrations immediately after cleaning. During the period following HAC system cleaning there were periods of elevated particle concentrations associated with technician activity in the house. But particle concentrations were generally low overnight.

- House 1 - During the study, the house was occupied by one adult, who worked during the evening, and two children during the day-time periods. The other adult in the home worked during the day and was home with the children in the evening. In the pre-cleaning period, there were periods of elevated particle concentrations. But the post-cleaning period had substantially higher peak concentrations that exceeded the range of the IAQDS data logger. The elevated concentrations during the post-cleaning period occurred for extended durations relative to the pre-cleaning period. Overnight particle concentrations were higher in the post-cleaning period.

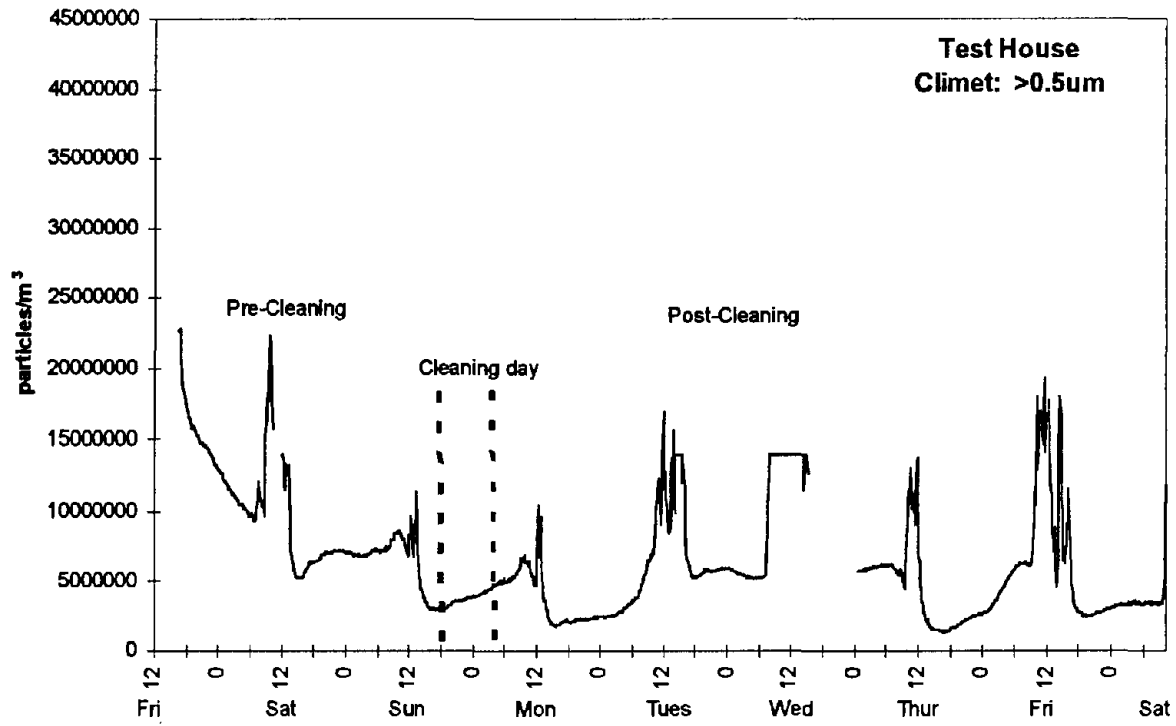


Figure 5-1. Airborne particle concentrations in the  $>0.5 \mu\text{m}$  size fraction at the Test House

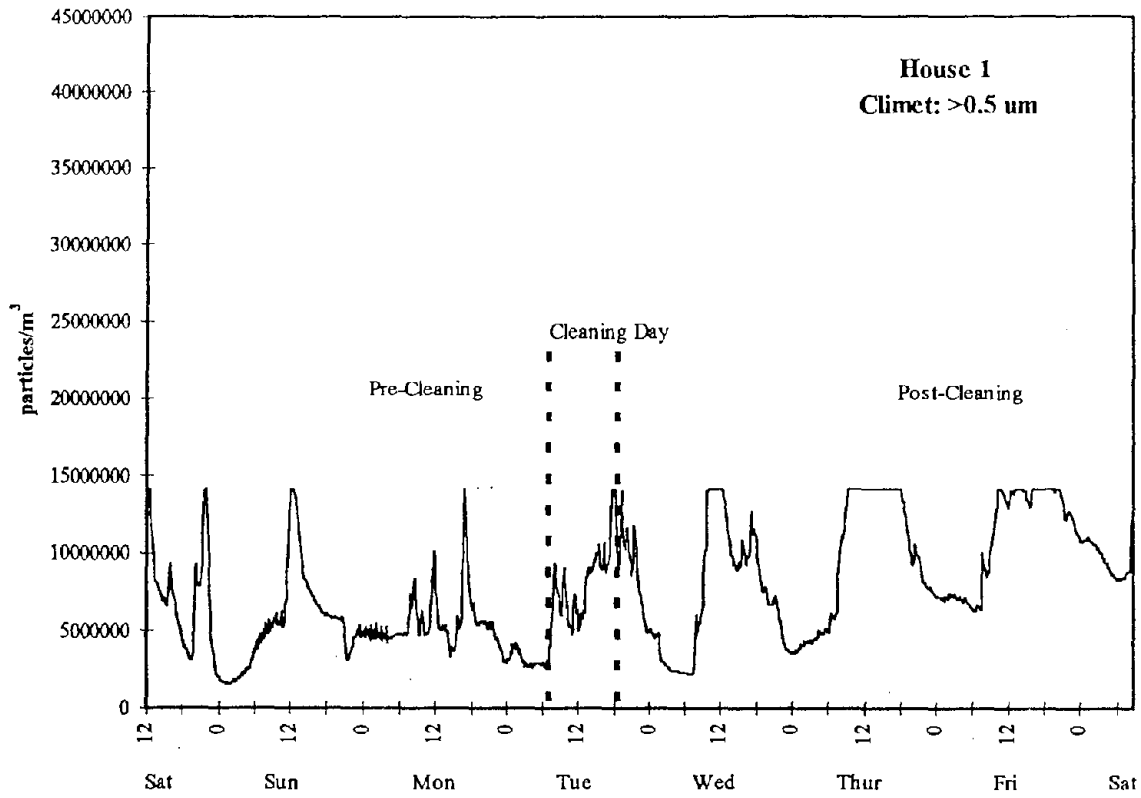


Figure 5-2. Airborne particle concentrations in the >0.5 μm size fraction at House 1

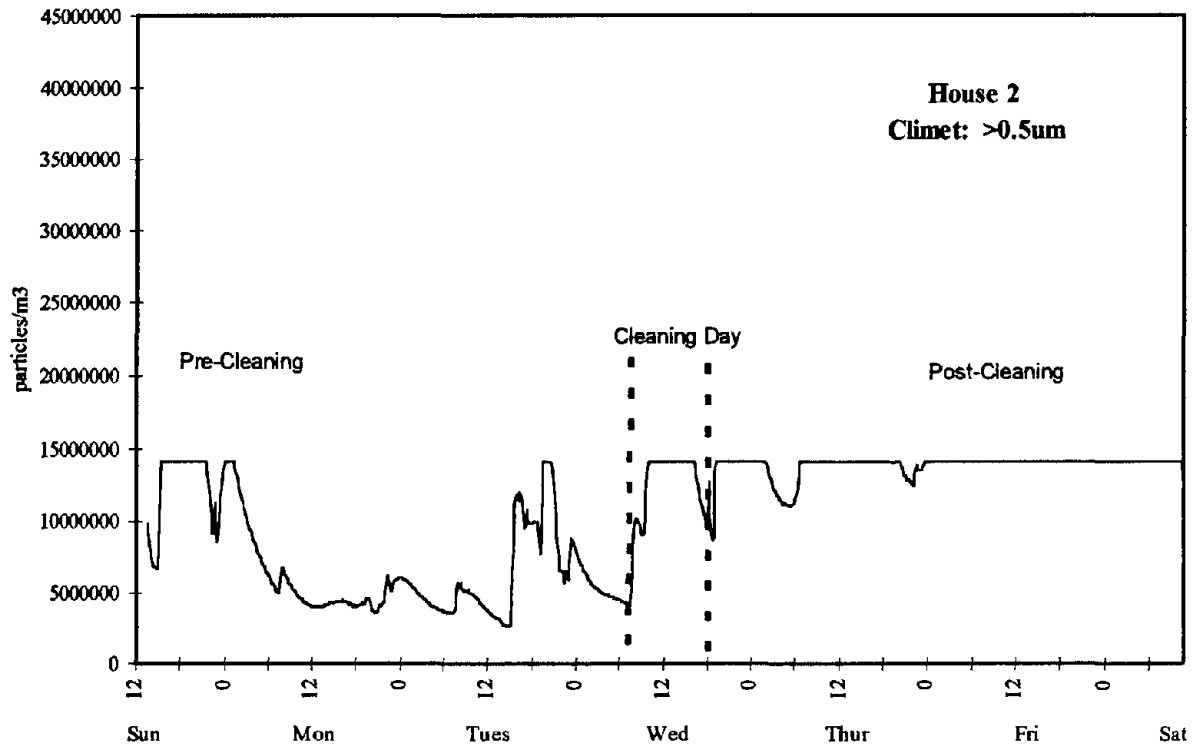


Figure 5-3. Airborne particle concentrations in the >0.5  $\mu\text{m}$  size fraction at House 2

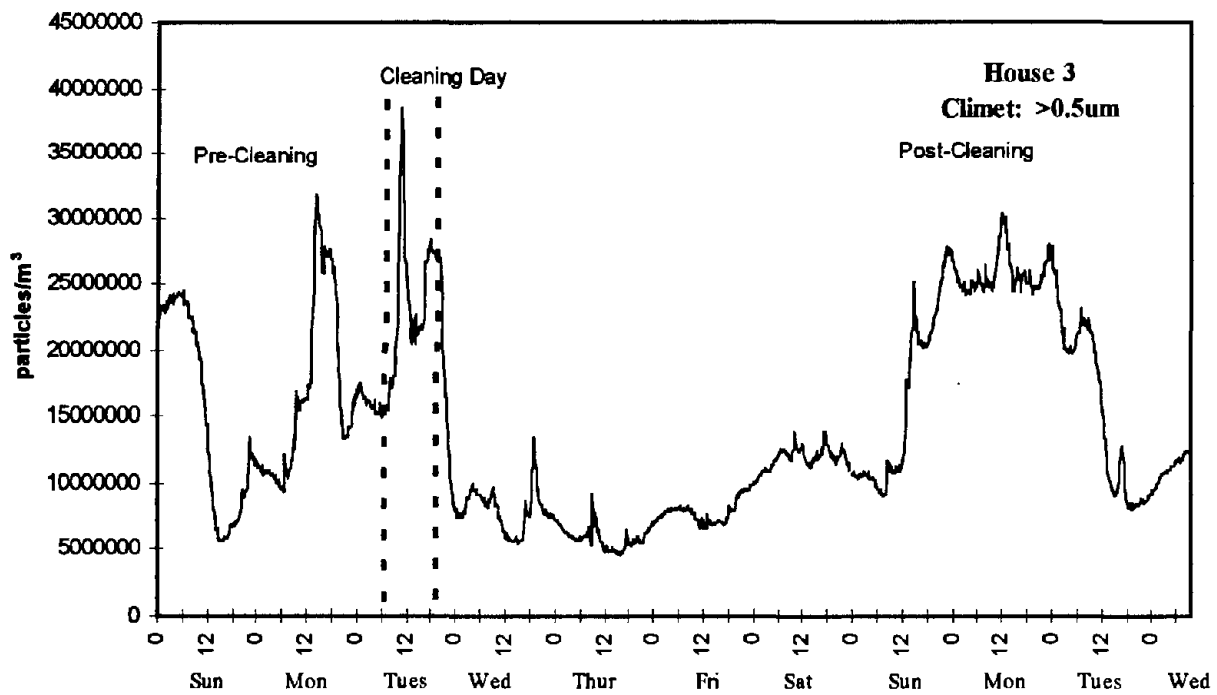


Figure 5-4. Airborne particle concentrations in the >0.5µm size fraction at House 3

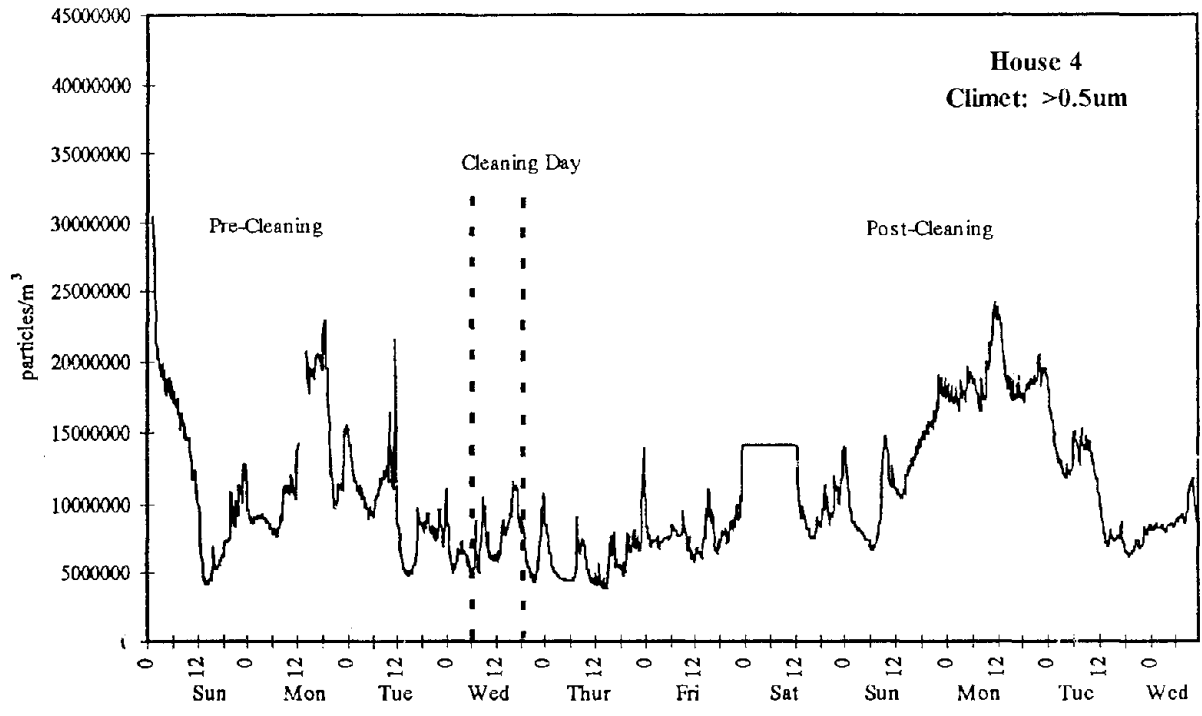


Figure 5-5. Airborne particle concentrations in the >0.5  $\mu\text{m}$  size fraction at House 4

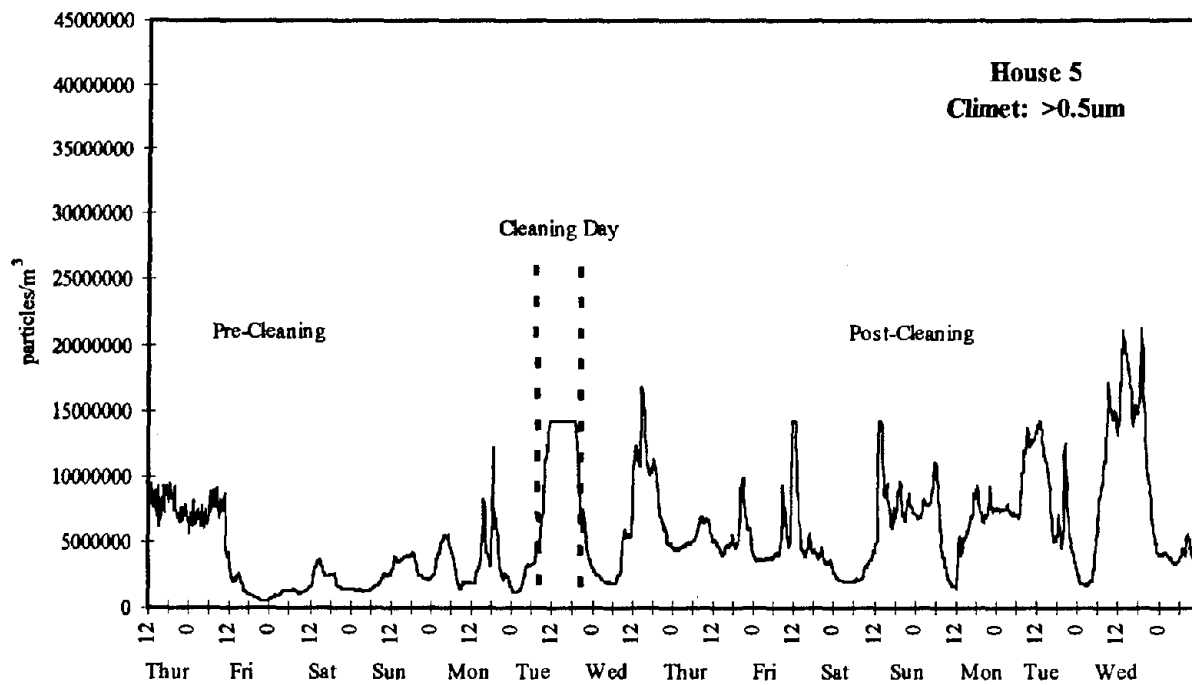


Figure 5-6. Airborne particle concentrations in the >0.5 μm size fraction at House 5

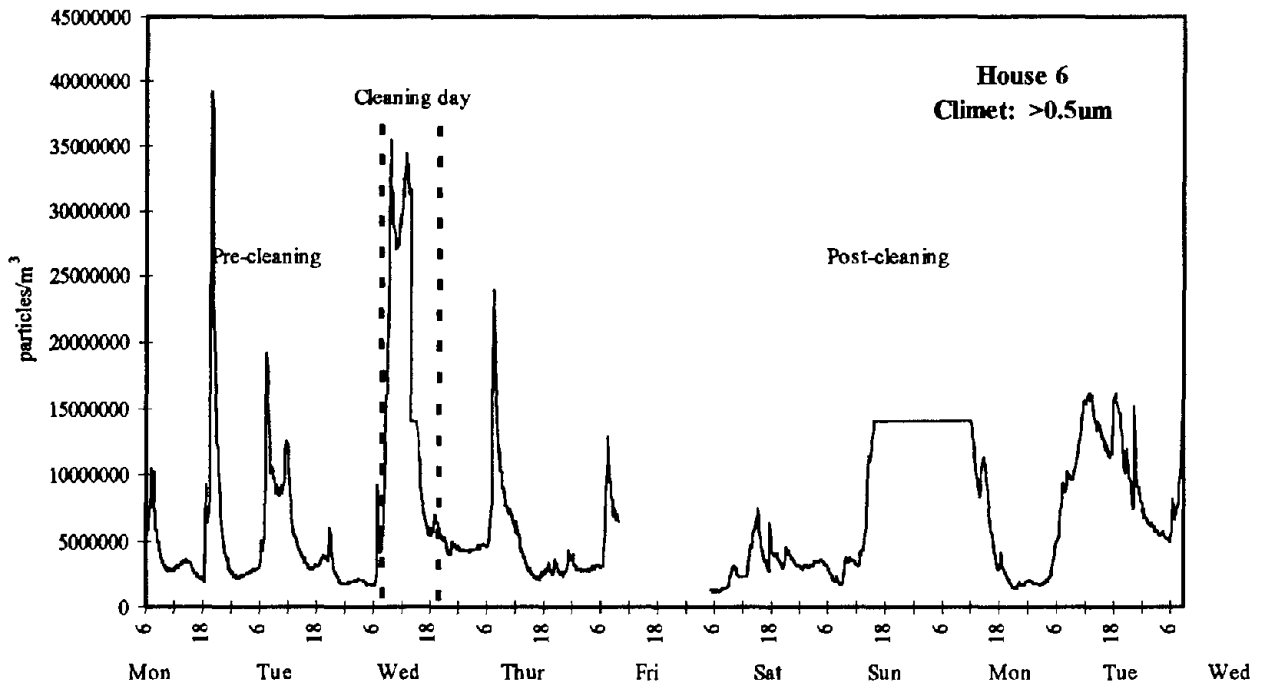


Figure 5-7. Airborne particle concentrations in the >0.5  $\mu\text{m}$  size fraction at House 6

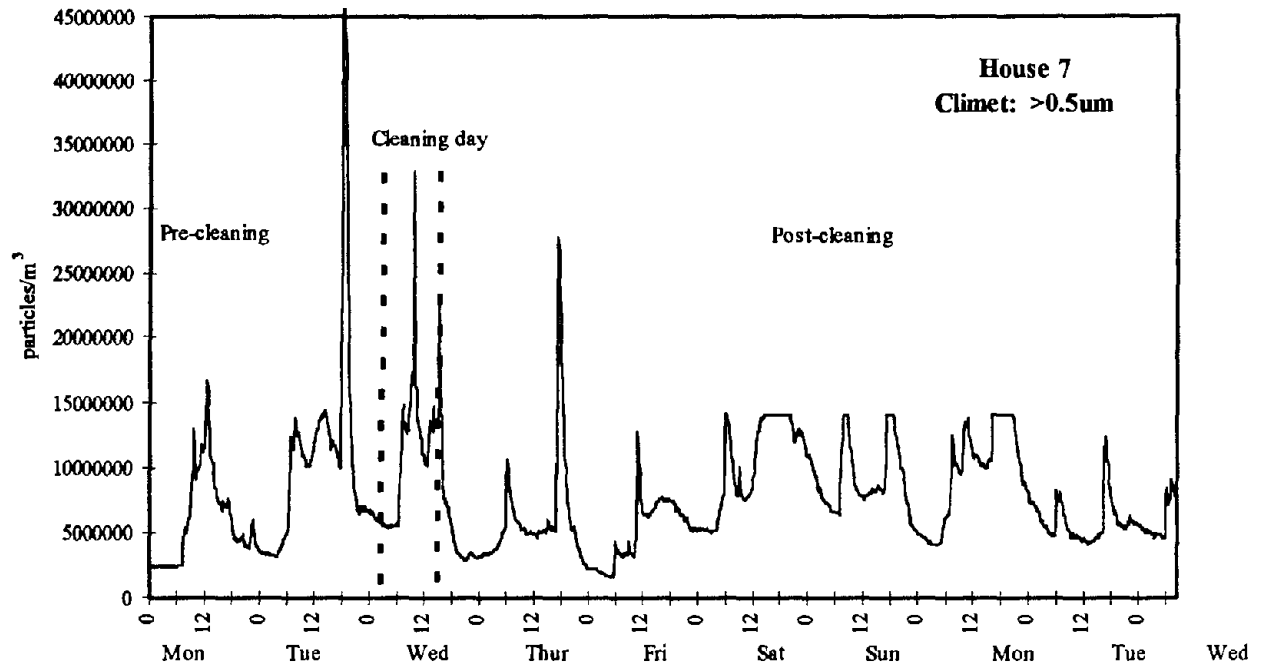


Figure 5-8. Airborne particle concentrations in the >0.5  $\mu\text{m}$  size fraction at House 7

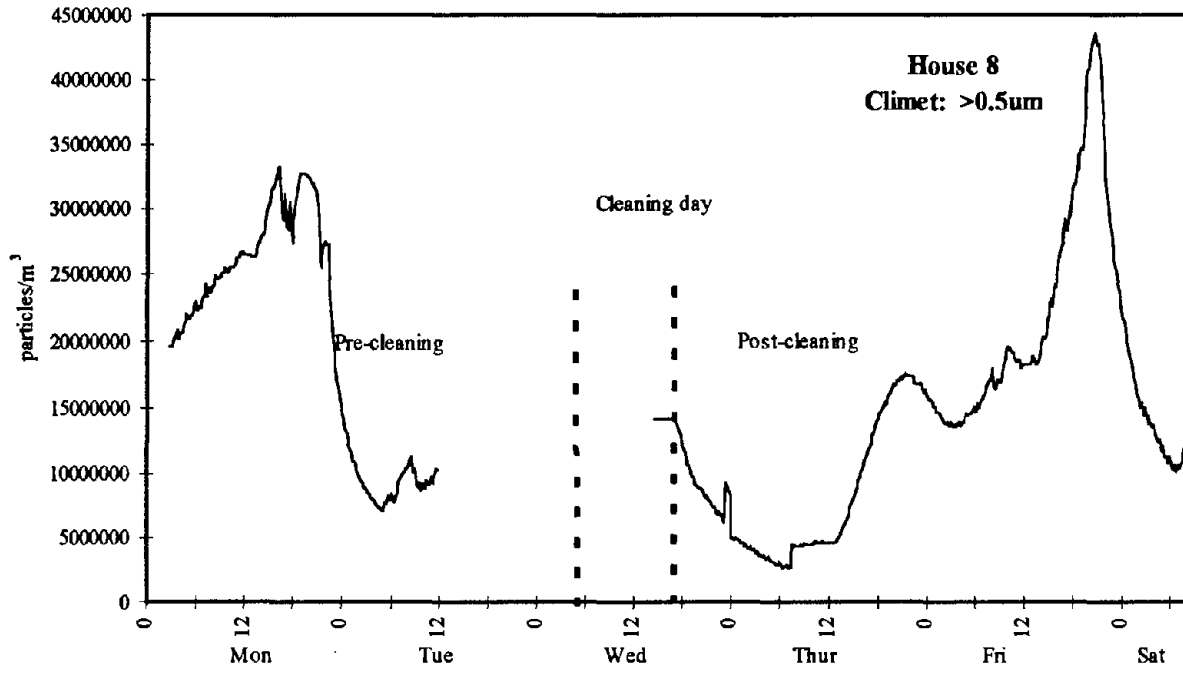


Figure 5-9. Airborne particle concentrations in the >0.5 μm size fraction at House 8

- House 2 - This house was monitored on the same week as house one. It was cleaned on Wednesday. The house was occupied by two adults, who were both out of the house, at work, during the week days. Particle concentrations were elevated on Sunday when the occupants were at home and the instrumentation was set up. But the levels fell on Monday and Tuesday. There was an increase in particle concentrations on the Tuesday prior to cleaning. Particle concentrations increased substantially on the day of cleaning, exceeding the IAQDS full-scale range. The particle concentrations stayed above the full-scale range for nearly the entire post-cleaning monitoring period, even though the occupants were gone during the day. The reason for these high concentrations is not known.

- House 3 - Particle concentrations were substantially lower in the first four days after cleaning but increased Sunday through Tuesday due to either higher outdoor concentrations or increased occupant activity. Results at House 4 suggest the change was due to outdoor concentration increases.

- House 4 - This house was located across the street from House 3. It was cleaned on Wednesday. The changes in concentration after cleaning are similar to those at House 3. The concentrations after cleaning were initially lower than during the pre-cleaning period, but on Sunday and Monday the concentrations were substantially elevated, the same as at House 3. This suggests that the post-cleaning increases at both houses 3 and 4 were due to higher outdoor concentrations.

- House 5 - This house was available for monitoring over a longer period both before and after HAC system cleaning. The occupants were not in the home from Thursday until Monday evening. Their return to the house and increased activity is indicated by increased particle concentrations on Monday. After cleaning, the particle concentrations dropped rapidly. During the following days, there were elevated concentrations during the day, which dropped overnight when there was no activity. The changes suggest that particle concentrations were highly impacted by occupant activity.

- House 6 - Prior to cleaning there were short periods of high concentrations, but following cleaning there were extended periods with high concentrations. The high concentrations occurred on the weekend when there were periods of high activity in the home. It should be noted that particle concentration, although high on the day of cleaning, dropped rapidly after the air handler was returned to service.

- House 7 - The house was occupied by two children who were in the home most of the time and two adults who worked during the day. There was no substantial difference in the peak concentrations or the variation in the particle concentrations between the pre- and post-cleaning periods.

- House 8 - Only a limited amount of data could be collected at this house because a thunderstorm occurred that resulted in a power failure while the occupants were gone on the weekend prior to cleaning. Although the average concentration was lower after cleaning, the peak concentration was high on the last day of the study. The impact of HAC system cleaning on particle concentrations at this house can not be determined.

In addition to the data for particles  $>0.5 \mu\text{m}$ , data were collected for the  $>5.0 \mu\text{m}$  fraction with the Climet. Data were not available for all houses or all time periods. Time-series plots of the data for the  $5.0 \mu\text{m}$  size fraction are included in Appendix E of this report. Figures 5-10 and 5-11 present examples of the data. At House 4 (Fig. 5-10), the concentrations of particles on the day following cleaning were similar, or higher, to the concentrations measured prior to cleaning and on the day of cleaning. The low concentrations on Sunday, Monday, and Tuesday following cleaning reflect the fact that the homeowners and children left for vacation and were not present in the home. Figure 5-11 shows the results at a home occupied throughout the period by two adults and two children. There is no indication during the first two days following HAC system cleaning that the concentrations of particles  $>5.0 \mu\text{m}$  are substantially lower than prior to cleaning.

A review of the changes in concentrations over the monitoring periods at the study houses suggests the following:

- On the day of cleaning the particle concentrations were elevated in the home, most likely due to increased activity by the duct cleaners and the research team. But soon after the air handler was returned to service, the concentrations dropped rapidly. There was no indication that particle concentrations increased in the home immediately following cleaning due to a “burst” of residual dust from the system.

- The continuous monitoring data show substantial temporal variability in indoor particle concentrations. Changes in indoor concentrations at Houses 3 and 4 suggest that outdoor air particle concentrations had a substantial impact on indoor air concentrations. Both the continuous air monitoring data and integrated mass concentration data suggest that outdoor particle sources, indoor particle sources other than the HAC system, and occupant activity may have such a high impact on indoor particle concentrations that the impact of mechanical cleaning of the HAC system on indoor particle concentrations may not be detectable using these monitoring and sampling methods. Assessment of the impact of HAC system cleaning on indoor air quality parameters is further complicated by the normal temporal variability of indoor air contaminant concentrations.

#### **5.5.2.2 Measurement Results for the LAS-X**

The LAS-X measures particle counts in sixteen channels from  $0.1 \mu\text{m}$  to  $7.5 \mu\text{m}$  diameter. Measurements were made throughout the study period at each home. The means and standard deviations of concentrations of particles in each of the 16 size fractions were calculated for the pre- and post-cleaning periods. The means for each size fraction are depicted in Figures 5-12 (a, b, c, and d). The mean and standard deviations for all periods at all houses are included in Appendix F to this report.

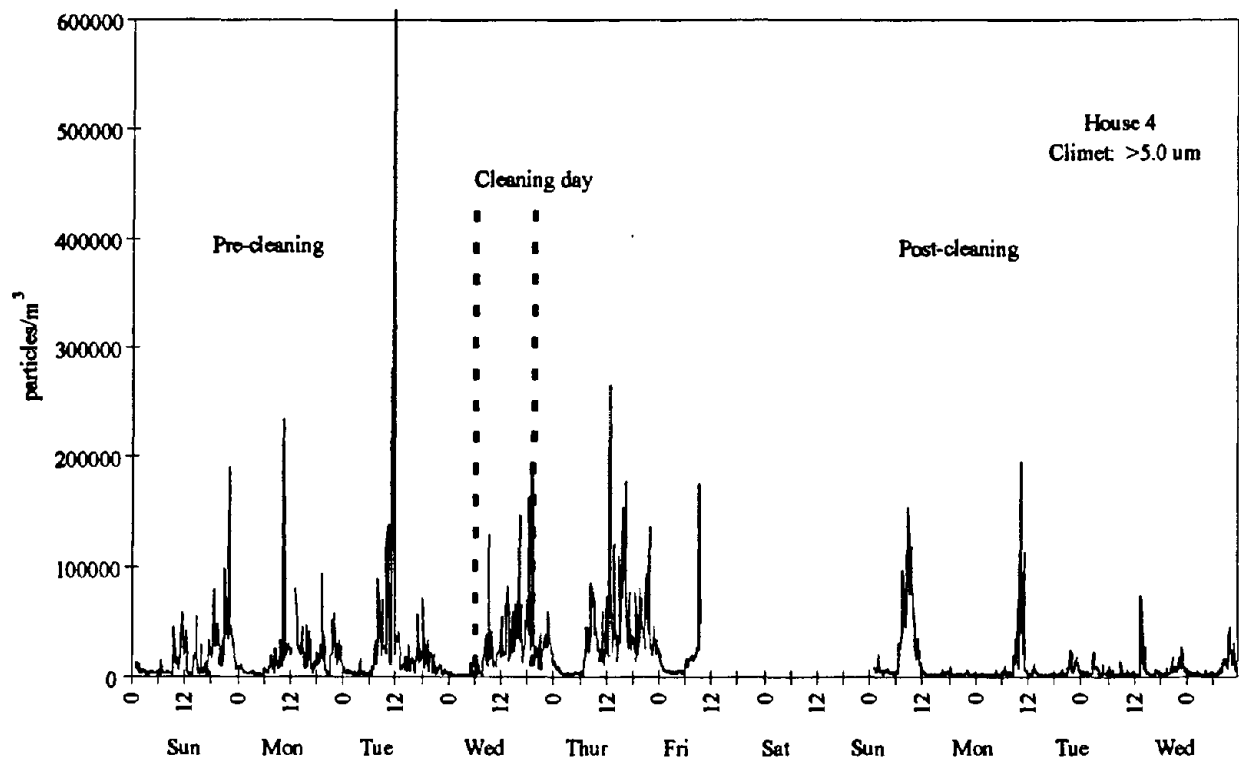


Figure 5-10. Airborne particle concentrations in the >5.0 μm size fraction at House 4



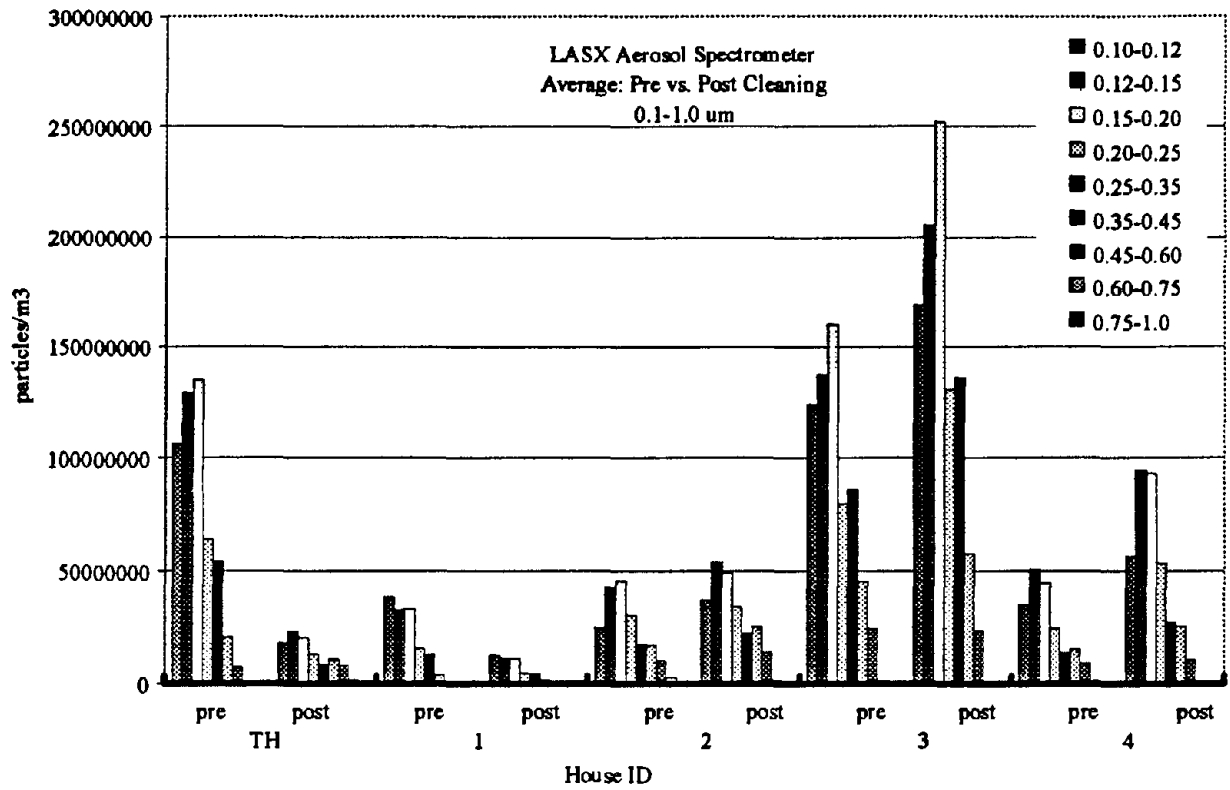


Figure 5-12a. Airborne particle concentrations measured with the LAS-X

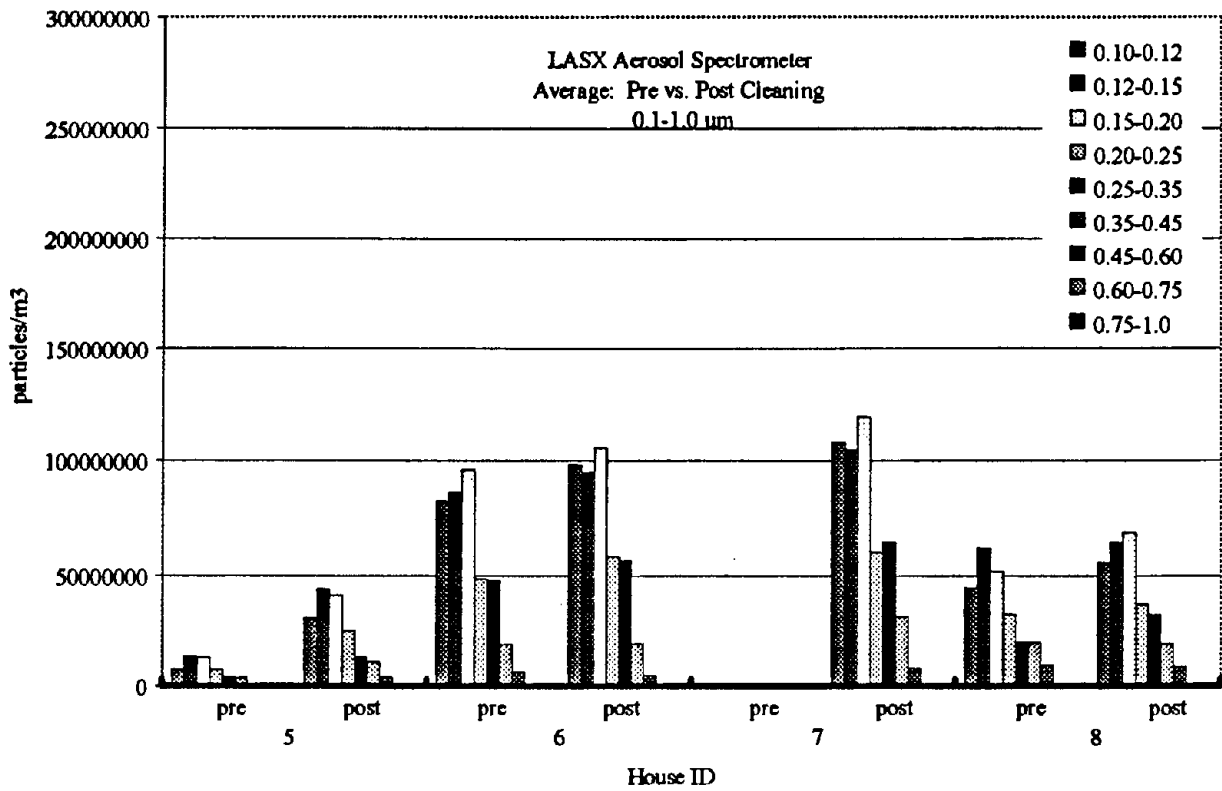


Figure 5-12b. Airborne particle concentrations measured with the LAS-X

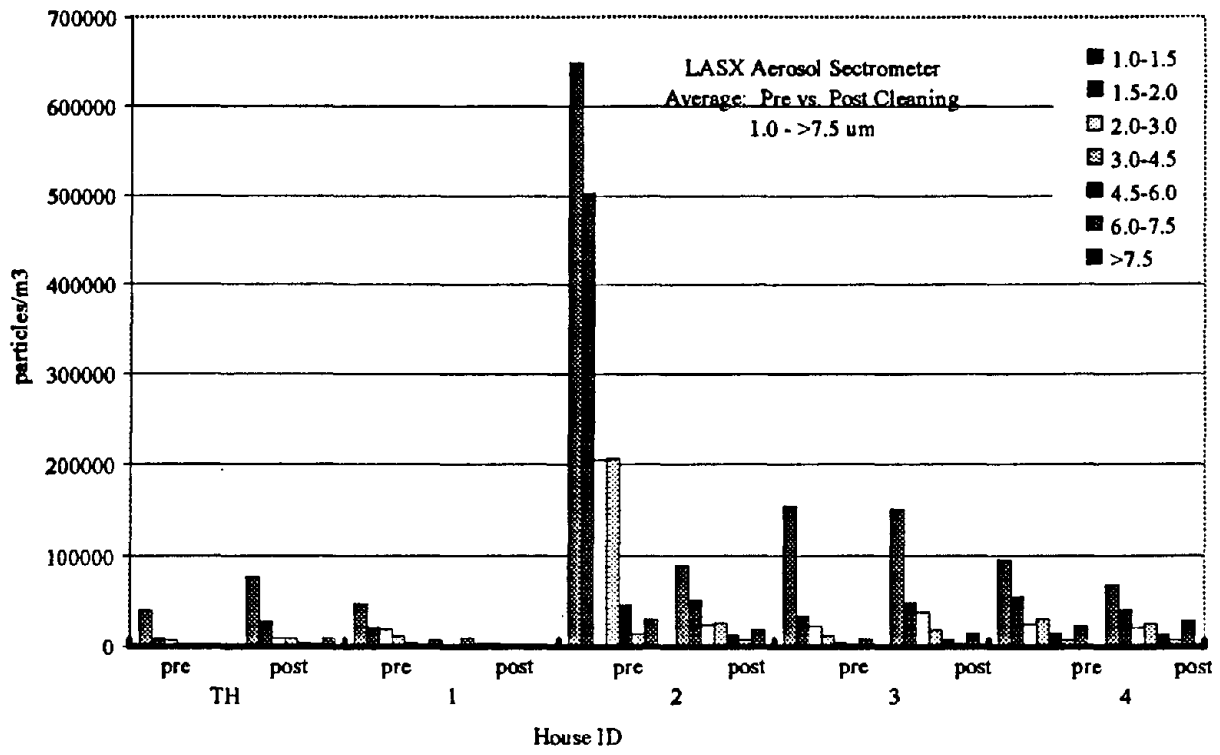


Figure 5-12c. Airborne particle concentrations measured with the LAS-X

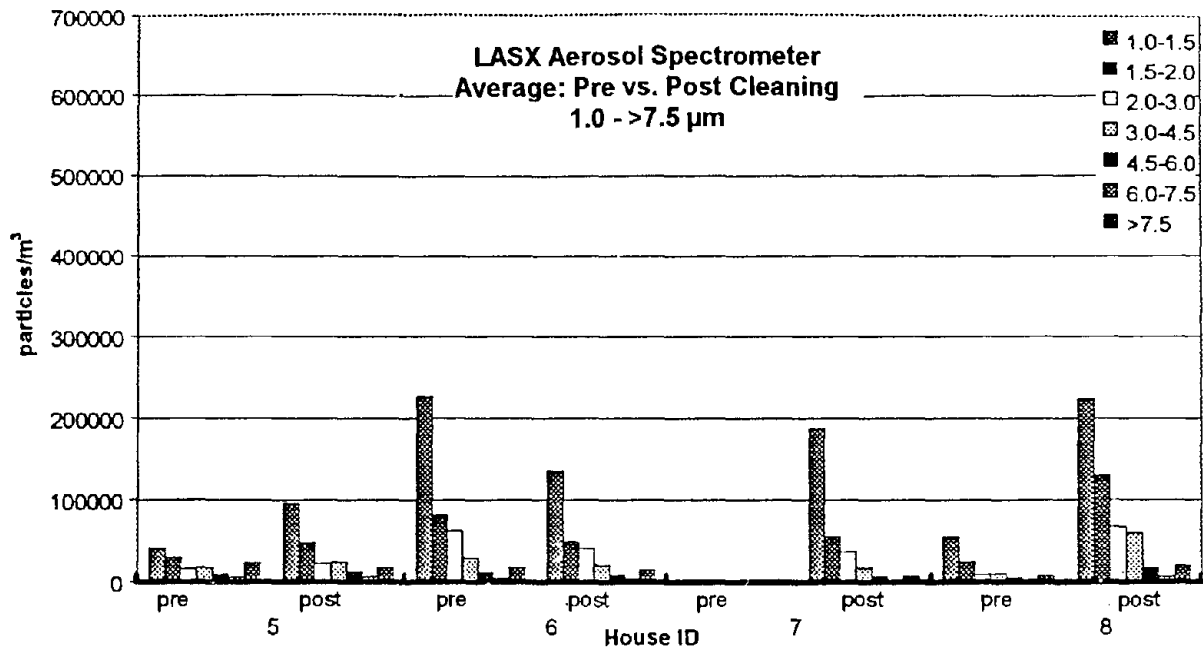


Figure 5-12d. Airborne particle concentrations measured with the LAS-X

For particles in the size ranges from 0.1 to 1.0  $\mu\text{m}$  diameter, there was no clear trend in the differences in the mean concentrations between the pre- and post-cleaning periods. Post-cleaning concentrations were generally lower at the Test House and House 1. But for the other houses, the concentrations were similar or higher. For the large size fractions (1.0 to 7.5  $\mu\text{m}$ ), post-cleaning concentrations were lower at Houses 1, 2, and 6. At the other houses they were similar or higher. The ratio of the mean concentrations in the post-cleaning period divided by the pre-cleaning mean concentrations are presented in Figure 5-13 (a and b). It should be noted that the ratios were not available for House 7. Post/pre-cleaning ratios were not included in the figure for the EPA IAQ Test House because the house is unoccupied and the changes in particle concentrations may not be the same as at the occupied field study homes. For the particle size fractions less than 0.60  $\mu\text{m}$ , the post/pre-cleaning ratio was generally above 1.0, except at House 1. Houses 4 and 5 generally had the highest ratio in these size categories. House 5 had consistently higher ratios. The differences between the other houses are probably not significant because the post/pre-cleaning ratios are based on the mean concentration during the period and particle concentrations were highly variable as indicated in the table included in Appendix F. In the particle size fractions from 0.60 to 1.5  $\mu\text{m}$ , House 5 continues to stand out as the house with the highest ratio. For the large size fractions, the ratio continues to be higher for House 5 than for most of the other houses. This is not inconsistent with the activity in the house during the study. Due to a family emergency, the occupants left the home on the day that the instrumentation was set-up and there were no occupants in the home during almost all of the pre-cleaning period; they returned on the evening prior to HAC system cleaning. However, the two adults and two children did occupy the home during the entire post-cleaning period. The dramatic differences in activity in the home between the pre- and post-cleaning periods apparently had a significant impact on the concentrations of particles in the home and the post/pre-cleaning ratio. The data from this home provide further indication that occupant activity and other sources in the home mask any changes in airborne particle concentrations that may result from HAC system cleaning.

The other house with high post/pre-cleaning ratios is House 8. The differences between this house and the other houses is particularly dramatic for the size fractions greater than 1.0  $\mu\text{m}$ . This house had the highest levels of dust in the ducts. At this house the occupants were gone on the Sunday and Monday prior to cleaning, but were in the home all of the rest of the week. This appears to be another case where the activity of the occupants is the strongest impact parameter. It is not clear why the post/pre-cleaning ratios are so high for the 1.0 to 6.0  $\mu\text{m}$  size fractions.

Examples of LAS-X measurement results are presented in Figures 5-14, 5-15, and 5-16.

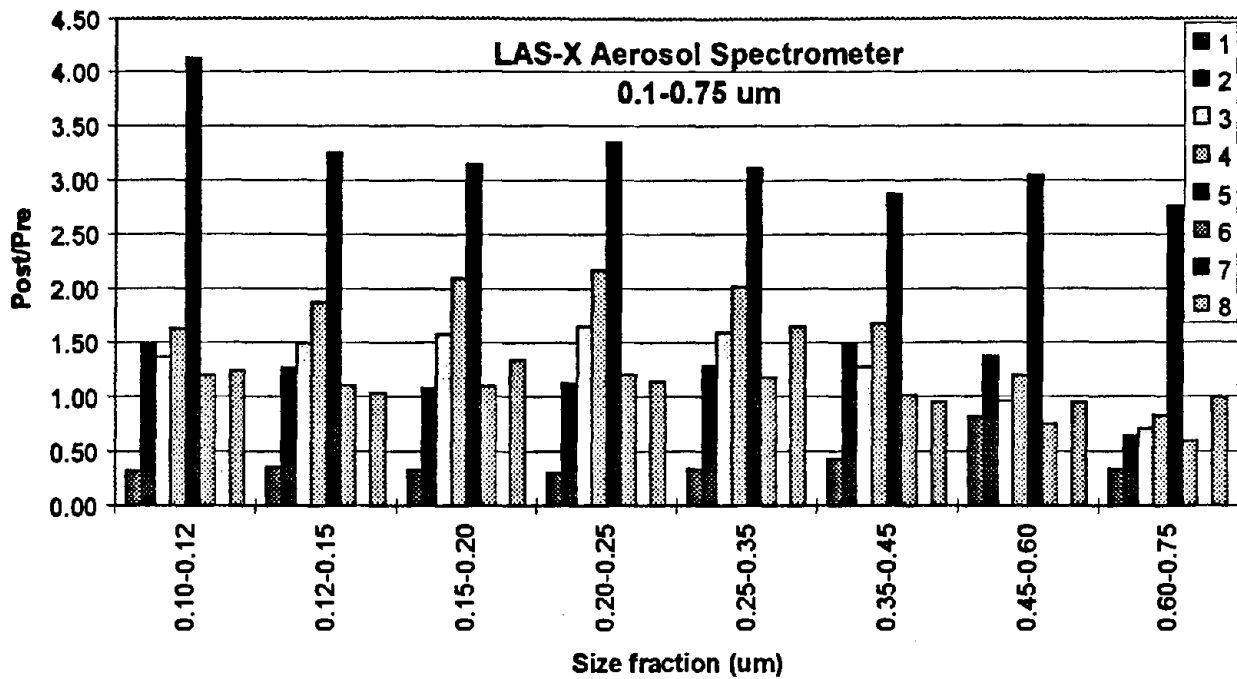


Figure 5-13a Mean particle concentration ratios measured with the LAS-X for eight houses

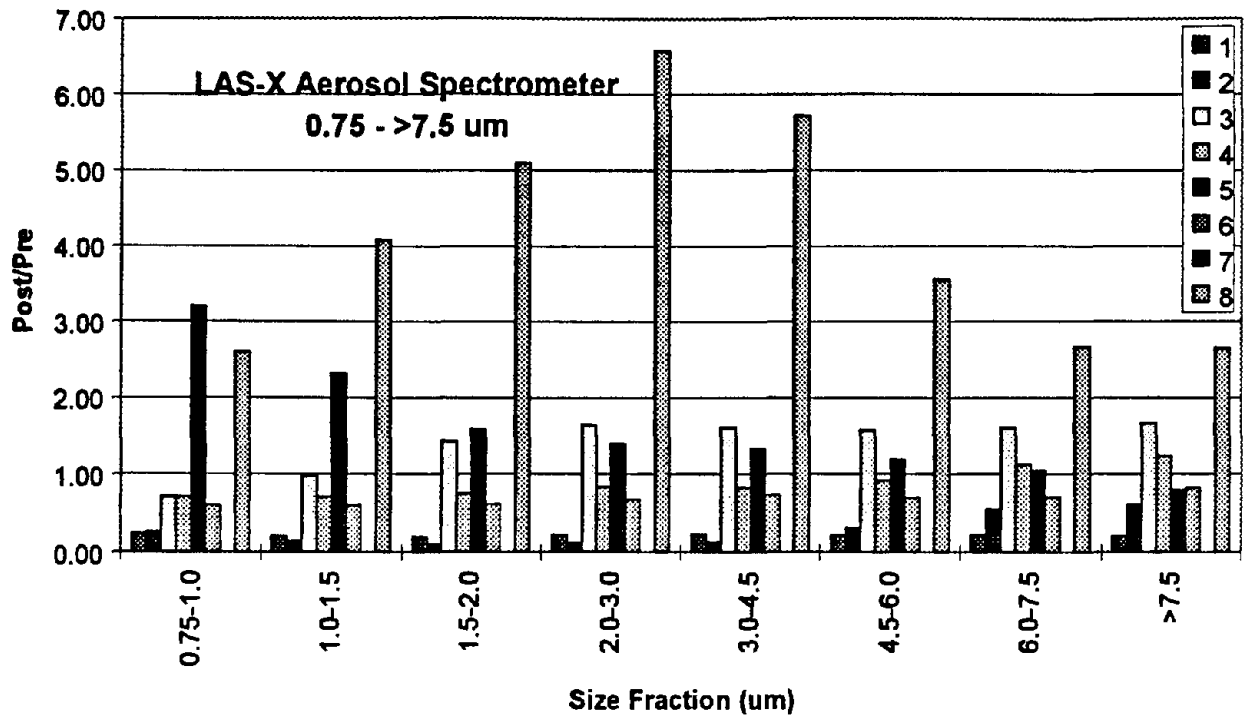


Figure 5-13b. Mean particle concentration ratios measured with the LAS-X for eight houses

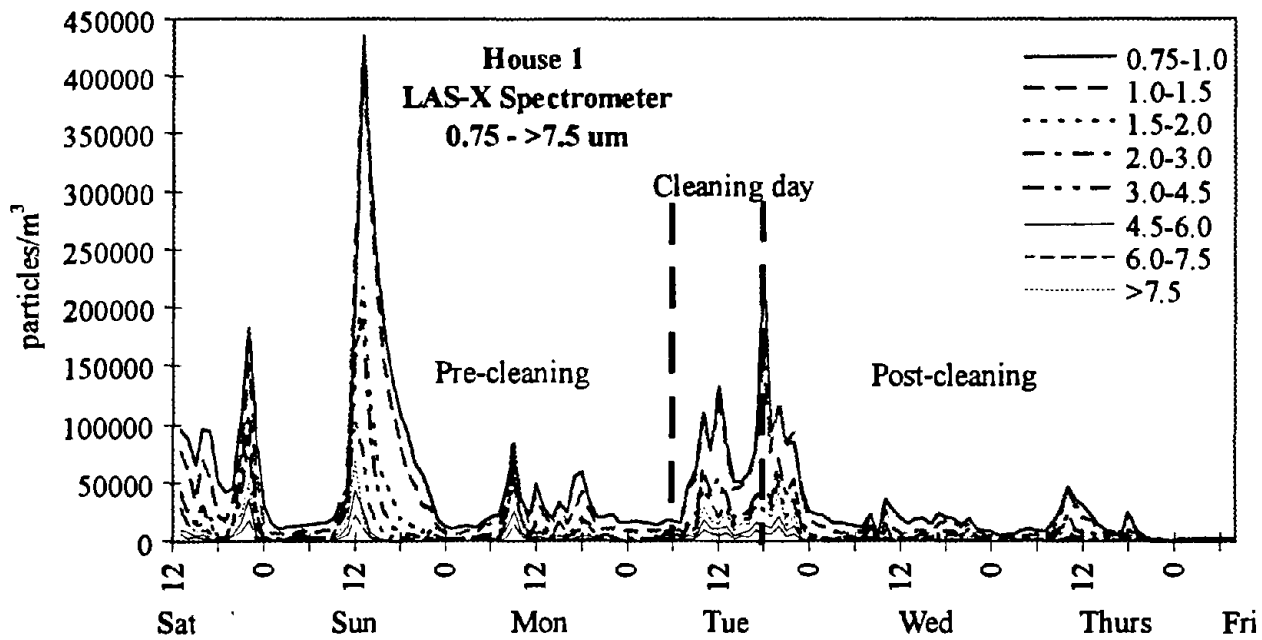
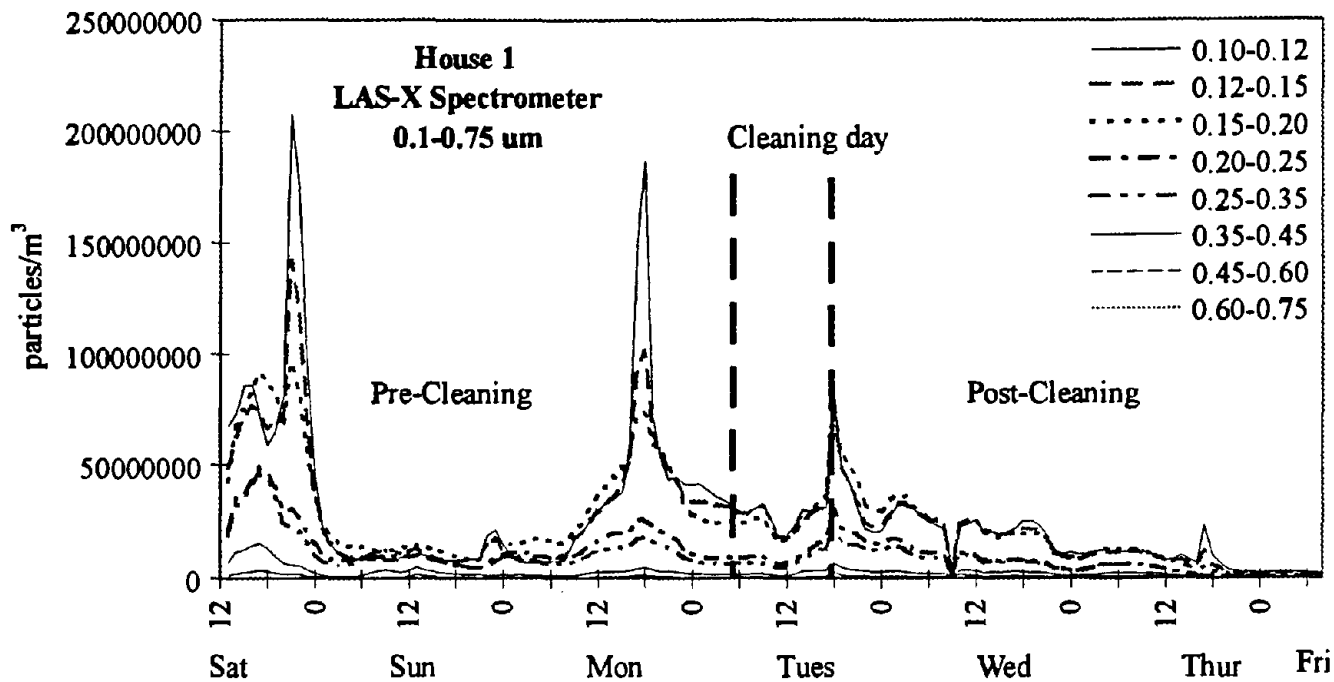


Figure 5-14. LAS-X aerosol spectrometer measurement results at House 1

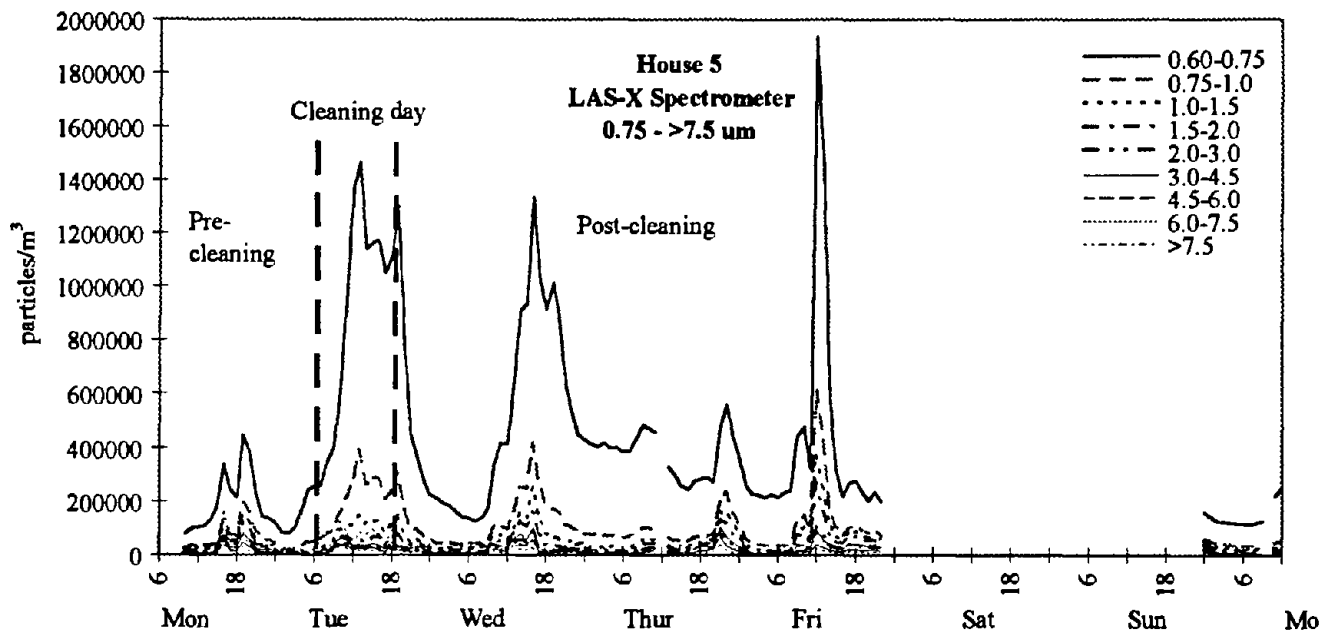
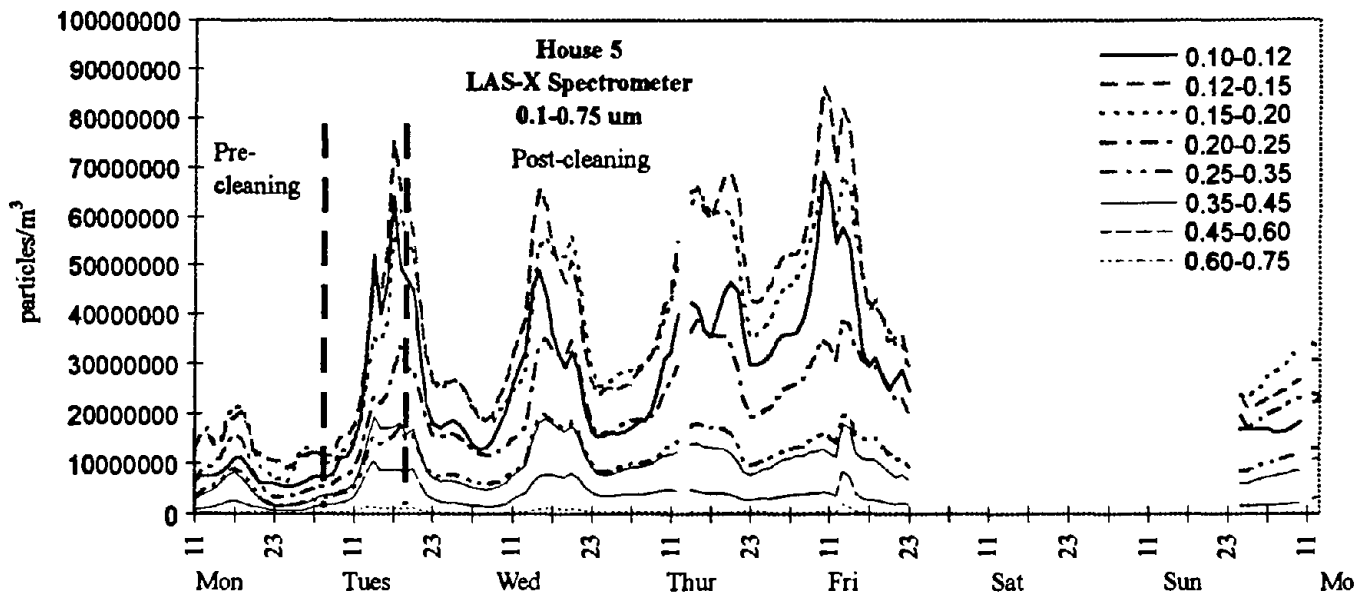


Figure 5-15. LAS-X aerosol spectrometer measurement results at House 5

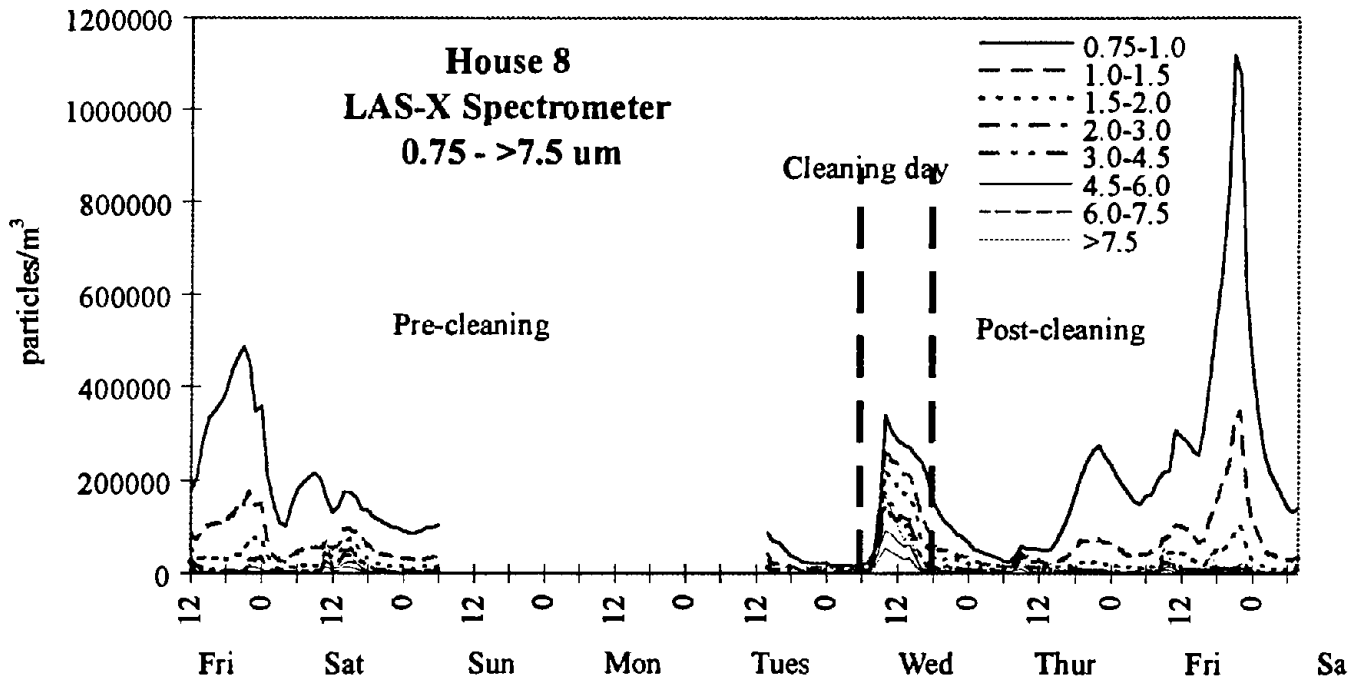
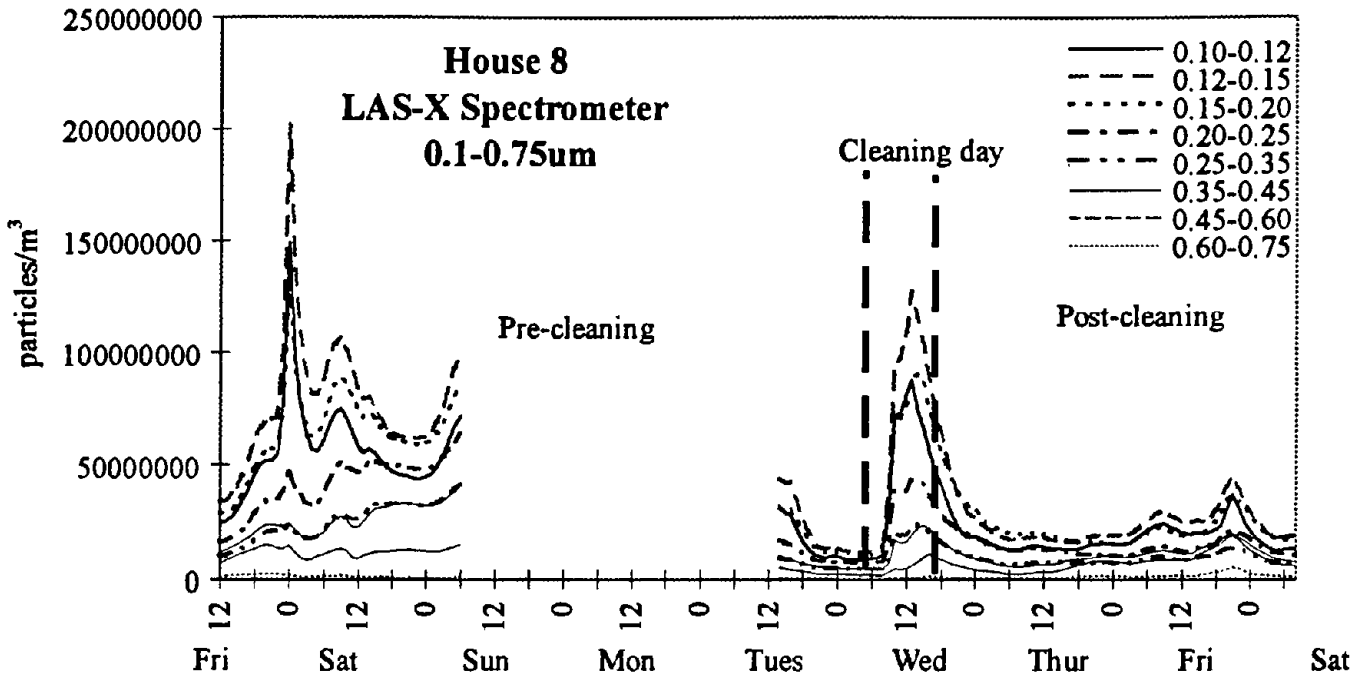


Figure 5-16. LAS-X aerosol spectrometer measurement results at House 8

### 5.5.3 Concentrations of Airborne Fibers in the Study Homes

Concentrations of airborne fibers were collected indoors and outdoors at each home using an integrated sampling method. Samples were collected for sequential 24-hr periods on two days prior to, and two days following, HAC system cleaning. The results are presented in Table 5-15. The concentrations of airborne fibers were low at all of the study homes in both pre- and post-cleaning samples. Fibers were rarely detected in outdoor samples and with one exception (House 4, post-cleaning), the concentrations were near the detection limit. The indoor concentrations ranged from less than 0.001 fiber/cm<sup>3</sup>, the minimum detection limit, to 0.007 fibers/cm<sup>3</sup> in two pre-cleaning samples at the Test House. Fibers were detected in one or more samples at all homes, regardless of whether there were any pets in the home. This was not surprising because all homes contain fibers due to the presence of furnishings and carpets. There was no relationship between the presence of pets and the number of samples in which fibers were detected or the concentrations of fibers in the samples. The concentrations of fibers measured at the study homes were too low and too variable to draw any conclusions about the impact of HAC system cleaning on airborne fiber concentrations.

Airborne fiber concentrations were also measured with a “real-time” optical monitor, the MIE Fibrous Aerosol Monitor, at four of the homes. The results are also presented in Table 5-15. Plots of the concentrations at two houses are depicted in Figures 5-17 (House 6) and 5-18 (House 8). The mean fiber concentrations measured with the FAM-1 after HAC system cleaning were lower at the IAQ Test House, but the standard deviation was large and there was a limited data set due to problems with the instrument at the Test House. At House 6, the mean concentration in the post-cleaning period was higher because concentrations of fibers were high on the last two days of the study from Saturday evening to Sunday afternoon. The source of the fibers was not determined. The high concentrations at House 8 during the pre-cleaning period may be related to the presence of a long-haired cat in the home. The home also had the highest levels of fibers in the ducts based on visual observation. The concentrations were substantially lower after HAC system cleaning. The concentrations of fibers measured with the FAM-1 in the pre-cleaning period were substantially higher than those measured with the integrated sampling method. The samples were collected in the same room as the continuous monitor. The reason for the discrepancy between the results with the two measurement methods is not known.

One sample from the pre-cleaning set and one sample from the post-cleaning set at each study home were analyzed by SEM to characterize the types of particles and fibers in the samples. The primary purpose of the analysis was to identify the types of fibers in the air samples. However, because fiber concentrations were low, there were few fibers to identify. The results are included in Appendix G and summarized below.

Table 5-15 Airborne Fiber Concentrations in the Study Homes

| House | Location  | fibers/cm <sup>3</sup> |                  |                    |               |                |        |
|-------|-----------|------------------------|------------------|--------------------|---------------|----------------|--------|
|       |           | Pre-Cleaning           |                  |                    | Post-Cleaning |                |        |
|       |           | Sample 1 <sup>a</sup>  | Sample 2         | FAM-1 <sup>b</sup> | Sample 1      | Sample 2       | FAM-1  |
| TH    | Outdoor   | ND <sup>c</sup>        | ND               |                    | 0.002         | ND             |        |
|       | Primary   | 0.007                  | 0.002            | 0.0130             | 0.001         | ND             | 0.0020 |
|       | Secondary | 0.007                  | ND               |                    | ND            | 0.003          |        |
| 1     | Outdoor   | ND                     | ND               |                    | ND            | 0.001          |        |
|       | Primary   | 0.004                  | SEM <sup>d</sup> |                    | SEM           | - <sup>e</sup> |        |
|       | Secondary | 0.005                  | 0.001            |                    | 0.006         | 0.003          |        |
| 2     | Outdoor   | ND                     | ND               |                    | ND            | ND             |        |
|       | Primary   | 0.003                  | SEM              |                    | SEM           | - <sup>f</sup> |        |
|       | Secondary | 0.003                  | 0.003            |                    | 0.008         | 0.003          |        |
| 3     | Outdoor   | ND                     | ND               |                    | ND            | ND             |        |
|       | Primary   | ND                     | SEM              |                    | SEM           | 0.001          |        |
|       | Secondary | ND                     | 0.001            |                    | 0.001         | 0.001          |        |
| 4     | Outdoor   | ND                     | ND               |                    | ND            | 0.005          |        |
|       | Primary   | 0.003                  | SEM              | - <sup>g</sup>     | SEM           | 0.002          | 0.0035 |
|       | Secondary | 0.004                  | 0.002            |                    | 0.006         | 0.001          |        |
| 5     | Outdoor   | 0.002                  | ND               |                    | ND            | - <sup>e</sup> |        |
|       | Primary   | ND                     | SEM              |                    | SEM           | 0.004          |        |
|       | Secondary | ND                     | 0.008            |                    | ND            | 0.003          |        |
| 6     | Outdoor   | ND                     | ND               |                    | ND            | ND             |        |
|       | Primary   | 0.001                  | SEM              | 0.0007             | SEM           | ND             | 0.0081 |
|       | Secondary | 0.002                  | 0.002            |                    | 0.003         | 0.001          |        |
|       | Duplicate | -                      | -                |                    | 0.001         | 0.001          |        |
| 7     | Outdoor   | ND                     | ND               |                    | 0.001         | ND             |        |
|       | Primary   | 0.003                  | SEM              |                    | SEM           | 0.002          |        |
|       | Secondary | 0.003                  | 0.002            |                    | 0.002         | 0.001          |        |
| 8     | Outdoor   | 0.001                  | 0.001            | 0.058              | ND            | ND             | 0.0010 |
|       | Primary   | 0.001                  | SEM              |                    | SEM           | ND             |        |
|       | Secondary | ND                     | 0.001            |                    | 0.001         | 0.002          |        |

<sup>a</sup> Two 24-hr integrated samples collected pre- and post-cleaning

<sup>b</sup> Mean concentration measured during the period with the FAM-1; monitored at one house each week

<sup>c</sup> ND: Concentration less than minimum detection limit of 0.001 fibers/cm<sup>3</sup>

<sup>d</sup> One sample analyzed by scanning electron microscopy, but fibers not quantified

<sup>e</sup> Sampling pump failed

<sup>f</sup> No sample collected

<sup>g</sup> Data logger problem; data lost

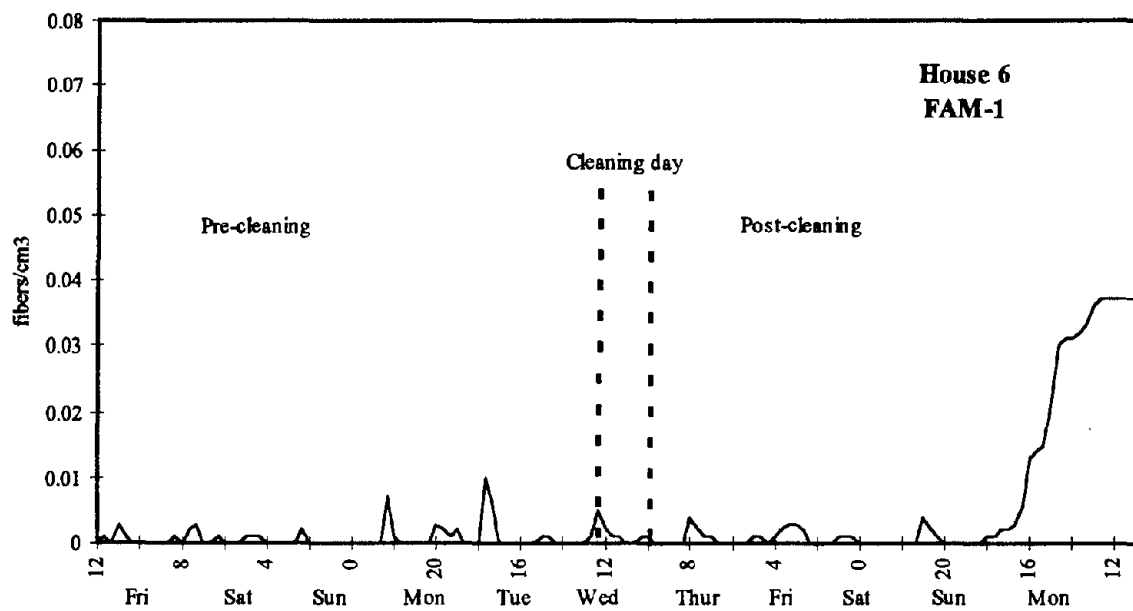


Figure 5-17. FAM-1 fiber measurement results at House 6

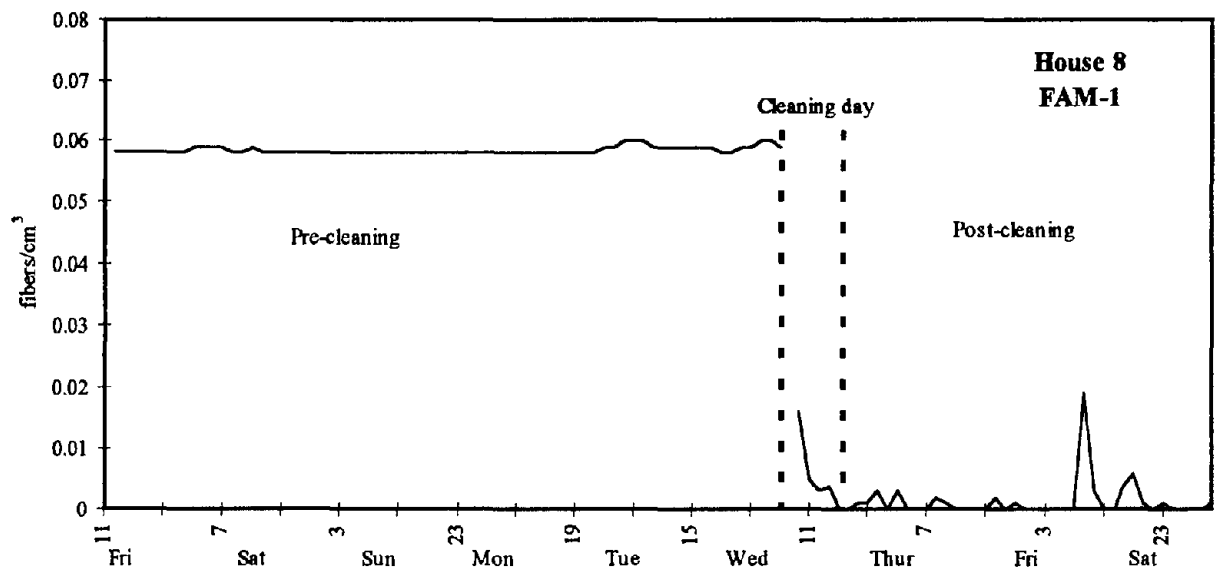


Figure 5-18. FAM-1 fiber measurement results at House 8

#### **5.5.3.1 Test House SEM Results**

Similar particles and fibers were observed in the pre- and post-cleaning samples. The samples contained the following types of particles and fibers:

- Silicon(Si)/aluminum (Al)-rich particles (clay minerals) - major contribution
- Copper (Cu)-rich particles - moderate contribution
- Si-rich particles (quartz) - minor contribution
- Calcium (Ca)/sulfur (S)-rich particles - minor contribution
- Iron (Fe)-rich particles - minor contribution
- Cellulose fibers - minor contribution
- Fibrous glass - minor contribution

#### **5.5.3.2 House 1 SEM Results**

Particles observed in the pre-cleaning sample included the following:

- Carbon (C)-rich particles (Combustion material) - 85% of particles
- Silicon(Si)/aluminum (Al)-rich particles (clay minerals) - 10% of particles
- Miscellaneous (Earth crustal materials) - 5% of particles

The % of the sample in these categories are estimates. Fibers were not observed in the sample.

In the post-cleaning sample, the particles were 100% carbon-rich particles

#### **5.5.3.3 House 2 SEM Results**

Particles observed in the pre-cleaning sample were reported as 100% carbon rich particles (carbonaceous fragments). In the post-cleaning sample, 95% of the particles were carbon-rich and 5% were miscellaneous (earth crustal materials). No fibers were observed.

#### **5.5.3.4 House 3 SEM Results**

The laboratory reported that the pre-cleaning sample contained primarily carbonaceous particles with a minor amount of earth crustal particles (Si/Al-rich and Si-rich particles). The post-cleaning sample consisted mainly of C-rich particles that were flakes. The sample also contained pollen, mold, earth crustal materials, and feldspar.

#### **5.5.3.5 House 4 SEM Results**

The laboratory reported that the pre-cleaning sample contained primarily carbon-rich particles that were predominantly flakes with a morphology similar to that of skin. They also reported cellulose fibers, earth crustal materials, and carbon spheres that may have been mold. The post-cleaning sample had the same C-rich flakes plus Si/Al-rich, Si-rich, and Ca-rich particles. Pollen and molds were not observed in the post-cleaning sample.

#### **5.5.3.6 House 5 SEM Results**

The laboratory reported that the pre-cleaning sample contained primarily carbon-rich particles that were predominantly skin flakes. Ca/S particles that were likely gypsum were identified in the sample. They also reported cellulose fibers, wood, salt, and earth crustal materials. The post-cleaning sample had similar particles plus pollen.

#### **5.5.3.7 House 6 SEM Results**

The laboratory reported that the pre-cleaning sample contained primarily carbon-rich particles that were dominantly skin flakes. The sample also contained Ca/S particles that were likely gypsum, cellulose fibers, earth crustal materials and pollen. The post-cleaning sample had similar particles and fibers.

#### **5.5.3.8 House 7 SEM Results**

The laboratory reported that the majority of particles in the pre-cleaning sample were skin flakes/animal dander. A minor amount of cellulose material was reported. They also reported various earth crustal materials, pollen, and salt. The post-cleaning sample contained moderate amounts of skin flakes and earth crustal materials plus cellulose materials, pollen, and other particles.

#### **5.5.3.9 House 8 SEM Results**

The laboratory reported that the majority of particles in the pre-cleaning sample were skin flakes/animal dander. A minor amount of cellulose material was reported. They also reported various earth crustal materials, fly ash, pollen, and salt. The post-cleaning sample contained moderate amounts of Si/Mg-rich flakes that were probably talc. The sample also included skin flakes and earth crustal materials plus pollen, and other particles. No fibers were observed in samples from this house even though there was a long-hair cat, there were heavy accumulations of fibers in the ductwork, and the fiber concentrations measured with the FAM-1 were the highest in the study.

The results from the SEM analyses suggest that the airborne particles are typical of indoor air samples, consisting of earth crustal materials, carbonaceous particles, pollens, molds, skin flakes, some fibers, and particles from building products (gypsum) and consumer products (talc). The reader is encouraged to review the complete results included as Appendix D, which also includes micrographs of selected particles.

#### 5.5.4 Fungi Air Samples

The results of the bioaerosol sampling for fungi before and after cleaning at all nine houses are found in Table 5-16. The goal of the bioaerosol sampling was to collect a snapshot in time both pre- and post-cleaning of the airborne fungal levels. Bioaerosol sampling provides short-term samples and over the course of time the levels in a building may vary substantially. Therefore, the conclusions that can be drawn are limited.

The results of the two sampler measurements either from the rooms or the supply have been averaged and the means are shown in the Table 5-16. As discussed previously, in the houses where the secondary supply was located in the ceiling, a second room sample was collected in its place. This includes houses 3, 4, and 5. The levels of fungal bioaerosols in the supply samples and room samples were essentially the same with two exceptions. In both the Test House and House 5, the levels of airborne fungi were more than three times higher in the room than in the duct. While all of the numbers in House 5 are very low and probably not a concern, in the Test House the room had 300 cfu/m<sup>3</sup> compared to 113 cfu/m<sup>3</sup> in the ducts. The full significance of this result cannot be evaluated with so few samples, but it is interesting to note. Also of interest is the level of fungi in House 2. The numbers of fungi isolated both in the supply ducts and in the room are considerably higher than those in the other houses. The high levels can be attributed to a burst of *Penicillium spp.* in the first 20 minutes of sampling. Approximately 90% of the of the organisms on the three plates were *Penicillium spp.*, and 90% of those occurred in the first 20 minutes of sampling. In other words, 900 out of 1000 *Penicillium spp.* on the plates were collected in the first 20 minutes. If those 900 are subtracted, the fungal aerosol levels drop to 130 cfu/m<sup>3</sup>. This level is similar to the levels measured at the other houses.

Table 5-16. Fungal Air Sample Results

| House | Cfu/m <sup>3</sup>       |               |              |               |
|-------|--------------------------|---------------|--------------|---------------|
|       | Supply Duct <sup>a</sup> |               | Room         |               |
|       | Pre-Cleaning             | Post-Cleaning | Pre-Cleaning | Post-Cleaning |
| TH    | 113                      | 93            | 400          | 214           |
| 1     | 146                      | 91            | 146          | 113           |
| 2     | 646                      | 200           | 663          | 117           |
| 3     | 107                      | 100           | 168          | 93            |
| 4     | 300                      | 300           | 159          | 270           |
| 5     | 14                       | 2             | 51           | 80            |
| 6     | 68                       | 58            | 90           | 93            |
| 7     | 49                       | 34            | 128          | 70            |
| 8     | 74                       | 84            | 78           | 70            |

<sup>a</sup> Mean of measurements in supply ducts serving the primary and secondary sampling locations (rooms), except at houses 3, 4, and 5, where supply duct measurements were made only in the primary room.

Mechanical cleaning of the HAC system without the use of chemical biocides did not appear to impact fungal bioaerosol concentrations. A comparison of fungal bioaerosol levels demonstrated no notable difference between the numbers of fungi collected during pre-cleaning and those collected post-cleaning, except for House 2. The decrease from 650 cfu/m<sup>3</sup> to 200 cfu/m<sup>3</sup> in the supply and 170 cfu/m<sup>3</sup> in the room at House 2 would probably be considered substantial. However, as discussed previously the high levels on all three samples can be attributed to a single burst in the first 20 minutes of sampling. When the organisms responsible for the burst are removed from the calculation, the fungal cfu levels were 130 cfu/m<sup>3</sup>, a value lower than either the supply or the room post-cleaning levels. The significance or source of that burst cannot be determined with the limited sampling performed in this study.

### 5.5.5 Comparison of IAQ Measurement Results With Duct Dust Levels

One of the questions routinely raised is when should an air conveyance system be cleaned. It was beyond the scope of this study to address that issue in a quantitative manner. However, one factor that might be considered in making a decision regarding HAC system cleaning would be the level of dust in the system. This could be a critical parameter if there was a relationship between duct dust levels and the indoor air quality parameters such as airborne particle and fiber concentrations. This study facilitated a limited assessment of the relationship of duct dust levels and airborne particle concentrations. Results of the duct dust measurements and airborne particle concentrations during the pre-cleaning period are summarized in Table 5-17.

Table 5-17. Comparison of Duct Dust Levels and Airborne Particle Concentrations Prior to HAC System Cleaning

| House | Duct Dust (g/m <sup>2</sup> ) |                | Airborne Particle Mass (µg/m <sup>3</sup> ) |                                | Airborne Particles X 10 <sup>6</sup> /m <sup>3a</sup> |
|-------|-------------------------------|----------------|---|--------------------------------|---|
|       | Supply                        | Return         | PM <sub>10</sub> <sup>a</sup>               | PM <sub>2.5</sub> <sup>a</sup> |   |
| TH    | 2.33                          | - <sup>b</sup> | 11.1  | 7.5                            | 6.97  |
| 1     | 8.62                          | 19.83          | 10.7  | 6.5                            | 5.6   |
| 2     | 3.37                          | 24.13          | 15.2  | 11.8                           | 7.21  |
| 3     | 1.91                          | 7.80           | 17.7  | 16.5                           | 16.01   |
| 4     | 1.48                          | 7.89           | 15.6  | 11.8                           | 10.98   |
| 5     | 2.28                          | 11.34          | 10.0  | 5.7                            | 3.52  |
| 6     | 2.30                          | 5.26           | 10.3  | 6.5                            | 5.06  |
| 7     | 3.34                          | 12.91          | 14.3  | 11.7                           | 8.07  |
| 8     | 26.03                         | 35.11          | 10.9  | 11.3                           | 20.15   |

<sup>a</sup> Mean concentrations for the period prior to HAC system cleaning

<sup>b</sup> No measurements in the return

Mean dust levels ranged from 1.5 to 26 g/m<sup>2</sup> in the supply ducts and from 5.2 to 35 g/m<sup>2</sup> in the return. Mean PM<sub>2.5</sub> and PM<sub>10</sub> concentrations in the pre-cleaning period ranged from only 5.7 to 17.7 µg/m<sup>3</sup> and do not appear to be related to the dust levels in the ducts. For the mean airborne particle concentrations in the >0.5 µm fraction there does not appear to be a strong relationship with duct dust levels, although the highest concentration of particles was measured in the house with the highest duct dust levels, House 8. Although the data set is very limited, a regression analysis for the eight field study homes gave a correlation coefficient (r<sup>2</sup>) of 0.644 for airborne particle concentrations (particles X 10<sup>6</sup>/m<sup>3</sup>) versus duct dust levels in the return ducts.

Examination of the data for bacteria and fungi in the surface samples (Tables 5-6 and 5-7) fail to show any relationship between levels of the microbials and the duct dust levels. The highest bacteria levels were measured at Houses 4, 5, and 7, but these houses did not have the highest duct dust levels. Fungi levels in surface samples were highest at Houses 1 and 4 in the supply and House 3 in the return. But these are not the houses with the highest duct dust levels. The fungi levels were relatively low at House 8, the house with the highest duct dust levels.

No statements can be made about the relationship of airborne fiber concentrations and duct dust levels. Airborne fiber concentrations were low and the fiber content of the duct dust samples was not determined.

## 5.6 Heating and Cooling System Measurement Results

Measurements were made of a number of parameters related to the heating and cooling system at each study home prior to, and following, HAC system cleaning in an attempt to determine the impact of the HAC system cleaning. The parameters measured included air flow rates, static pressures in the supply and return ducts, differential pressures, coolant line temperatures, and air handler blower current. Additionally, temperature and relative humidity were measured in the supply and return ducts and system operating durations were measured. The intent of the measurements was to identify trends and indications of improved HAC system performance. It was determined during development of the study design, that quantitative determination of changes in overall system efficiency would be difficult within the scope of this study. Results of the measurements are reported below and estimates of the change in heat removal by the cooling coil are provided for two homes that had large changes in air flow rates.

### 5.6.1 System Air Flow Rates

Air flow rates were measured with a vane anemometer at each supply register and each return air grille in the homes. Multiple measurements were made on each diffuser and grill to obtain accurate flows across the surface. Measurements were made on two days prior to cleaning and on two days following cleaning.

The supply and return air flow rates are summarized in Table 5-18. The volumetric air flow from the supply registers and diffusers was higher at all houses except House 2. The change in flow ranged from -3.7 to 17.0%. Although the number of measurements was too small to make a statistical estimate of the significance of the differences between pre- and post-cleaning measurements, the standard deviation shows that the differences are not likely to be significant for changes of less than 10%. Air flows in the supply did increase by over 10% at Houses 1, 4, 5, and 8.

Return air flows increased at six of the nine study homes. Based on the standard deviation, the change is expected to be significant only at Houses 5 and 6, which had increases of 37.6 and 14.1 %.

Although the data are not conclusive due to the small sample size and the limited number of measurements, they do suggest that HAC system cleaning increased air flows to some extent.

One of the limitations of the data collected in this study was that the measurements were performed at the supply registers and diffusers and at the return air grilles in the house. This approach was taken because it was recognized that measurements of air flow rates in the supply ducts would be difficult for residential systems. The supply ducts in the study homes typically consisted of two branch ducts off the air handling unit supply plenum. Take-offs for the branch (feeder) ducts to the rooms were often located very

Table 5-18. Supply and Return Air Flow Rates

| House |                  | m <sup>3</sup> /hr |       |                       |        |       |                       |
|-------|------------------|--------------------|-------|-----------------------|--------|-------|-----------------------|
|       |                  | Supply             |       |                       | Return |       |                       |
|       |                  | Pre-               | Post- | % Change <sup>a</sup> | Pre-   | Post- | % Change <sup>a</sup> |
| TH    | Avg <sup>b</sup> | 1883               | 1987  | +5.5                  | 2084   | 2109  | +1.2                  |
|       | SD <sup>b</sup>  | 30                 | 26    |                       | 14     | 26    |                       |
| 1     | Avg              | 1304               | 1449  | +11.1                 | 2041   | 1971  | -3.4                  |
|       | SD               | 6                  | 53    |                       | 50     | 46    |                       |
| 2     | Avg              | 1837               | 1769  | -3.7                  | 1791   | 1685  | -5.9                  |
|       | SD               | 46                 | 57    |                       | 42     | 75    |                       |
| 3     | Avg              | 1923               | 2108  | +9.6                  | 2322   | 2394  | +3.1                  |
|       | SD               | 1                  | 241   |                       | 139    | 15    |                       |
| 4     | Avg              | 1734               | 1943  | +12.0                 | 2301   | 2440  | +6.0                  |
|       | SD               | 3                  | 94    |                       | 213    | 57    |                       |
| 5     | Avg              | 1072               | 1415  | +32                   | 1025   | 1410  | +37.6                 |
|       | SD               | 30                 | 34    |                       | 28     | 25    |                       |
| 6     | Avg              | 1541               | 1606  | +4.2                  | 1310   | 1495  | +14.1                 |
|       | SD               | 187                | 37    |                       | 62     | 39    |                       |
| 7     | Avg              | 2022               | 2181  | +7.9                  | 1987   | 1966  | -1.1                  |
|       | SD               | 66                 | 100   |                       | 25     | 38    |                       |
| 8     | Avg              | 1450               | 1697  | +17.0                 | 1559   | 1692  | +8.5                  |
|       | SD               | 11                 | 80    |                       | 198    | 177   |                       |

<sup>a</sup> % Change = (Post-cleaning average - pre-cleaning average)/pre-cleaning average X 100

<sup>b</sup> Average and Standard Deviation for two pre-cleaning and two post-cleaning measurements

close to the supply plenum which would have made it difficult to make accurate measurements of air flow rates by traverses of the ducts with pitot tubes or hot-wire anemometers. Measurements of air flow rates at the first home of the study, the EPA IAQ Test House (Table 5-18), showed that measurements of air flow rates at supply registers and the return grille could be performed with good precision as indicated by the low standard deviation and acceptable accuracy as demonstrated by the good mass balance between the supply and return. However, as shown in the table, the measurements were not as good at other houses, as indicated by the large standard deviation for some homes and the poor mass balance in some cases. The reason for the large standard deviations at some homes is not known. The poor mass balance is most likely attributable to air leakage in either the supply or return air ductwork. The leakage can not be accounted for in these measurements. It should also be noted that some of the increase in the supply air flow may have been attributed to remediation of minor deficiencies in the ductwork at some houses. For example, at House 8, a floor boot for the kitchen supply register was loose and re-attached on the day of HAC system cleaning. At House 7, a branch duct had fallen off the main supply trunk and was taped on to the duct, resulting in substantial leakage. After cleaning, the amount of leakage was reduced by a better repair of the problem.

Because the return air flows were measured at the return air grilles in the houses, the measurement results do not account for duct leakage, which was probably significant for some of these systems. As a result, the air flow measurement results from the study may not be an accurate measurement of the air flow through the air handler. To obtain that measurement value, air flow rates should have been measured by a traverse of the return air duct near the AHU. In most cases, there was sufficient length of straight return duct such that a measurement location could have been identified that had reasonably well-established flow. In future testing of this type, this measurement should be made in addition to the measurements at the return air grilles.

### **5.6.2 Measurements of Static and Differential Pressures**

Static pressures were measured in the supply and return ducts on two days prior and two days following HAC system cleaning. Differential pressure across the coil was measured continuously and data recorded with the IAQDS. Results of the measurements are presented in Table 5-19. The static pressure in the supply ducts increased at some houses, but decreased at others; there was no clear trend in the changes. The pre-cleaning static pressure in the supply duct at House 5 was substantially lower than the post-cleaning measurement because of two large leaks in the supply side of the system. An access panel on the AHU supply plenum was loose and there was a major leak where the supply trunk was connected to the AHU supply plenum. The access panel was fixed and, although the leakage at the supply trunk was not completely corrected, the amount of leakage was reduced after HAC system cleaning.

Table 5-19. Static and Differential Pressure Measurements

| House | Supply-Static Pressure<br>(inches of H <sub>2</sub> O) |                |             | Return-Static Pressure<br>(inches of H <sub>2</sub> O) |                |             | Differential Pressure (inches<br>of H <sub>2</sub> O) |       |             |
|-------|--|----------------|-------------|--|----------------|-------------|---|-------|-------------|
|       | Pre-   | Post-          | %<br>Change | Pre-   | Post-          | %<br>Change | Pre-  | Post- | %<br>Change |
| TH    | 0.130  | 0.105          | -19.2       | -0.380   | -0.370         | -2.6        | 0.510   | 0.520 | 2.0         |
| 1     | 0.092  | - <sup>a</sup> | -           | -0.220   | - <sup>a</sup> | -           | 0.311   | 0.311 | 0           |
| 2     | 0.057  | - <sup>a</sup> | -           | -0.133   | - <sup>a</sup> | -           | 0.189   | 0.145 | -23.3       |
| 3     | 0.289  | 0.282          | -2.4        | -0.476   | -0.587         | 23.3        | 0.772   | 0.866 | 12.2        |
| 4     | 0.416  | 0.385          | -7.5        | -0.380   | -0.508         | 33.7        | 0.200   | 0.200 | 0.0         |
| 5     | 0.055 <sup>b</sup>                                     | 0.129          | 134.5       | -0.129   | -0.203         | 57.4        | 0.200   | .270  | 35.0        |
| 6     | 0.092  | 0.094          | 1.6         | -0.169   | -0.219         | 29.6        | 0.290   | 0.314 | 8.3         |
| 7     | 0.044  | 0.050          | 13.6        | -0.168   | -0.190         | 13.1        | 0.226   | 0.236 | 4.4         |
| 8     | 0.125  | 0.096          | -23.2       | -0.145   | -0.159         | 9.7         | 0.274   | 0.259 | -5.6        |

<sup>a</sup> No measurement taken

<sup>b</sup> Static pressure was low due to high air leakage rates at a loose access panel and a seam in the supply trunk that had broken away from the AHU supply plenum

The static pressure increased in the return air duct at the six occupied field study homes where measurements were made. Post-cleaning measurements were not made at the first two houses of the field study due to technician error. The increased static pressure was consistent with increased air flows measured in the returns at the six houses, except for House 7 where there was no apparent increase in air flows measured at the return air grille in the house.

The differential pressure increased by 5% or more following HAC system cleaning at three houses, was not substantially different at five houses, and decreased substantially at one house. The results are not easily explained. The AHU at House 2 was less than one year old and there was only a light coating of dust on the cooling coil. But, based on visual observation, the cooling coil at House 8 was excessively dirty, with substantial blockage of the coil due to dirt and fibers. These two houses represented the extreme cases; debris and dirt levels were reasonably similar for the cooling coils at the other seven houses.

### 5.6.3 Air Handler Unit Blower Motor Current Readings

The AHU blower motor current was measured at five of the nine houses twice before and twice after HAC system cleaning using a clamp-on meter. Measurements were not made at the first two houses due to technician error. Measurements were not made at Houses 4 and 5 due to problems accessing the wiring harness for the blower motor. Results for the measurements are presented in Table 5-20. With the exception of the measurements at the Test House, the AHU blower motor current readings were higher following HAC system cleaning. The increase would represent an increase in power to the blower motor which would be expected if the air flow rate increased due to cleaning. The current readings provide an indication that HAC system cleaning had a positive impact on the performance of the air conveyance system.

It would have also been useful in this study to have measured the current for the compressor. During future testing to assess the impact of HAC system cleaning on system performance and energy use, it will be useful to make more comprehensive measurements over longer time periods.

Table 5-20. Air Handler Blower Motor Current Measurement Results

| House | Amps         |               |
|-------|--------------|---------------|
|       | Pre-Cleaning | Post-Cleaning |
| TH    | 4.0          | 4.0           |
| 1     | a            | a             |
| 2     | a            | a             |
| 3     | 5.7          | 5.9           |
| 4     | a            | a             |
| 5     | a            | a             |
| 6     | 5.5          | 5.7           |
| 7     | 7.1          | 7.3           |
| 8     | 4.3          | 4.6           |

\* Measurements not performed due to access problems or configuration/routing of wiring harness

#### **5.6.4 Coolant Line Temperatures**

Relative coolant temperatures were measured by attaching a solid state temperature sensor to the surface of the coolant lines. The sensor was then wrapped with insulation. Results of the measurements are presented in Table 5-21. The temperatures of the coolant lines at the inlet to the cooling coil were not substantially different in the pre- and post-cleaning time periods if the large standard deviations are considered. The temperatures of the coolant line at the outlet from the cooling coil were lower after HAC system cleaning at six of the seven houses with complete data sets, but the differences between pre- and post-cleaning periods were small except at House 3. Lower temperatures in the coolant line at the outlet of the cooling coil would be indicative of increased heat transfer if the cooling coil was more efficient due to HAC system cleaning. The results, therefore, provide an indication that HAC system cleaning may improve cooling coil efficiency.

The measurement of temperatures on the surfaces of the coolant lines were useful only for assessing the relative difference between pre- and post-cleaning periods. As can be seen in the table, some of the temperatures measured on the coolant inlet line are higher than would be expected. Placement of the sensors on the coolant lines was difficult and it was difficult to insulate the sensors properly. Although the measurement was useful because it provided an indication that the coolant temperatures in the outlet from the cooling coil were lower after HAC system cleaning, the measurement had little quantitative value. To be useful, and to obtain the level of accuracy and precision needed for this parameter, the temperatures of the refrigerant need to be measured in the transfer lines and the flow rate of the refrigerant should be measured. This was not feasible in this field study, but could be done in the Pilot HAC system Test Facility or at the EPA IAQ Test House.

#### **5.6.5 Estimates of Changes in Cooling Coil Heat Transfer Efficiency**

Temperature and relative humidity were measured in both the supply and return ducts at a location as close as possible to the AHU where the air was expected to be well-mixed. The measurement results for those parameters are not included in this report, but are available for the purposes of data interpretation and further data analysis. As described previously, the study design did not include measurements that could be used to quantitatively assess changes in overall system efficiency. However, the air flow data, AHU blower motor current measurement data, and the supply and return temperature and RH data were used to determine the change in enthalpy across the cooling coil and to estimate the total heat removed by the cooling coils for two of the study houses. Houses 5 and 6 were selected for this exercise because they had the largest change in return air flows following cleaning. House 5 had a 38% increase in the return air flow and House 6 had a

14% increase. To make the estimates, steady-state values for temperature and relative humidity and the average air flows were plotted on a psychrometric chart and the enthalpy values were determined. At House 5, the estimated heat transfer for the cooling coil was 15,505 Btu/hr prior to HAC system cleaning and 17,720 Btu/hr following cleaning, which represents a 14% increase. At House 6, the post-cleaning estimate was 21,041 Btu/hr, a 23% increase over the pre-cleaning estimate of 17,046 Btu/hr.

Table 5-21. Coolant Line Temperature Measurements

| House |      | Inlet <sup>a</sup> |                | Outlet <sup>b</sup> |                |
|-------|------|--------------------|----------------|---------------------|----------------|
|       |      | Pre                | Post           | Pre                 | Post           |
| TH    | Mean | 17.6               | 18.8           | 21.3                | 19.8           |
|       | SD   | 0.3                | 0.2            | 2.8                 | 1.7            |
| 1     | Mean | 11.5               | 7.1            | 28.6                | 25.7           |
|       | SD   | 5.0                | 6.7            | 4.1                 | 5.6            |
| 2     | Mean | 19.8               | 19.3           | 25.5                | 25.3           |
|       | SD   | 1.5                | 1.3            | 2.7                 | 2.2            |
| 3     | Mean | 10.8               | 9.25           | 32.7                | 23.5           |
|       | SD   | 3.5                | 2.1            | 2.9                 | 1.0            |
| 4     | Mean | 11.8               | 13.3           | 21.3                | 20.0           |
|       | SD   | 4.7                | 3.8            | 2.9                 | 2.4            |
| 5     | Mean | - <sup>c</sup>     | - <sup>c</sup> | - <sup>c</sup>      | - <sup>c</sup> |
|       | SD   |                    |                |                     |                |
| 6     | Mean | 20.5               | 21.0           | 21.0                | 22.2           |
|       | SD   | 1.4                | 0.5            | 0.9                 | 0.4            |
| 7     | Mean | 19.4               | 18.3           | 24.1                | 23.6           |
|       | SD   | 2.2                | 2.4            | 0.2                 | 0.2            |
| 8     | Mean | - <sup>d</sup>     | 7.4            | - <sup>d</sup>      | 21.3           |
|       | SD   |                    | 1.7            |                     | 2.4            |

<sup>a</sup> Mean and standard deviation for entire pre-cleaning to 6:00 a.m. on day of cleaning

<sup>b</sup> Mean and standard deviation for period from 6:00 a.m. on the day following cleaning until end of monitoring period

<sup>c</sup> Data lost due to instrument failure

<sup>d</sup> Data lost due to power failure

Without knowing the amount of power consumed by the condensing unit, the overall improvement in efficiency can not be calculated for the system. However, the increased rate of heat transfer would support an increased overall system efficiency. The higher rate of heat removal would also shorten the cycle times of the system, which would offset minor increases in power consumption by the fan and condensing unit.

### **5.7 Evaluation of Study Design, Field Protocol, and Test Methods**

As described in previous sections, the study was designed as a pilot study to evaluate the effectiveness of current HAC system cleaning methods, collect an initial data set on the impact of HAC system cleaning on indoor air quality and system performance, evaluate methods and test protocols for assessing HAC system cleaning effectiveness and its impact, and to collect information that could be used to develop and refine a research strategy for further evaluation of HAC system cleaning in residential and non-residential dwellings. The study methods and protocols successfully addressed those objectives. It was recognized early in the study design stage that a nine-home pilot study would not provide sufficient data for statistical analyses or for making definitive conclusions on the impact of HAC system cleaning. However, the assumption was that the a population of nine homes would be sufficient to identify trends in pre-cleaning versus post-cleaning samples of the measurement parameters. Analysis of the data does not indicate clear trends for the IAQ measurement parameters, but the data for the HAC system performance parameters are encouraging because they suggest that HAC system cleaning may improve system performance. The lack of conclusive results to document changes in indoor air quality parameters due to HAC system cleaning, although disappointing, should not be considered a negative result. On the contrary, the data collected in the study suggest that short-term sampling and monitoring of particles, bioaerosols, and fibers are unlikely to be useful for determining whether HAC system cleaning has an impact on either short-term or long-term indoor air quality parameters. The study results suggest that a technical approach involving this type of monitoring will not be useful because are there too many sources of particles indoors, particularly the occupants and the outdoor sources, and that temporal variability of particle concentrations make it difficult to discern an effect of HAC system cleaning on indoor air quality. New approaches need to be considered to evaluate the impact of HAC system cleaning.

The methods for measurement of IAQ parameters used in the study generally worked well. The integrated sampling method for PM<sub>2.5</sub> and PM<sub>10</sub> is a well-documented method used extensively in indoor air quality monitoring projects. The 20 L/min sampling rate of the method provides adequate mass over eight to 24 hour sampling periods for accurate and precise gravimetric measurements. No problems were encountered with this method during the study.

The measurements of particle concentrations with the Climet optical particle counters provided useful data on temporal variations in particle concentrations. The instrument is limited by the fact that data can only be output for one of the two size fractions for which data are collected. Because of the limited internal storage capacity, it is necessary to make frequent visits to test sites to download the data if data are required for both channels. In this study, data for the  $>0.5 \mu\text{m}$  size fraction were recorded with the Blue Earth data logger in the IAQDS. However, because of the configuration of the interface between the Climet and the Blue Earth, the full scale output of the Climet could not be recorded with the IAQDS. The interface needs to be evaluated to determine how to resolve this problem for future field monitoring studies.

The LAS-X generally worked well during the study. There were some problems with the RS-232 interface and the direct data dump to the computer. These problems need to be resolved.

The integrated sampling method used for fibers is a well-documented NIOSH method. Fiber concentrations were low during the study and the precision of the method could not be evaluated with the data from the study. The MIE FAM-1 fiber monitor was particularly troublesome during this study. There were problems with the data logger during the study. These problems need to be resolved before the instrument is used in other monitoring programs. The performance of the instrument needs to be evaluated. Although the instrument may be useful for pre- and post-cleaning comparisons, the performance of the instrument for different types of fibers, different fiber lengths, and low fiber concentrations is not well-documented.

The methods used for collection of bioaerosols are frequently-used methods. No problems were encountered with these methods. The surface sampling methods for microbiologicals also worked well.

The MVDS worked well for collection of dust samples from the ductwork when it was fitted with the brush attachment. The collection efficiency of the prototype model was evaluated and found to be highly efficient on non-porous surfaces for loose dust. The collection efficiency of the MVDS with the brush attachment has not been documented for the type of dust that occurs in "real" ductwork. However, based on visual observation, the sampler is highly efficient. Because the method is used primarily for comparison of pre- and post-cleaning samples, quantitative measures of collection efficiency may not be required. The MVDS does not collect dust efficiently from cooling coils based on visual observations during the study. A new method needs to be developed if quantitative measurements of dust on cooling coils are required.

The methods used to measure HAC system parameters worked reasonably well during the study, but should be improved if the measurements are required in future studies. The measurements of air flow rates with the vane anemometer at supply registers, diffusers, and return air grilles worked well. Measurements at the EPA IAQ Test House showed that the precision of the method can be quite good. Poorer precision at some houses is likely due to highly non-uniform air flow at some registers and diffusers. Measurements of air

flow rates at the supply registers and return air grilles should be supplemented with measurements of air flow in the return duct near the AHU by a pitot tube traverse method. The latter measurement will provide a better estimate of the “system” air flow through the AHU. Measurements at registers and grilles in the house do not account for the leakage in the supply and return air ducts.

Measurements of static pressures and differential pressure are relatively straight forward and easy to accomplish. The sensor used to measure differential pressure had a full-scale range of 0.5 inches of H<sub>2</sub>O, which was inadequate at House 3. Different sensors may be needed for some systems.

Current measurements are also relatively easy to perform. In this study, measurements were not made at some homes because the wiring was inaccessible or in a wiring harness. Generally, the measurements can be performed. It may have been useful to measure the current for the compressor. This measurement should be considered in future studies.

Relative differences in coolant temperatures between pre- and post-cleaning periods were determined by measuring the temperature on the outside surface of the coolant inlet and outlet lines. This method did not work well. The temperature sensors were difficult to attach and difficult to insulate. The method may be useful for obtaining “indications” of relative changes in large field studies. If this measurement parameter is required, the method needs to be refined and a different type of sensor should be used that is easier to attach. For accurate and precise measurements, the refrigerant temperature and pressure should be measured in the refrigerant lines.

In future studies to assess the impact of HAC system cleaning on system performance and energy use, more comprehensive measurements of HAC system parameters should be performed over longer time periods. These measurements will require installation of meters and measurement devices into the system and collection of data with data acquisition systems.

## 6.0 QUALITY ASSURANCE/QUALITY CONTROL

Quality control and quality assurance activities were implemented in the project according to guidelines in the Work Assignment Quality Assurance Project Plan (QAPP) entitled, *Quality Assurance Project Plan for the Pilot Field Study to Evaluate the Effectiveness of Cleaning Air Conveyance Systems and the Impact on Indoor Air Quality in Residences* (Fortmann, 1996b) and the *Field Microbiological Investigation of Ventilation System Cleaning: Project Work/QA Plan* (RTI, 1996).

Quality control samples, including blanks and duplicates, were analyzed as part of this study. In addition, quality control procedures were included in the sampling and analysis phases of this study. During the initial testing at the EPA Indoor Air Quality Test House, the Acurex Environmental Quality Assurance Officer performed a systems audit. Based on the audit, some modifications were made to test protocols and methods and corrective action was taken as appropriate.

To the extent possible, the methods used in this study were standardized methods or methods for which performance has been well-documented. Some methods, such as the collection of dust from the surfaces of ductwork were developed for this project. Data quality indicator goals for the project are listed in Table 6-1.

### 6.1 Quality Control Samples

Quality control samples consisted of blanks and duplicates.

#### 6.1.1 Field Blanks

Field blanks for particles and fibers consisted of filters not used for sampling but handled in the same manner as those used for field sampling. Filters were placed in petri dishes, carried to the field but not used, returned to the laboratory, and conditioned at constant temperature and relative humidity in the EPA weighing facility along with the field samples. The filters were weighed in batches with the field samples. For fibers, the blanks were submitted to the laboratory blind and analyzed with the field samples. Blanks for microbial samples consisted of cassettes and swabs carried to the field but not used.

Six filters were submitted to the laboratory as blanks for fiber analysis. The results reported for all six filters were  $<0.001$  fibers/cm<sup>3</sup>, the minimum detection limit for the method.

Table 6-1. Data Quality Indicator Goals For Parameters Measured in the Project

| Measurement Parameter                        | Bias (%)              | Precision (%)     | Completeness (%) |
|--|-----------------------|-------------------|------------------|
| Duct dust - MVDS                             | 45 - 125 <sup>a</sup> | ± 25              | >90              |
| Duct dust - NADCA vacuum method              | > 75 <sup>a</sup>     | ± 20              | >90              |
| Microbial areal density - filter             | 80 - 120              | ± 20              | >90              |
| Microbial areal density - swab               | 90 - 110              | ± 20              | >90              |
| Bioaerosol measurement (cfu/m <sup>3</sup> ) | 80 - 120              | ± 20              | >90              |
| PM <sub>10</sub> mass (µg/m <sup>3</sup> )   | 75 - 125 <sup>b</sup> | ± 25              | >90              |
| PM <sub>2.5</sub> mass (µg/m <sup>3</sup> )  | 75 - 125 <sup>b</sup> | ± 25              | >90              |
| Fine particle concentration (Climet)         | - <sup>c</sup>        | ± 25 <sup>d</sup> | >90              |
| Fine particle concentration (LAS-X)          | - <sup>c</sup>        | ± 25              | >90              |
| Fiber concentration (integrated samples)     | - <sup>e</sup>        | ± 45 <sup>e</sup> | >90              |
| Fiber concentration (FAM-1 monitor)          | ND <sup>f</sup>       | ± 25 <sup>f</sup> | >90              |
| Temperature                                  | ± 1.0 °C              | ± 1.0 °C          | >90              |
| Relative humidity                            | ± 5% RH               | ± 5               | >90              |
| Differential pressure                        | ± 25                  | ± 25              | >90              |
| Air flow rate (volumetric)                   | ± 20 <sup>b</sup>     | ± 20 <sup>b</sup> | >90              |

<sup>a</sup> Percent Recovery

<sup>b</sup> Based on EPA Large Building Studies QAPP

<sup>c</sup> Bias has not been determined for the instrument; measurement results were used to determine relative differences pre- and post-cleaning

<sup>d</sup> Based on limited measurements in a pilot scale test facility at Research Triangle Institute

<sup>e</sup> NIOSH Method 7400 B counting rules; Method 7400 states that overall accuracy of the method has not been determined. Precision DQI is as stated in Method 7400 for fiber counts

<sup>f</sup> Manufacturer does not specify accuracy; precision based on manufacturer's estimates for 0.1 fiber/cm<sup>3</sup> and 100 min sampling time

Nine filters were submitted to the laboratory for gravimetric analysis. Tare weights and final weights were determined for each filter. The measurements gave mass concentrations of 4, 12, 4, 10, 7, 5, 4, 2, and 12 µg per filter. The average for the nine blanks was 6.7 µg/filter. For a 24 hour sample at a concentration of 10 µg/m<sup>3</sup>, the mass on the filter would be 288 µg. The average error contributed by a blank value of 6.7 µg/filter for the two weighings (tare and final) would be approximately 2 percent.

Field blanks for microbial sampling and analysis methods included SDA cassettes, TSA cassettes, and swabs. For the six SDA cassettes, two samples had one colony count, but the other four had no counts. The TSA field blanks included one sample with one background count and five samples with no colonies. On 16 swab field blanks, only one sample had detectable colonies (four); all other samples had no background contamination.

## 6.1.2 Method Precision and Bias

### 6.1.2.1 Method Precision

Duplicate samples of duct dust were collected with the MVDS at all houses to assess the precision of the method. The results, presented previously in Table 5-4 are repeated here in Table 6-2.

Table 6-2. Results of Duplicate Duct Dust Measurements With The MVDS

| House | Location   | g/m <sup>2</sup> |           |       |       | %RSD |
|-------|------------|------------------|-----------|-------|-------|------|
|       |            | Primary          | Duplicate | Mean  | S.D   |      |
| TH    | Supply     | 0.80             | 1.09      | 0.94  | 0.20  | 22   |
| 1     | Supply     | 10.80            | 11.89     | 11.85 | 0.06  | 1    |
|       | Supply     | 26.28            | 100.72    | 63.65 | 52.64 | 83   |
|       | Return     | 0.24             | 0.25      | 0.25  | 0.007 | 3    |
| 2     | Supply     | 2.22             | 2.73      | 2.48  | 0.36  | 15   |
|       | Supply     | 0.18             | 0.16      | 0.17  | 0.01  | 1    |
| 3     | Return     | 13.15            | 16.54     | 14.85 | 2.40  | 16   |
|       | Supply     | 0.54             | 0.34      | 0.44  | 0.14  | 32   |
|       | Supply     | 0.19             | 0.26      | 0.23  | 0.05  | 22   |
|       | Return     | 0.42             | 0.37      | 0.40  | 0.04  | 9    |
| 4     | Supply     | 1.27             | 1.47      | 1.37  | 0.14  | 10   |
|       | Return     | 6.22             | 5.11      | 5.67  | 0.78  | 14   |
|       | Duct Liner | 1.62             | 1.55      | 1.59  | 0.05  | 3    |
|       | Supply     | 0.34             | 0.12      | 0.23  | 0.16  | 80   |
| 5     | Supply     | 2.62             | 2.52      | 2.57  | 0.07  | 3    |
|       | Return     | 11.49            | 10.47     | 10.98 | 0.72  | 7    |
|       | Supply     | 0.32             | 0.23      | 0.28  | 0.06  | 23   |
|       | Return     | 1.97             | 0.59      | 1.28  | 0.98  | 76   |
| 6     | Supply     | 2.00             | 2.03      | 2.02  | 0.2   | 1    |
|       | Return     | 3.62             | 6.52      | 5.07  | 2.05  | 40   |
|       | Return     | 0.18             | 0.23      | 0.21  | .04   | 17   |
| 7     | Supply     | 4.22             | 5.07      | 4.65  | 0.60  | 13   |
|       | Return     | 9.03             | 11.66     | 10.35 | 1.86  | 18   |
|       | Supply     | 0.44             | 0.80      | 0.62  | 0.25  | 41   |
| 8     | Supply     | 36.07            | 45.98     | 41.03 | 7.01  | 17   |
|       | Supply     | 1.13             | 0.63      | 0.88  | 0.35  | 40   |
|       | Supply     | 0.80             | 0.65      | 0.73  | 0.11  | 15   |
|       | Return     | 0.19             | 0.26      | 0.23  | 0.05  | 22   |

The percent relative standard deviation for the duplicate dust samples ranged from 1 to 80%. Twenty-one of the 28 duplicates met the data quality indicator goal of  $\pm 25\%$ . Five sets of duplicates with a %RSD greater than 25% were post-cleaning samples with low dust mass concentrations. In spite of the fact that the dust deposits were generally not uniformly distributed, the precision of the method was quite good.

Results for duplicate samples collected with the NADCA vacuum method were presented in Table 5-3. The following summarizes the results:

| <u>Primary (g/m<sup>2</sup>)</u> | <u>Duplicate (g/m<sup>2</sup>)</u> | <u>%RSD</u> |
|----------------------------------|------------------------------------|-------------|
| 0.036                            | 0.034                              | 3.5         |
| 0.030                            | 0.032                              | 4.6         |
| 0.027                            | 0.024                              | 8.3         |
| 0.013                            | 0.013                              | 0           |
| 0.007                            | 0.006                              | 10.8        |

All of the duplicates met the data quality indicator goal of  $\pm 20\%$ .

Duplicates of each microbiological surface measurement were obtained by collecting swab and vacuum samples on co-located sites except in the Test House where the swab method was not appropriate for the porous fiberglass duct liner surface. All measurement results are included in Appendix D. The data from each house were treated as replicates across all samples because the variability between sampling locations in the ducts was similar to the variability between co-located measurements with the two sampling methods. The results presented previously in Tables 5-6 and 5-7, therefore, are representative of the replicates. As shown in these tables, four to eight locations were sampled in the supply ducts and two to six locations were sampled in the return ducts at each house. For bacteria samples, the relative standard deviation ranged from 13 to 228% for samples collected at all of the locations at a house. For fungi samples, the relative standard deviation ranged from 13 to 243%. Review of the data in Appendix D shows that the relative standard deviation for the samples collected at the same location with the two methods are in a similar range. For most sampling locations, the precision goal of  $\pm 20\%$  could not be met due to the non-uniform distribution of the contaminants in the HAC system.

Duplicates for PM<sub>2.5</sub> and PM<sub>10</sub> were collected at the EPA IAQ Test House and at House 5. Samples were collected side-by-side at the primary sampling location in the home. The results were as follows:

| <u>House</u> | <u>Parameter</u>  | <u>Primary (µg/m<sup>3</sup>)</u> | <u>Duplicate (µg/m<sup>3</sup>)</u> | <u>%RSD</u> |
|--------------|-------------------|-----------------------------------|-------------------------------------|-------------|
| TH           | PM <sub>2.5</sub> | 7.4                               | 7.3                                 | 1.0         |
| TH           | PM <sub>10</sub>  | 9.8                               | 9.1                                 | 5.2         |
| 5            | PM <sub>2.5</sub> | 6.6                               | 4.7                                 | 23.4        |
| 5            | PM <sub>10</sub>  | 14.2                              | 13.0                                | 6.2         |

The four duplicates met the data quality indicator goal for the method of  $\pm 25\%$ .

Duplicate fiber samples were collected at the Test House and House 6. At House 5, the concentrations in both samples were 0.001 fibers/cm<sup>3</sup>, the minimum detection limit of the method. At the Test House, the pump failed for the duplicate sample.

The precision of measurements with continuous monitors was not determined during this study due to limitations of resources.. Data quality indicator(DQI) goals for these measurements were based on manufacturer's specifications and historical data for the instruments. For temperature and relative humidity sensors, the performance was checked at each house by comparison during setup with an aspirated psychrometer. The sensors were used only if they met the DQI goals for bias. But sufficient instrumentation was not available to co-locate continuous monitors to measure precision on a continuous basis.

#### **6.1.2.2 Method Bias**

The performance of the MVDS for collection of dust (particulate and fibrous materials) was evaluated in the laboratory prior to the field study. Results of the methods evaluation are presented in Appendix A. The collection efficiency of the MVDS with its specially designed nozzle was determined by applying known quantities of particulate matter to galvanized steel sheets, then samples were collected from the surface. The collection efficiency was determined to be  $97.6 \pm 1.8\%$  for collection of newly-deposited dust from the sheet metal surface. Following the initial evaluation in the laboratory, visual observations during tests in the RTI Pilot Scale Test Facility (VanOsdell et al., 1997) indicated that the collection efficiency was not as good for particle deposits that had been conditioned by exposure to high relative humidity. As a result, the sampler was modified to include a brush attachment to improve the collection efficiency. The collection efficiency with the brush was not quantified prior to the field study. Additional testing will be performed to obtain estimates of the collection efficiency of the sampler with the brush attachment. For the purposes of this study, which were to compare the amount of particulate and fibrous material on the duct surfaces before and after cleaning, quantitative estimates of method bias are not critical to interpretation of the data.

The NADCA method was used according to the procedures outlined in the NADCA Standard 1992-01 (NADCA, 1992). The bias of the method when used under field conditions was not determined in this study.

The bias of the integrated sampling method used to measure mass concentrations of PM<sub>2.5</sub> and PM<sub>10</sub> was not determined in this study due to resource limitations. The method has been accepted for use in the BASE program (U.S. EPA, 1994) and the EPA Large Building Studies Program (Fortmann et al., 1994). Because the data collected by the method was use for comparison of particle mass concentrations before and after HAC system cleaning, not for the purpose of exposure assessment, quantitative estimates of the method bias are not critical for the purposes of this study.

Bias of the method used to collect microbiological contaminants from surfaces of the HAC system can not be directly evaluated because there is not a standard reference duct surface material or a standard sampling method for comparison. Measurements in this study were used to compare concentrations on surfaces before and after HAC system cleaning. Assuming that the bias is relatively constant, data for this study can be used for comparative purpose. The data have not been used to estimate exposure or risk.

Bias of the bioaerosol measurements with the Mattson-Garvin sampler were not determined during this study. Such a determination was beyond the scope of this study. Jensen (1992) have shown that the Mattson-Garvin bioaerosol sampler used in this study measured concentrations approximately 10 to 13% below a reference sampler for two target organisms.

## 6.2 Method Performance

Method performance was documented by performing calibrations of continuous monitoring instrumentation prior to the field study and by quality control procedures implemented during the study. All Climet CI-4100 optical particle counters used in the study were sent to the manufacturer for calibration prior to the study. Calibration certificates are on file. There was no method available to check performance of the instruments during the field monitoring program. One of the two LAS-X Aerosol Spectrometers used in the study was sent to the manufacturer for routine maintenance and calibration prior to the study. The comparability of the other LAS-X used in the study was determined by collocating the instruments and collecting monitoring data for a 16-hour test period. The average percent difference in the readings between the two instruments during a 38 hour monitoring period were calculated as the average reading of the recently calibrated monitor minus the average of the other monitor, divided by the average reading of the recently calibrated monitor. The results were as follows:

| <u>Size Fraction</u> | <u>% Difference</u> | <u>Size Fraction</u> | <u>% Difference</u> |
|----------------------|---------------------|----------------------|---------------------|
| 0.1 - 0.12           | 63                  | 1.0 - 1.5            | 9                   |
| 0.12 - 0.15          | 5                   | 1.5 - 2.0            | -47                 |
| 0.15 - 0.20          | 25                  | 2.0 - 3.0            | 12                  |
| 0.20 - 0.25          | 1                   | 3.0 - 4.5            | -26                 |
| 0.25 - 0.35          | 110                 | 4.5 - 6.0            | -35                 |
| 0.35 - 0.45          | -6                  | 6.0 - 7.5            | -46                 |
| 0.45 - 0.60          | 21                  | > 7.5                | -59                 |
| 0.60 - 0.75          | -54                 |                      |                     |
| 0.75 - 1.0           | 25                  |                      |                     |

With the exception of the 0.1-0.12, 0.25-0.35, 0.60-0.75, and >7.5  $\mu\text{m}$  channels, the instruments were in good agreement. Because the instrument was used primarily for comparison of pre-cleaning and post-cleaning concentrations, the performance was considered acceptable. The instrument should be re-calibrated prior to use in other studies. Temperature, relative humidity, carbon dioxide, and pressure sensors in the IAQDS' were calibrated prior to the study. At the time of set-up at each house, the reasonableness of carbon dioxide readings were assessed. Differential pressure readings with the IAQDS were compared to measurements with a calibrated Air Data ADM-860. Indoor and outdoor temperature readings with the IAQDS were compared to readings with an aspirated psychrometer.

Gravimetric measurements were performed at the controlled weighing facility located in the EPA Annex in Research Triangle Park, NC. The balances were certified by the EPA during the twelve months prior to use in this study. Weighings were performed according to standard operating procedures developed for the EPA/ORD Large Building Study (Acurex, 1994) and include daily QC check filters and calibrated class S weights.

### 6.3 Data Completeness

The goal for data completeness was collection of greater than 90% of the planned samples. The data completeness is summarized in Table 6-3. The completeness goal was met for all sample types collected by integrated or grab sampling methods.

The goal for completeness of data collection with the continuous monitors was also >90 %. Data completeness for continuous monitoring of particle concentrations with the Climet CI-4100 was greater than 90% at all houses except House 8 where much of the pre-cleaning data were lost due to a power failure at the house. Data were greater than 90% complete for measurements with the LAS-X at all houses except House 7, where the pre-cleaning data were lost due to a computer problem. Problems with the data logger for the MIE FAM-1 fiber monitor occurred frequently; less than 90% of the planned data were collected. Data collection for differential pressures, coolant temperatures, supply and return temperature and relative humidity, ambient temperature and relative humidity indoors and outdoors were > 90% complete at all but House 8, where the power failure occurred. Static pressure measurements were completed for 32 of the 36 planned measurement periods. Measurements of AHU blower motor current were completed for only 20 of the 36 planned measurement periods. Measurements of supply and return air flow rates were completed for all of the 36 planned measurement periods.

Table 6-3. Summary of Data Completeness

| Sample Type             | Samples Collected/Number Planned |                |                  |
|-------------------------|----------------------------------|----------------|------------------|
|                         | Field Samples                    | Duplicates     | Blanks           |
| Duct Dust - MVDS        | 121/81 <sup>a</sup>              | 28/18          | 0/0 <sup>b</sup> |
| Duct Dust - NADCA       | 12/10                            | 5/5            | 0/0 <sup>b</sup> |
| Duct Surface - Bacteria | 130/72 <sup>a</sup>              | - <sup>c</sup> | 8/8              |
| Duct Surface - Fungi    | 130/72 <sup>a</sup>              | - <sup>c</sup> | 8/8              |
| PM <sub>2.5</sub>       | 104/108                          | 2/2            | 3/3              |
| PM <sub>10</sub>        | 103/108                          | 2/2            | 3/3              |
| Bioaerosols             | 36/36                            | 0/0            | 12/12            |
| Fibers                  | 105/108                          | 2/2            | 6/6              |

<sup>a</sup> Number planned was minimum; actual number changed due to different types of ductwork and accessibility

<sup>b</sup> PM blanks and check filters served as weighing blanks for all gravimetric analyses

<sup>c</sup> Duplicates consisted of side-by-side samples collected with a swab method and a vacuum method, results of which were reported as field samples

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## **APPENDIX A**

# **INITIAL EVALUATION OF METHODS FOR SAMPLING DUST FROM HEATING, VENTILATING, AND AIR-CONDITIONING SYSTEM (DUCT) COMPONENTS**

## **INTERIM DATA SUMMARY REPORT**

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EPA Contract No. 68-D4-0005  
Work Assignment No. 1-042  
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## 1.0 INTRODUCTION

The cleaning of heating, ventilating, and air-conditioning (HVAC) systems, also referred to as air duct cleaning, involves the physical removal of particulate matter and debris from air distribution systems and air handler components. There is currently little published research data on the effectiveness of air duct cleaning or its impact on indoor air quality and energy use for residential heating and cooling systems. A research program has been initiated by the U.S. Environmental Protection Agency (EPA) National Risk Management Research Laboratory (NRMRL) Air Pollution Prevention and Control Division (APPCD) to evaluate the effectiveness of HVAC cleaning and its impact on indoor air quality (IAQ) in residential buildings.

To evaluate the effectiveness of ACS cleaning, measurements will be performed to determine the mass of particulate matter in ducts and on other components of the ACS prior to, and following, cleaning. The National Air Duct Cleaners Association (NADCA) has published a Vacuum Test Method for documenting the effectiveness of cleaning galvanized ducts (NADCA 1992-01, *Mechanical Cleaning of Non-Porous Air Conveyance System Components*), but the method was not developed to measure dust levels prior to cleaning. The method is also applicable only to non-porous duct materials. Other methods are required for determining the effectiveness of cleaning of other types of duct materials, including fiberglass insulated ducts, fiberboard, and insulated flexible ducts.

The objective of the testing described in this report was to develop a method for collection of dust (particulate and fibrous matter) from porous and non-porous surfaces. The method needed to be applicable for collection of high levels of dust prior to HVAC cleaning and for collection of low levels of residual dust on surfaces following HVAC cleaning. Acurex Environmental, in support of the EPA research program, has performed testing to evaluate methods that can be used to sample dust from surfaces of various non-porous and porous ducts that are used in residential systems. The NADCA vacuum method was evaluated to determine if it could be used for the proposed field study even though it had not been developed for collection of high levels of dust or for collection from porous surfaces. Because it was not applicable for the purposes of this research program, an alternative method was developed and evaluated. This is an interim report that summarizes the results of the laboratory testing of the methods. Additional evaluation of the methods was performed during testing in a pilot-scale residential-sized ventilation system.

## 2.0 DESCRIPTION OF THE METHODS EVALUATED

The three methods selected for testing are described below.

### 2.1 NADCA Standard Method 1992-01

The NADCA Standard Method 1992-01 is described in the document entitled, *Mechanical Cleaning of Non-Porous Air Conveyance System Components*. The hardware for the method consists of a vacuum pump operated at 10 L/min, a filter cassette, and a template for sampling. The 37-mm diameter plastic filter cassette is used as the nozzle. The area of the nozzle, therefore is 10.75 cm<sup>2</sup>; at a flow rate of 10 L/min, the velocity at the face of the nozzle during sampling would be 15.5 cm/s, which is relatively low. The method is based on sampling a 100 cm<sup>2</sup> area, as defined by a template, and gravimetric determination of the dust collected on either matched weight filters or tared filters. According to the method, the weight of debris collected by the NADCA Vacuum Test should not exceed 1.0 mg/100 cm<sup>2</sup> after cleaning of a non-porous duct.

### 2.2 Acurex/EPA Medium Volume Sampler

A medium volume vacuum method was developed for this project. The sampler consists of the following components:

- Thomas Model 2107CA20A dual diaphragm vacuum pump with nominal free air flow of 50 L/min,
- Gelman Model 2220 stainless steel 47 mm diameter in-line low pressure filter holder,
- Whatman EPM 2000, 47 mm, high-volume air sampling filters rated at 99.997% retention for 0.3 µm DOP, and
- Nozzle developed by Acurex Environmental - stainless steel, 30 mm X 3 mm inlet (0.9 cm<sup>2</sup> face area of nozzle).

The prototype nozzle used in the tests described in this report was designed to optimize collection efficiency by using a small inlet area, a small dead volume in the nozzle, and stainless steel to reduce deposition of particles to the nozzle due to electrostatic forces. At 20 L/min, the velocity through the nozzle under free flow conditions would be 370 cm/s. Data reported below are for the final prototype nozzle, unless indicated otherwise.

### 2.3 High Volume Sampler

The high volume vacuum sampler with a cyclone for sample collection is the High Volume Furniture Sampler manufactured by CS<sub>3</sub>, Inc.. The sampler has been used in a number of EPA

studies for collection of lead, polyaromatic hydrocarbons, pesticides, and other contaminants from carpets and textile furnishings.

The sampler consists of a Dirt Devil Can Vac with a theoretical flow rate of 20 cfm, a cyclone for particle collection, a collection jar, flow controller, magnehelic gauge, associated tubing, and nozzle. During evaluations with this system a number of nozzles were evaluated. For sampling dust from flexible duct, a round, nominal 3-inch diameter, nozzle with a brush was used.

### **3.0 TEST PROCEDURES**

Methods evaluations were performed by depositing known amounts of particulate matter on pieces of duct materials, then performing sampling with the test equipment to determine the collection efficiency. The dust used for all methods evaluations was from a single lot of dust that had been collected from air conveyance systems during cleaning by a local company. Because the source of the dust, and its composition, was unknown, it could potentially include spores of microbiological organisms. Therefore, the first step in preparation of the dust was to sterilize it by steam autoclaving to reduce the hazard associated with handling of the dust. The dust was then passed through a 42 mesh sieve (0.139 inch, 354  $\mu\text{m}$  diameter opening) to remove fibers and large particles.

The initial work performed for the methods evaluation was development of a method to obtain uniform deposition of dust on the surfaces. The first method consisted of deposition of the dust over a large test area using a small sieve. Dust was placed into the sieve which was gently tapped while moving it across a known area of the substrate. To assess the uniformity of deposition on the surface, tared paper coupons were placed at random locations on the surface. Following dust application, the coupons were weighed and the loading on the surface was determined by difference between the tared coupons and the coupons with dust deposited on them. With this method, it was difficult to obtain uniform dust deposition; the coefficient of variation for six coupons was generally 20 to 40%. To obtain a more accurate measurement of the amount of dust loaded on a given surface, a second method was employed. This involved weighing a known mass of dust, placing it in the sieve, and applying it to a 100  $\text{cm}^2$  area on the surface using the same template that was used for sampling. The template was left in place, then the same area was sampled.

It should be noted that particles were deposited on the test surfaces by tapping the sieve above the surface. No attempt was made after depositing the particles to embed them into the porous substrates. The particle deposit on the substrates should, therefore, represent deposits that would be most easily removed during HVAC cleaning.

A template was used to define the sampling area for dust collection with the NADCA method and the Acurex/EPA medium volume sampling method. The template, which is the one recommended for the NADCA Vacuum Test Method, consists of a 15 mil thick piece of plastic with two 2 cm X 25 cm channels for sampling. The template is depicted in the NADCA method.

The tests were performed on the following duct materials:

- Galvanized duct, standard rectangular duct material
- Coated duct liner, Owens-Corning Aeroflex Plus Edge Coated Duct Liner, Type 150
- Fiberboard, CertainTeed, Ultra\*Duct Fiber Glass Duct Board Systems, and
- Insulated flexible duct, Thermoflex, M-KC, 6-inch

All test substrates were purchased from local suppliers. Detailed specifications for the materials will be included in the final report.

The evaluations were performed to obtain data for the collection efficiency and precision of the methods. Selected methods were applied to the galvanized duct, coated duct liner, and the fiberboard to determine the applicability of the methods to the different surface materials. The tests were generally performed in triplicate. The NADCA method is not suitable for sampling from flexible duct and was not evaluated. The test matrix, showing the test methods and the materials tested is presented in Table 3-1.

Table 3-1 Test Matrix For Validation of Dust Sampling Methods in the Pilot Scale Tests

| Test Nos. | HVAC Component Materials | NADCA 1992-01 | EPA/Acurex Dust Sampler | High Volume Surface Sampler |
|-----------|--------------------------|---------------|-------------------------|-----------------------------|
| 1,4,7,11  | Galvanized duct          | X             | X                       | X                           |
| 2,5,8     | Coated duct liner        | X             | X                       | - <sup>a</sup>              |
| 3,6,9     | Fiberboard               | X             | X                       | - <sup>a</sup>              |
| 7,8,10    | Insulated flexible duct  |               | X                       | X                           |

<sup>a</sup>Initial tests were performed with the high volume sampler, but the amount of mass of duct liner coating fragments or fibers collected was too high for practical application of this method to the substrate

## 4.0 TEST RESULTS

The following sections describe the collection efficiency and precision of each method for the various duct materials.

### 4.1 NADCA Method

The NADCA method was evaluated at dust loadings of approximately 3 mg/100cm<sup>2</sup>, a level three times the value considered as acceptable for demonstrating cleaning effectiveness, and at levels of 7 to 34 mg/100 cm<sup>2</sup>. Results for the lowest loading, 3 mg/100 cm<sup>2</sup>, on galvanized duct are presented in Table 4-1. Collection efficiency averaged 47% for the three replicate samples. The precision of the method was good, however, with a coefficient of variation of 2%.

Results for the initial evaluation of the NADCA method at dust loadings on galvanized duct of approximately 7 to 17 mg/100cm<sup>2</sup> are summarized in Table 4-2. The collection efficiency for the NADCA method ranged from 60 to 120%, with an average collection efficiency of 92%. The collection efficiency of 60% may be an outlier resulting from non-uniform distribution of the test dust on the metal surface. The precision of the method was  $\pm 22\%$ , which was acceptable considering that some of the variability was associated with the non-uniformity of particle deposition on the surface due to the particle deposition method used to create the test substrate.

Additional tests on galvanized duct were conducted with higher particle loading on the test substrates. The higher deposition rates were closer to those expected to be used in the pilot scale ventilation system tests and encountered in residences to be included in the field study. Results for these tests are also presented in Table 4-2. At an average loading of 27 mg/100 cm<sup>2</sup> on galvanized duct, the collection efficiency was  $70 \pm 19\%$ . The coefficient of variation for dust collection was 27%. However, because the dust was not uniformly deposited on the surface (the coefficient of variation for the six coupons used to determine dust loading on the surface was 23%), most of the variation observed for the NADCA method is likely to be a function of the variation in the dust deposit. The collection efficiency of 70% would be considered acceptable as a field method, although, as described below, the alternative method developed by the EPA was considered more appropriate for the research program and the NADCA vacuum method ultimately was not used for pre-cleaning sample collection in the field study.

Table 4-1 Results for Initial Tests With The NADCA Method For Dust Sampling From Galvanized Duct Surfaces With Low Dust Loading

| Substrate         | Replicate | Loading<br>(mg/100 cm <sup>2</sup> ) | Dust Collected<br>(mg/100 cm <sup>2</sup> ) | Collection<br>Efficiency (%) |
|-------------------|-----------|--------------------------------------|---|------------------------------|
| <b>Galvanized</b> | 1         | 2.9                                  | 1.4   | 48.3                         |
|                   | 2         | 2.9                                  | 1.4   | 46.7                         |
|                   | 3         | 3.0                                  | 1.4   | 46.7                         |
| <b>Average</b>    |           |                                      |   | <b>47.2 ± 0.9</b>            |

Table 4-2 Results for Initial Tests With The NADCA Method For Dust Sampling From Galvanized Duct Surfaces With High Dust Loadings

| Substrate                                  | Replicate | Loading<br>(mg/100 cm <sup>2</sup> ) | Dust Collected<br>(mg/100 cm <sup>2</sup> ) | Collection<br>Efficiency (%) |
|--|-----------|--------------------------------------|---|------------------------------|
| <b>Galvanized -Medium<br/>dust loading</b> | 1         | 8.5 ± 3.1                            | 7.2   | 84.7                         |
|  | 2         | 8.5 ± 1.7                            | 8.2   | 96.5                         |
|  | 3         | 16.8 ± 5.6                           | 10.2  | 60.4                         |
|  | 4         | 8.5 ± 1.2                            | 8.5   | 100                          |
|  | 5         | 7.4 ± 2.8                            | 9.0   | 120                          |
| <b>Average - Medium<br/>Loading</b>        |           |                                      |   | <b>92.3 ± 21.9</b>           |
| <b>Galvanized - Heavy<br/>dust loading</b> | 1         | - <sup>a</sup>                       | 15.5  | 57                           |
|  | 2         | - <sup>a</sup>                       | 16.5  | 60                           |
|  | 3         | - <sup>a</sup>                       | 24.9  | 91                           |
| <b>Average - HeavyLoading</b>              |           | <b>27.2 ± 6.3</b>                    | <b>19.0 ± 5.2</b>                           | <b>69.6 ± 19.0</b>           |

#### 4.2 Acurex/EPA Medium Volume Sampling Method

Results for tests with the Medium Volume Sampling Method operated at an air flow rate of 20 L/min are presented in Table 4-3 for galvanized duct, duct liner, and fiberboard substrates. Collection efficiency was high for the galvanized duct material, averaging 94% for the three replicates. The precision of the sampling method was excellent, with a coefficient of variation of only 3.3%. The method was not as effective for collection of dust from coated duct liner or fiberboard. The recovery efficiency for dust from coated duct liner was 72% if the estimated mass of background debris was subtracted. The mass of background debris, which may consist of fragments of the duct liner coating, fibers, or dust already on the surface of the liner as received from the manufacturer, was estimated by sampling a 100 cm<sup>2</sup> area on the surface of the test substrate on which dust was not deposited. The precision of the method for duct liner was good, with a coefficient of variation of 7%. Only an average of 63% of the applied dust could be recovered from fiberboard with the medium volume sampling method if the estimated mass of background debris was subtracted. As shown in the table, the mass of background material collected, which consisted primarily of fibers, was high, representing nearly a third of the total mass collected. The mass of dust recovered was consistent with visual observations of the areas sampled, on which dust could still be observed after cleaning.

A second series of tests was conducted with the medium volume sampling method at an air flow rate of 40 L/min. These tests were performed in an attempt to improve collection efficiency from the porous materials. Tests were also performed using a small nozzle fitted with a brush to collect dust from flexible ducting.

Results of the tests performed with an air flow rate of 40 L/min are presented in Table 4-4.

As shown in the table, the collection efficiency of the medium volume sampling method was higher at 40 L/min than at 20 L/min for all three test surfaces. For the galvanized duct surface there was not a substantial difference. Collection efficiency was greater than 90% both at 20 L/min and 40 L/min. However, for the other two test surfaces, the higher air flow rate resulted in a substantial improvement in the collection efficiency. For coated duct liner, the collection efficiency for the dust was 86% with at 40 L/min compared to 72% at 20 L/min. For the fiberboard, the collection efficiency was 76% at 40 L/min versus 63% at 20 L/min. For all three surfaces, the precision of the method was excellent, with coefficients of variation of less than 10 %.

As described in the following section, the high volume sampler had excellent collection efficiency for dust in flexible duct. However, the medium volume system with a small nozzle would be attractive for use in field studies due to its smaller size and lighter weight. A small nozzle would also facilitate easier access to flexible duct. Therefore, the medium volume sampler was evaluated with a small nozzle fitted with a brush. The method was found to work well, with an average collection efficiency of 97% and coefficient of variation of 3%, as shown in Table 4-5.

Table 4-3 Results for the Acurex/EPA Medium Volume Sampling Method Operated at 20 L/min for Dust Sampling From Duct Surfaces

| Substrate         | Test No.                   | Rep. | Loading (mg/100 cm <sup>2</sup> ) | Total Mass Collected <sup>a</sup> (mg/100 cm <sup>2</sup> ) | Background Mass Collected <sup>b</sup> (mg/100 cm <sup>2</sup> ) | Total Mass Recovery (%) | Dust Collection Efficiency <sup>c</sup> (%) | CV (%) <sup>d</sup> |
|-------------------|----------------------------|------|-----------------------------------|---|--|-------------------------|---|---------------------|
| <b>Galvanized</b> | 4                          | a    | 30.0                              | 28.2  | - <sup>e</sup>   | 94                      | 94  |                     |
|                   | 4                          | b    | 30.1                              | 27.2  | - <sup>e</sup>   | 90                      | 90  |                     |
|                   | 4                          | c    | 29.7                              | 28.7  | - <sup>e</sup>   | 97                      | 97  |                     |
|                   | <b>Average<sup>f</sup></b> | 4    |                                   | 29.9 ± 0.2  |  | 93.7 ± 3.1              | 93.7 ± 3.1                                  | 3.3                 |
| <b>Duct Liner</b> | 5                          | a    | 32.2                              | 25.1  | 0.1  | 78                      | 78  |                     |
|                   | 5                          | b    | 20.0                              | 20.3  | 1.0  | 71                      | 68  |                     |
|                   | 5                          | c    | 31.6                              | 22.4  | 0.3  | 72                      | 71  |                     |
|                   | <b>Average<sup>f</sup></b> | 5    |                                   | 31.3 ± 1.1  |  | 80.3 ± 2.1              | 72.1 ± 5.3                                  | 7.4                 |
| <b>Fiberboard</b> | 6                          | a    | 31.9                              | 20.0  | 6.7  | 84                      | 63  |                     |
|                   | 6                          | b    | 30.9                              | 22.1  | 6.9  | 94                      | 72  |                     |
|                   | 6                          | c    | 29.3                              | 15.7  | 5.7  | 73                      | 54  |                     |
|                   | <b>Average<sup>f</sup></b> | 6    |                                   | 30.7 ± 1.3  |  | 83.5 ± 10.4             | 62.6 ± 9.0                                  | 14.4                |

<sup>a</sup> Total mass collected may consist of dust deposited plus fiber, duct liner materials, or other debris on the surface of the substrate

<sup>b</sup> Mass collected from the substrate prior to deposition of the test dust

<sup>c</sup> % Recovery of dust loaded on surface (estimated mass of background debris subtracted from the total mass collected)

<sup>d</sup> % Coefficient of variation

<sup>e</sup> Background sample not collected

<sup>f</sup> Average for three replicate

Table 4-4 Results for the Acurex/EPA Medium Volume Sampling Method Operated at 40 L/min for Dust Sampling From Duct Surfaces

| Substrate         | Test No.                   | Rep. | Loading (mg/100 cm <sup>2</sup> ) | Total Mass Collected <sup>a</sup> (mg/100 cm <sup>2</sup> ) | Background Mass Collected <sup>b</sup> (mg/100 cm <sup>2</sup> ) | Total Mass Recovery (%) | Dust Collection Efficiency <sup>c</sup> (%) | CV (%) <sup>d</sup> |
|-------------------|----------------------------|------|-----------------------------------|---|--|-------------------------|---|---------------------|
| <b>Galvanized</b> | 7                          | a    | 30.0                              | 29.0  | 0  | 97                      | 97  |                     |
|                   | 7                          | b    | 30.8                              | 29.7  | 0  | 96                      | 96  |                     |
|                   | 7                          | c    | 30.9                              | 30.8  | 0  | 100                     | 100   |                     |
|                   | <b>Average<sup>e</sup></b> | 7    |                                   |   |  | 97.6 ± 1.8              | 97.6 ± 1.8                                  | 1.9                 |
| <b>Duct Liner</b> | 8                          | a    | 30.1                              | 28.0  | 1.9  | 93                      | 87  |                     |
|                   | 8                          | b    | 30.1                              | 28.5  | 1.5  | 95                      | 90  |                     |
|                   | 8                          | c    | 30.2                              | 26.0  | 1.7  | 86                      | 80  |                     |
|                   | <b>Average<sup>e</sup></b> | 8    |                                   |   |  | 91.3 ± 4.7              | 85.6 ± 4.7                                  | 5.5                 |
| <b>Fiberboard</b> | 9                          | a    | 30.0                              | 30.0  | 7.0  | 100                     | 77  |                     |
|                   | 9                          | b    | 30.0                              | 30.0  | 8.2  | 100                     | 69  |                     |
|                   | 9                          | c    | 30.0                              | 37.7  | 13.0   | 126                     | 82  |                     |
|                   | <b>Average<sup>e</sup></b> | 9    | 30.7 ± 1.3                        |   |  | 109 ± 15                | 76.1 ± 6.5                                  | 8.6                 |

<sup>a</sup> Total mass collected may consist of dust deposited plus fiber, duct liner materials, or other debris on the surface of the substrate

<sup>b</sup> Mass collected from the substrate prior to deposition of the test dust

<sup>c</sup> Recovery (%) of dust loaded on surface (estimated mass of background debris subtracted from the total mass collected)

<sup>d</sup> Coefficient of variation (%)

<sup>e</sup> Average for three replicate

Table 4-5 Results for Tests With The Medium Volume Method For Dust Sampling From Flexible Duct Surfaces

| Substrate            | Replicate | Loading<br>(mg/100 cm <sup>2</sup> ) | Dust Collected<br>(mg/100 cm <sup>2</sup> ) | Collection<br>Efficiency (%) |
|----------------------|-----------|--------------------------------------|---|------------------------------|
| <b>Flexible Duct</b> | 1         | 30.2                                 | 30.1  | 100                          |
|                      | 2         | 30.1                                 | 28.3  | 94                           |
|                      | 3         | 30.7                                 | 30.2  | 98                           |
| <b>Average</b>       |           |                                      |   | <b>97.4 ± 3.0</b>            |

#### 4.3 High Volume Sampling Method

Results for the high volume sampling method are presented in Table 4-6. The collection efficiency for dust deposited in flexible duct average 96% at a loading of 29 mg/100 cm<sup>2</sup> and 99% for a loading of 14.7 mg/100 cm<sup>2</sup>. For both tests, the precision was excellent.

The high volume sampling method was also evaluated for its applicability to galvanized duct, coated duct liner, and the fiberboard. The method was not suitable for any of the three substrates because of the high flow rate. With the galvanized duct material, the sampler drew dust from under the template, resulting in collection efficiencies of greater than 100%. For duct liner, the sampling method collected 4.3 mg/100 cm<sup>2</sup> of background material (dust, fibers, and coating fragments) from clean, unused duct liner. The sampler collected 18 mg/100 cm<sup>2</sup> of fibers from fiberboard that had no dust deposited on it. Because of the very high mass of background material collected, the sampler was considered unsuitable for these substrates.

## 5.0 SUMMARY AND RECOMMENDATIONS

The following observations were made during the laboratory testing:

- Collection efficiency for the NADCA method used to sample dust from galvanized duct was approximately 50% at a loading of 3 mg/100 cm<sup>2</sup>. At loadings of approximately 8 mg/100 cm<sup>2</sup>, the collection efficiency was good, with acceptable precision. At loadings of approximately 27 mg/100 cm<sup>2</sup>, the collection efficiency was 70% and the coefficient of variation was 27%. Visual observations indicated that some particulate matter is lost from the sampler as it is removed from the template when sampling from surfaces with high dust loading. Therefore, although the sampling method has acceptable collection efficiency and precision, an alternative method is recommended for the proposed research studies to evaluate cleaning of air conveyance systems.

Table 4-6 Results for High Volume Method For Dust Sampling From Duct Surfaces

| Substrate            | Test No.                   | Rep. | Loading (mg/100 cm <sup>2</sup> ) | Dust Collected (mg/100 cm <sup>2</sup> ) | Dust Collection Efficiency (%) | CV (%) <sup>a</sup> |
|----------------------|----------------------------|------|-----------------------------------|--|--------------------------------|---------------------|
| <b>Flexible Duct</b> | 7                          | a    | 29.3                              | 28.9                                     | 99                             |                     |
|                      | 7                          | b    | 30.0                              | 27.5                                     | 92                             |                     |
|                      | 7                          | c    | 29.2                              | 28.3                                     | 97                             |                     |
|                      | <b>Average<sup>b</sup></b> | 7    | <b>29.5 ± 0.4</b>                 |  | <b>96 ± 3.6</b>                | <b>3.8</b>          |
| <b>Flexible Duct</b> | 8                          | a    | 14.7                              | 14.3                                     | 97                             |                     |
|                      | 8                          | b    | 14.7                              | 14.7                                     | 100                            |                     |
|                      | 8                          | c    | 14.8                              | 14.6                                     | 99                             |                     |
|                      | <b>Average<sup>b</sup></b> |      | <b>14.7 ± 0.02</b>                |  | <b>98.7 ± 1.5</b>              | <b>1.5</b>          |

<sup>a</sup> Coefficient of variation

<sup>b</sup> Average for three replicates

- The NADCA method will be suitable for verifying the effectiveness of cleaning of galvanized ducts, but it should not be used in this program to determine dust levels in ducts prior to cleaning or for use on porous surfaces because the method was not developed for those applications.
- The Acurex/EPA medium volume sampling method, operated at 20 L/min with a specially designed nozzle, had a collection efficiency of 94% for galvanized duct loaded with 30 mg/100 cm<sup>2</sup> of dust. Collection efficiencies were 72% and 63%, respectively, for coated duct liner and fiberboard if the estimated mass of background debris was subtracted. When operated at 40 L/min, the collection efficiencies were substantially improved and are acceptable for use in the planned testing. Collection of background material from the test substrates represents a problem for quantifying dust levels under field conditions. This problem needs to be further addressed in the pilot scale ventilation system tests.
- The medium volume dust sampler was evaluated in this study under laboratory conditions using freshly deposited particulate matter on porous and non-porous surfaces. Although the tests demonstrate that the method has potential application for sample collection under field conditions, additional testing should be performed

in ducts where dust deposits have accumulated over long time periods and have been subjected to environmental conditions that may cause the dust to adhere more strongly to the duct surfaces. Under field conditions it may be necessary to use a nozzle with a brush attachment to obtain high collection efficiencies.

- Both the medium volume and high volume sampling methods provided excellent collection efficiency for dust deposited in flexible duct.
- The high volume sampling method does not appear to be suitable for galvanized duct, coated duct liner, or fiberboard using the current sampling protocol.

## **APPENDIX B**

### **FLOOR PLANS, HAC DIAGRAMS, AND HAC EQUIPMENT LIST FOR THE STUDY HOMES**

#### **Note**

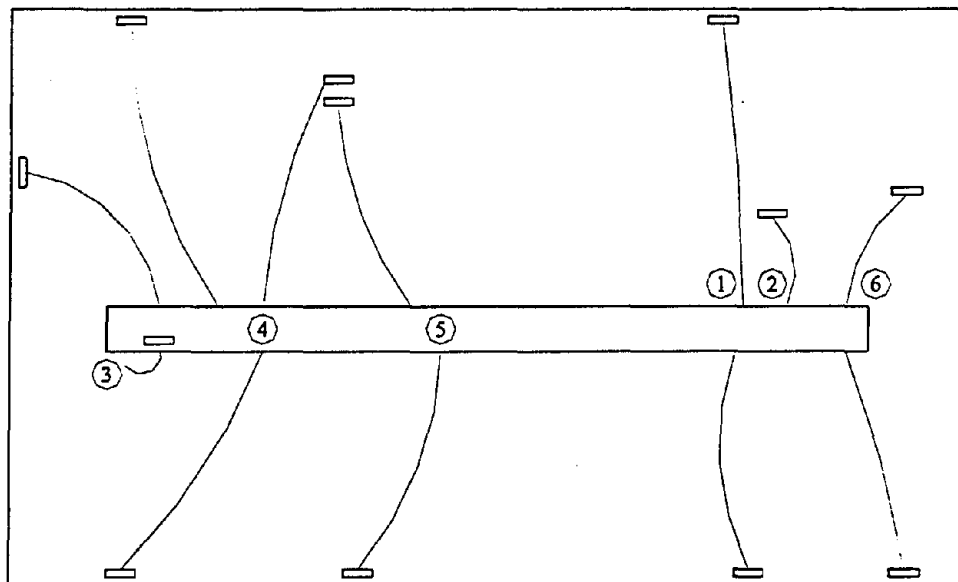
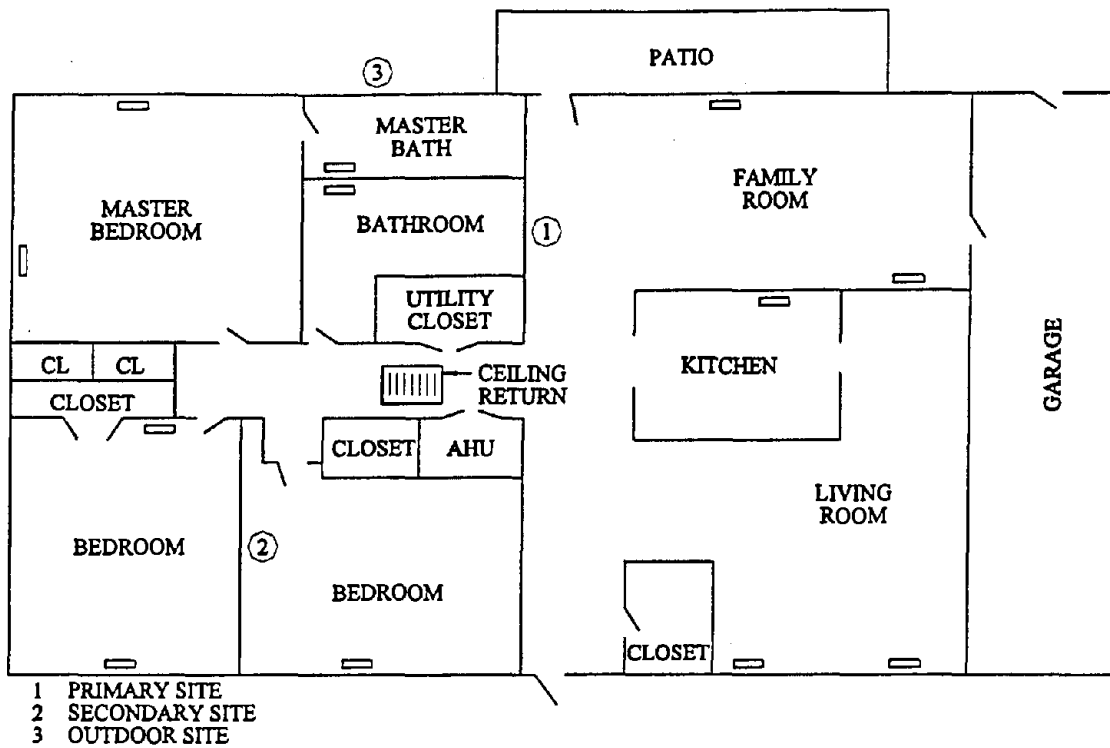
Floor plans are sketches and not drawn to exact scale.

Sampling locations are indicated on the floor plan as (1) the primary site and (2) the second location in the home.

The outdoor location was generally more than 10 meters away from the house.

Diagram of the duct layout is not to an exact scale.

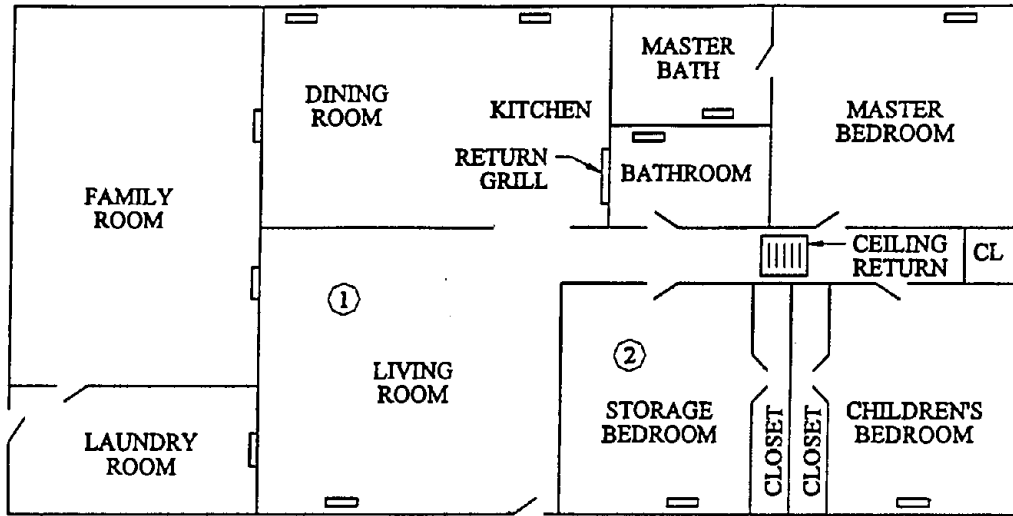
Numbers on HAC layout diagram indicate sampling locations in the ducts that are described below the diagram.



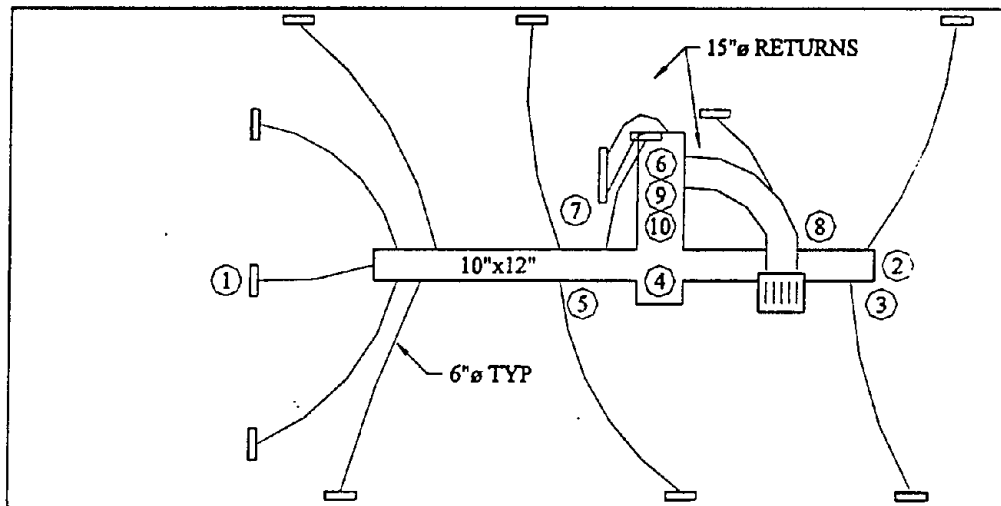
- 1 MAIN TRUNK - LEFT BACK SHORT OF FIRST FEEDER DUCT
- 2 MAIN TRUNK - LEFT BACK JUST PAST FIRST FEEDER DUCT
- 3 MAIN TRUNK - RIGHT FRONT NEAR THIRD FEEDER DUCT
- 4 MAIN TRUNK - RIGHT FRONT NEAR SECOND FEEDER DUCT
- 5 MAIN TRUNK - RIGHT FRONT NEAR PLENUM BOX
- 6 MAIN TRUNK - NEAR LEFT END CAP

Test house

③ |

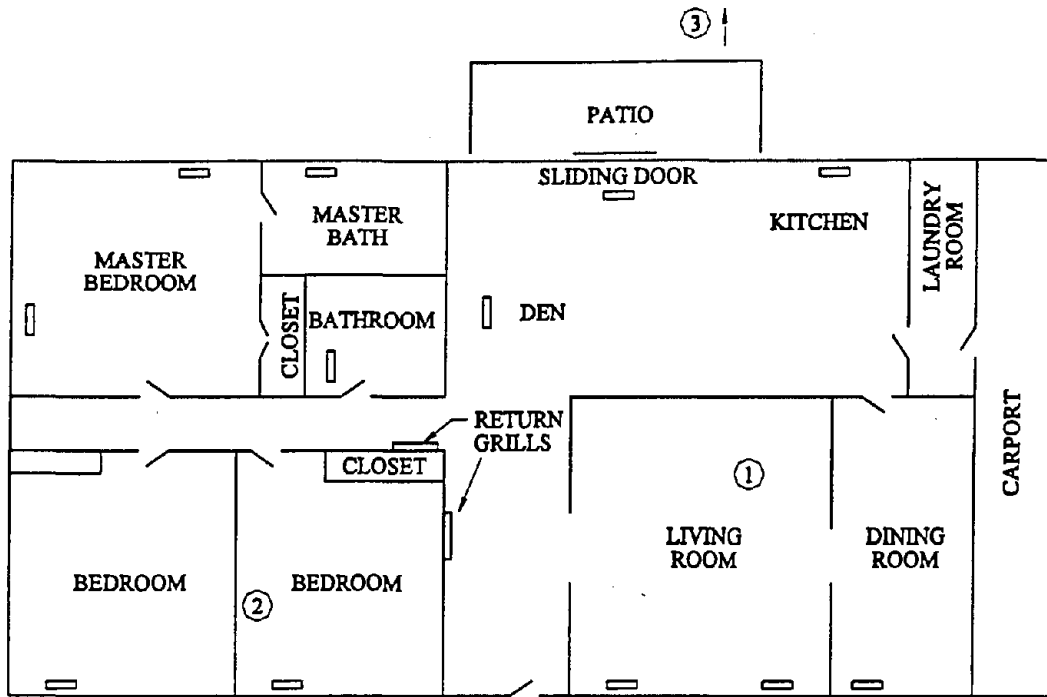


- 1 PRIMARY SAMPLING SITE
- 2 SECONDARY SAMPLING SITE
- 3 OUTDOOR SAMPLING SITE

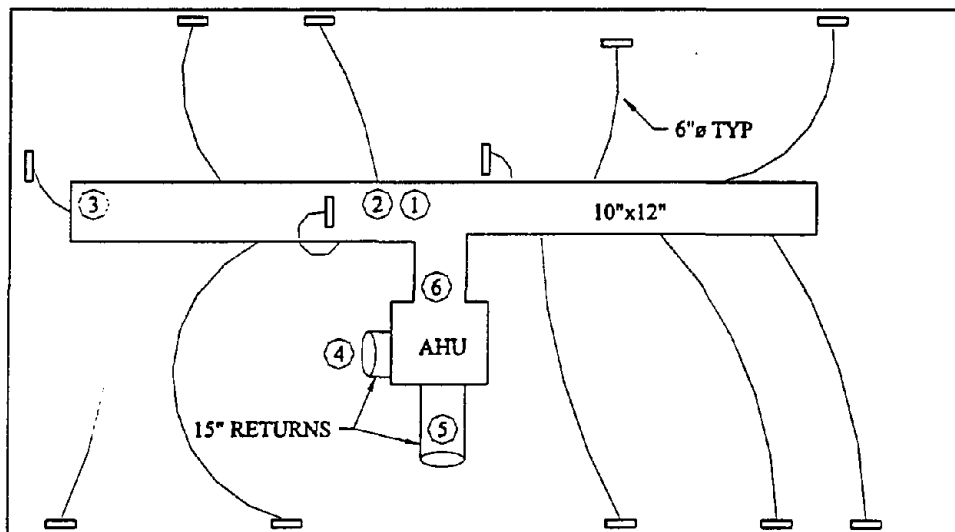


- 1 FAMILY ROOM SUPPLY (IN HOUSE BY GRILL)
- 2 MAIN TRUNK - RIGHT END CAP
- 3 FEEDER DUCT - TO CHILDREN'S BEDROOM
- 4 MAIN TRUNK - CENTER BY AHU
- 5 FEEDER DUCT - TO STORAGE BEDROOM
- 6 RETURN AT BLOWER
- 7 RETURN FROM KITCHEN (IN HOUSE BY GRILL)
- 8 RETURN FROM CEILING
- 9 AHU FOIL LINER (IN HOUSE BY GRILL)
- 10 COOLING COIL

House 1

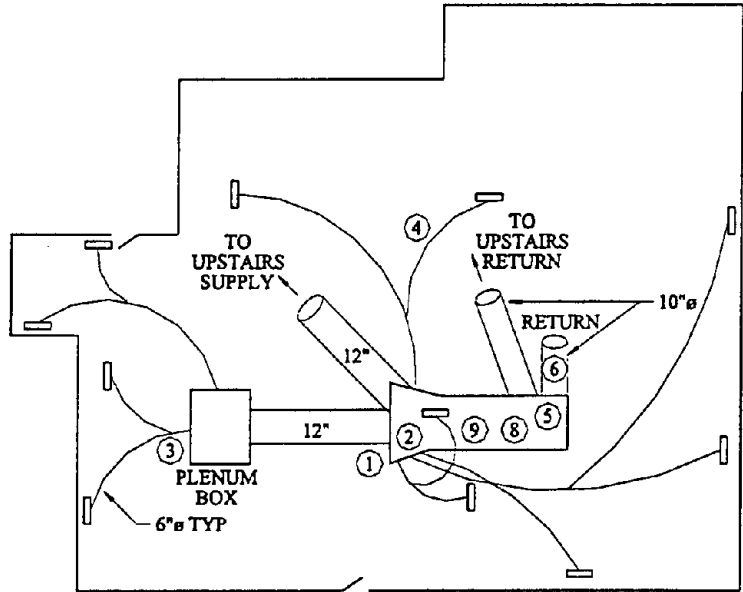
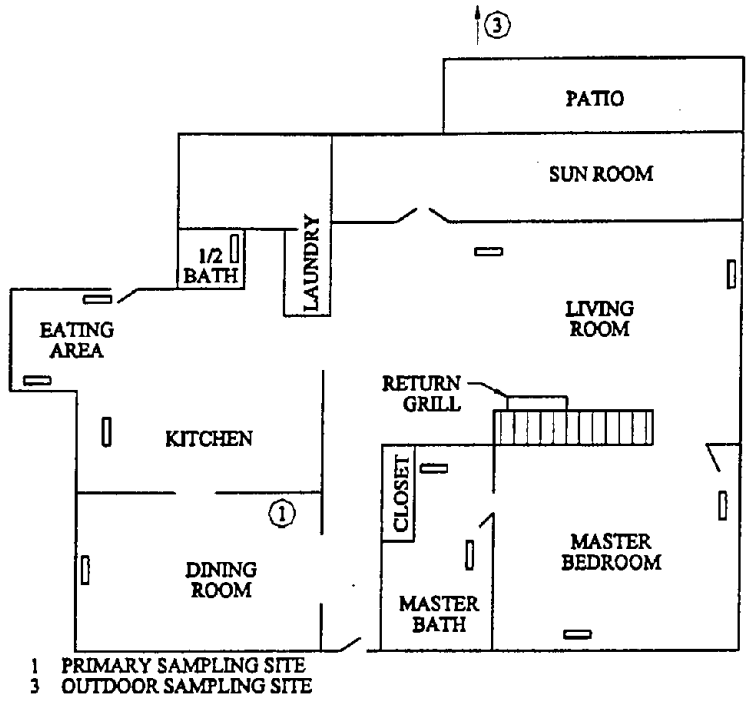


- 1 PRIMARY SAMPLING SITE
- 2 SECONDARY SAMPLING SITE
- 3 OUTDOOR SAMPLING SITE



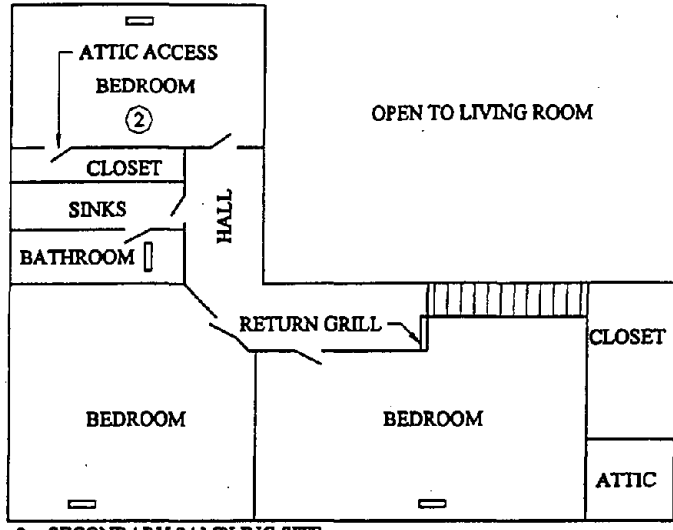
- 1 MAIN TRUNK - LEFT CENTER
- 2 MAIN TRUNK - RIGHT CENTER
- 3 MAIN TRUNK - NEAR LEFT END CAP
- 4 RETURN - AT GRILL IN HALL (INSIDE HOUSE)
- 5 RETURN - NEAR AHU
- 6 COOLING COIL

House 2

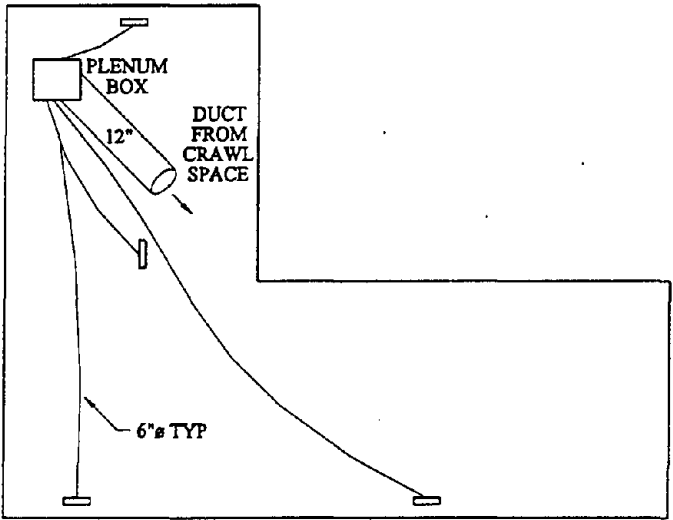


- 1 MAIN FLEXIBLE TRUNK
- 2 GALVANIZED PLENUM BOX
- 3 FLEX DUCT FROM DINING ROOM TO SECOND GALVANIZED PLENUM BOX
- 4 FLEX DUCT TO LIVING ROOM
- 5 FLEX DUCT AT PLENUM BOX
- 6 FLEX DUCT FROM LIVING ROOM
- 7 FLEX DUCT AT UPSTAIRS RETURN AIR GRILL
- 8 FOIL LINER
- 9 COOLING COIL

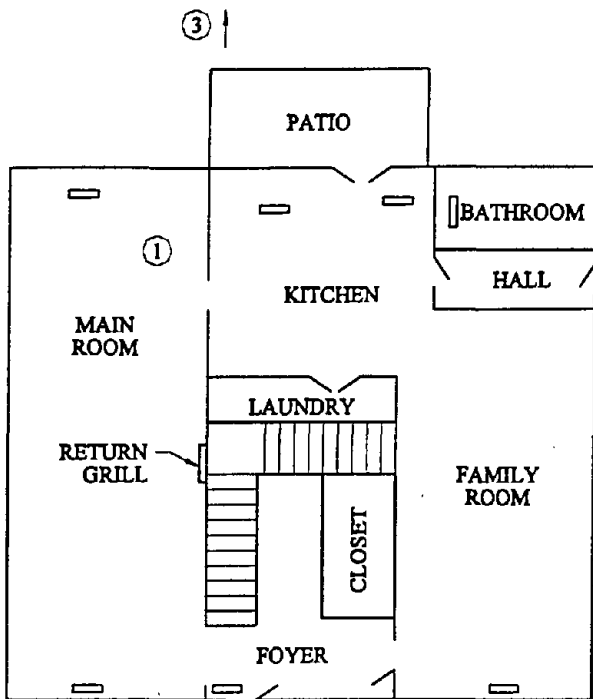
House 3 first floor



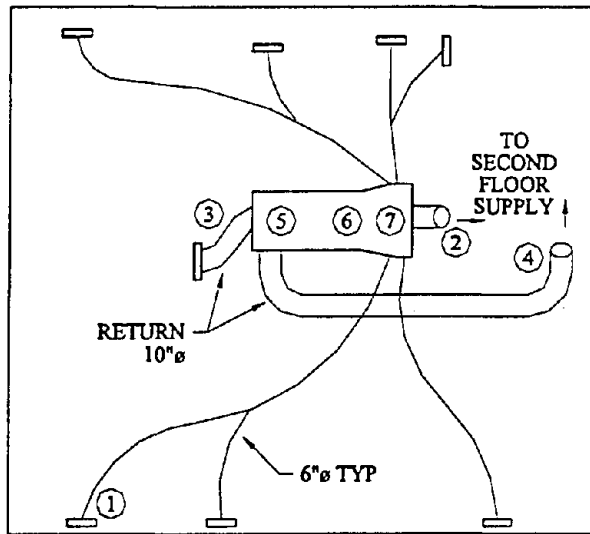
2 SECONDARY SAMPLING SITE



House 3 second floor

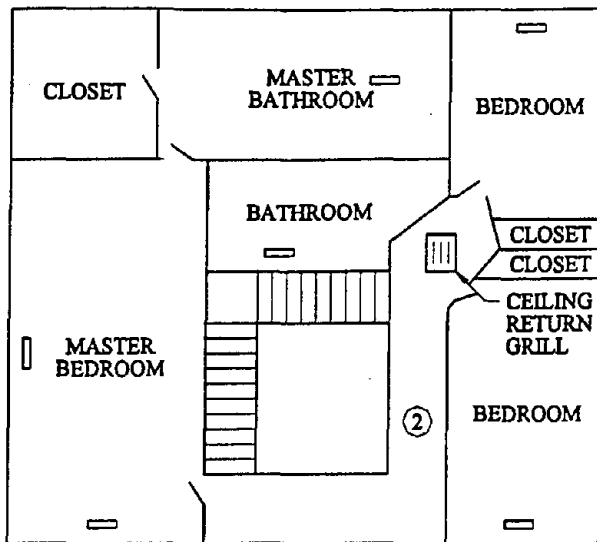


- 1 PRIMARY SAMPLING SITE
- 3 OUTDOOR SAMPLING SITE

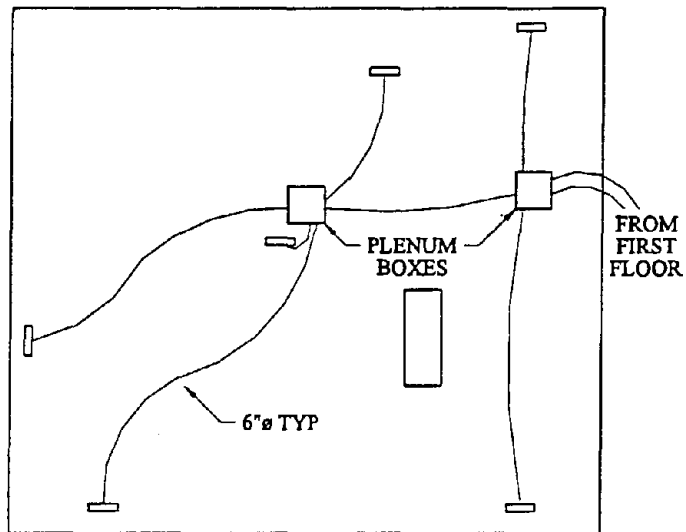


- 1 FLEX TO LIVING ROOM
- 2 FLEX TO SECOND FLOOR
- 3 FLEX FROM FIRST FLOOR
- 4 FLEX AT UPSTAIRS RETURN AIR GRILL
- 5 FOIL LINER
- 6 COOLING COIL
- 7 GALVANIZED PLENUM BOX DUCT LINER

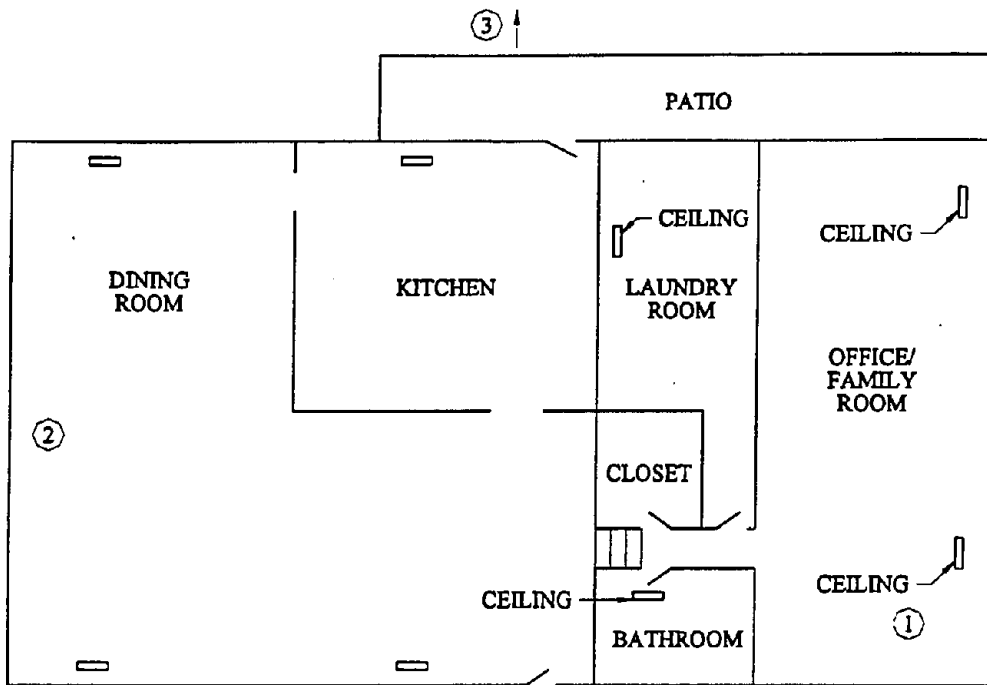
House 4, first floor



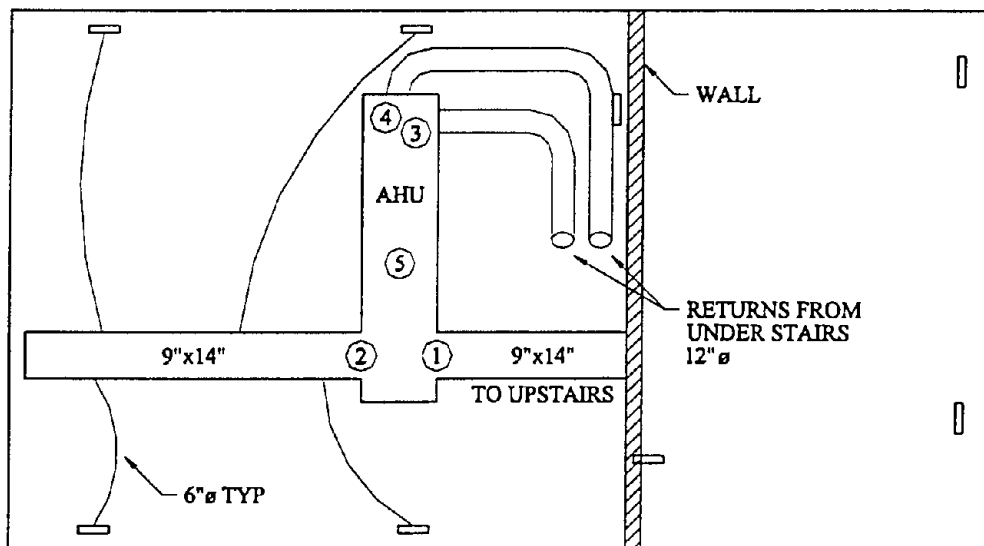
2 SECONDARY SAMPLING SITE



House 4, second floor

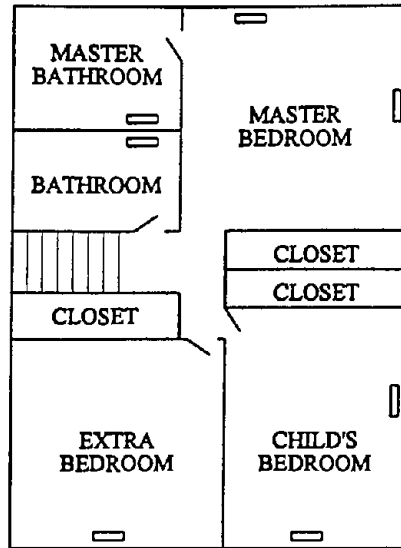


- 1 PRIMARY SAMPLING SITE
- 2 SECONDARY SAMPLING SITE
- 3 OUTDOOR SAMPLING SITE

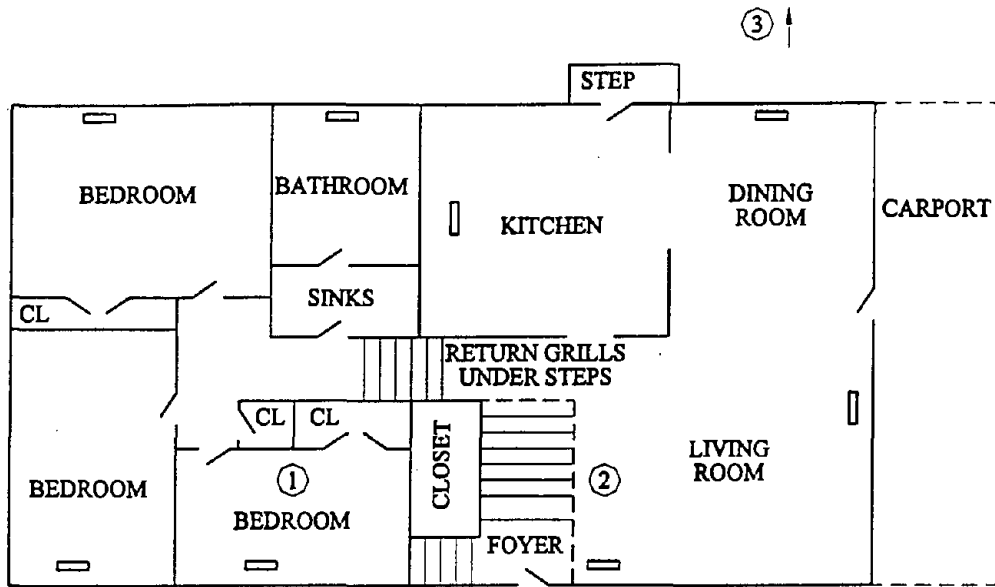


- 1 MAIN TRUNK - RIGHT SIDE
- 2 MAIN TRUNK - LEFT SIDE
- 3 GALVANIZED DUCT NEAR AH - RIGHT SIDE
- 4 GALVANIZED DUCT NEAR AHU - BACK SIDE
- 5 COOLING COIL

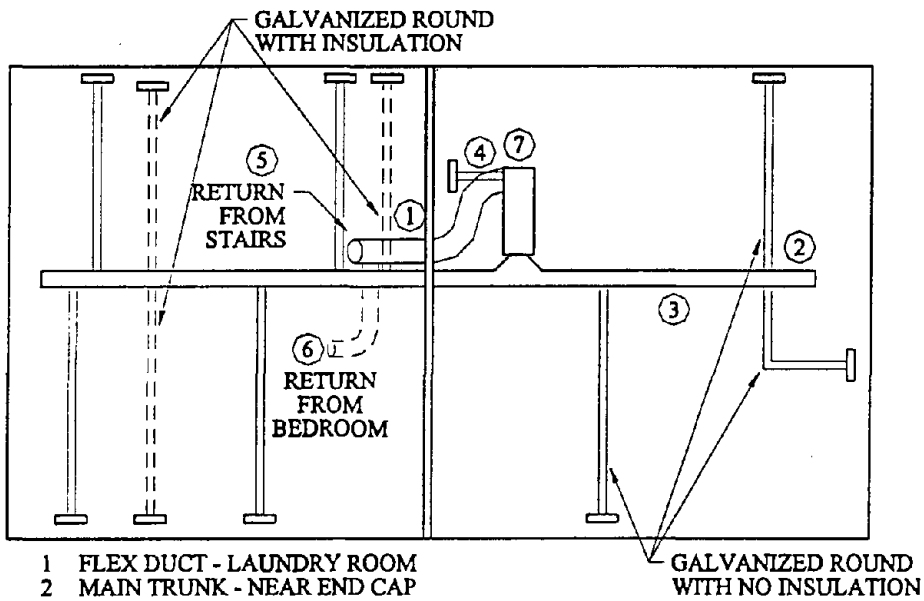
House 5, first floor



House 5, second floor

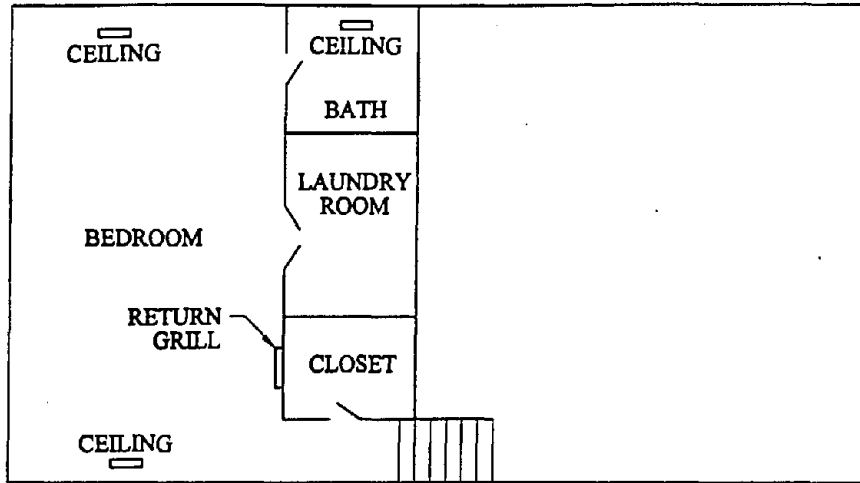


- 1 PRIMARY SAMPLING SITE
- 2 SECONDARY SAMPLING SITE
- 3 OUTDOOR SAMPLING SITE

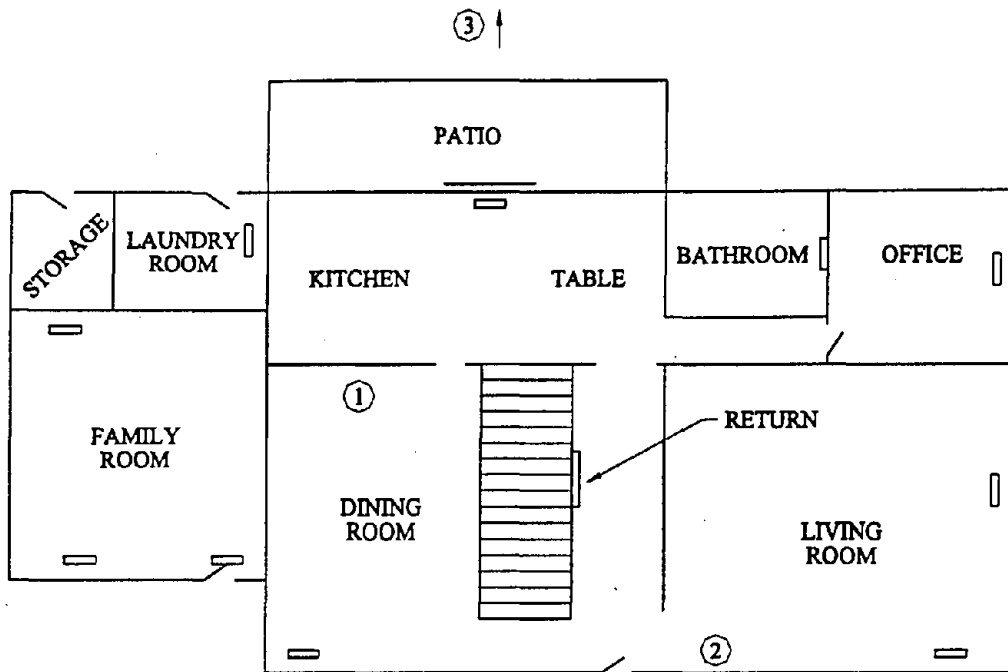


- 1 FLEX DUCT - LAUNDRY ROOM
  - 2 MAIN TRUNK - NEAR END CAP
  - 3 MAIN TRUNK - NEAR MIDDLE
  - 4 GALVANIZED DUCT UPSTREAM OF FILTER
  - 5 FLEX DUCT UNDER STAIRS
  - 6 AT BEDROOM RETURN GRILL
  - 7 GALVANIZED DUCT NEAR AHU
- == BASEMENT REGISTER FROM CEILING  
 --- SPLIT-LEVEL REGISTER FROM FLOOR

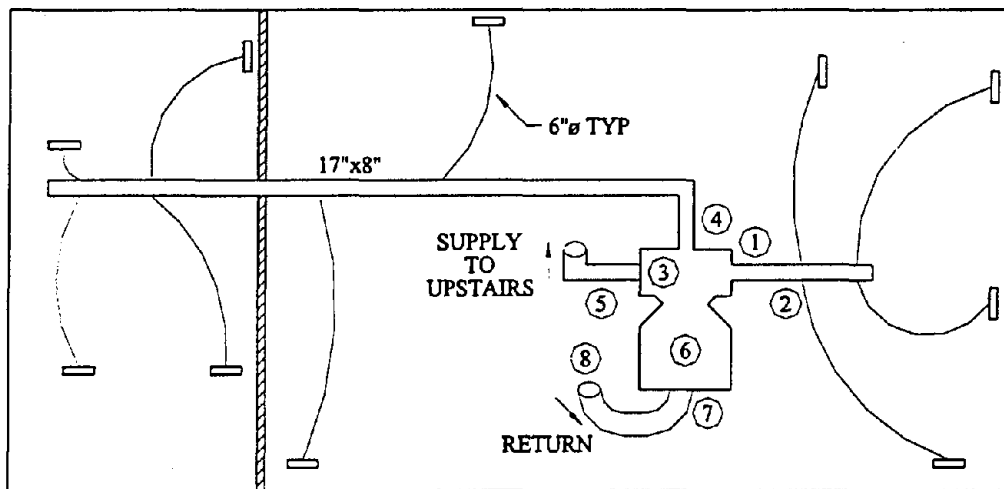
House 6



House 6, basement

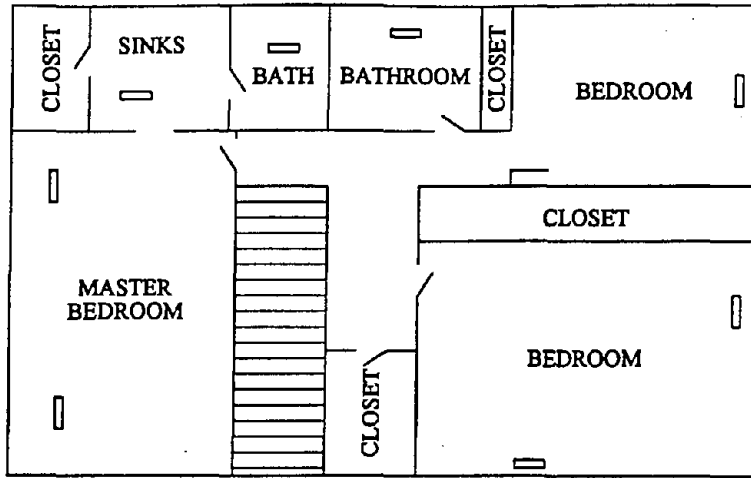


- 1 PRIMARY SAMPLING SITE
- 2 SECONDARY SAMPLING SITE
- 3 OUTDOOR SAMPLING SITE



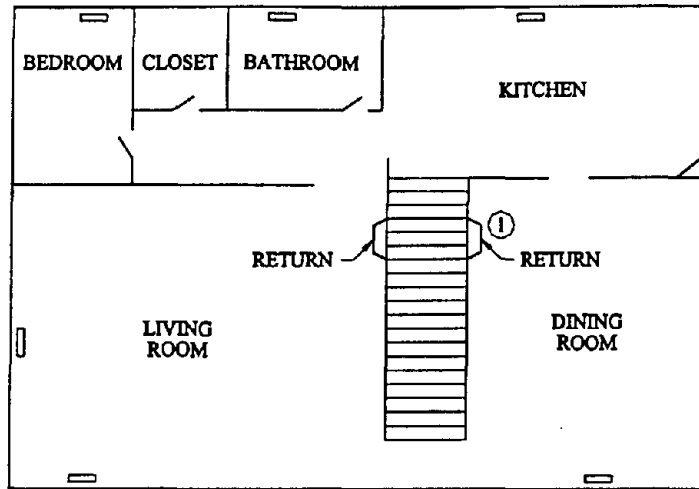
- 1 MAIN TRUNK - LEFT AT DISCONNECT
- 2 MAIN TRUNK - LEFT AT DISCONNECT NEAR FEEDER DUCT
- 3 PLENUM BOX - RIGHT SIDE
- 4 MAIN TRUNK - LEFT
- 5 MAIN TRUNK - TO UPSTAIRS
- 6 MAIN TRUNK - TRANSITION
- 7 GALVANIZED DUCT UPSTREAM OF AHU
- 8 GALVANIZED DUCT UPSTREAM OF RETURN AIR GRILL

House 7, first floor

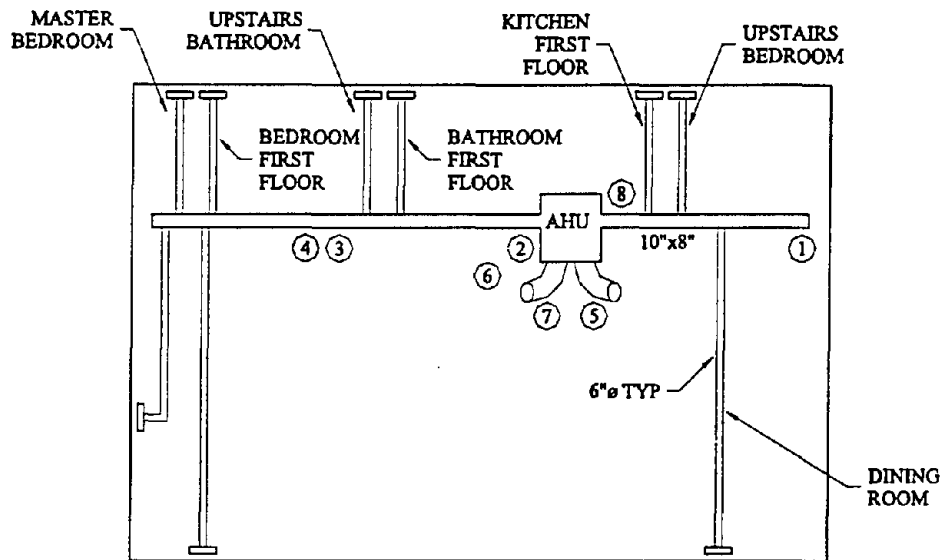


House 7, upstairs

③

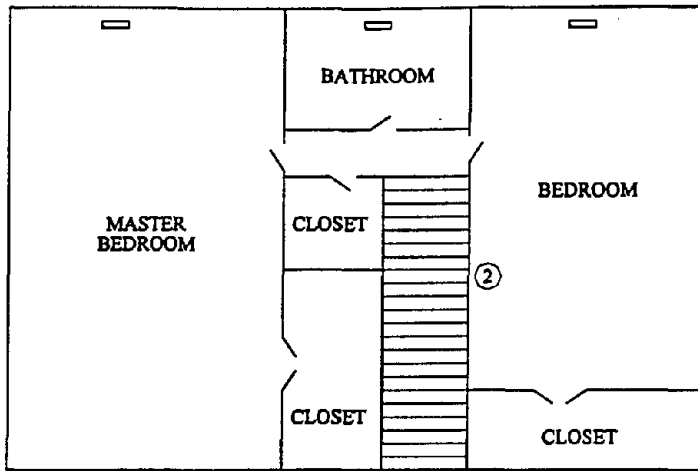


- 1 PRIMARY SAMPLING SITE
- 3 OUTDOOR SAMPLING SITE



- 1 MAIN TRUNK - NEAR END CAP
- 2 MAIN TRUNK - NEAR CENTER
- 3 MAIN TRUNK - RIGHT OF DISCONNECT
- 4 MAIN TRUNK - LEFT OF DISCONNECT
- 5 AT DINING ROOM RETURN GRILL
- 6 AT AHU
- 7 GALVANIZED DUCT - RIGHT BRANCH
- 8 COOLING COIL

House 8, first floor



2 SECONDARY SAMPLING SITE

House 8, second floor

| House # |         | Heating             |  | Cooling             |  | Compressor              |
|---------|---------|---------------------|--|---------------------|--|-------------------------|
| 1       | manf    | Inner City Products |  | Trane               |  | Cumberland              |
|         | model # | NHGK075AF01         |  | EAHB300             |  | OAU-252A                |
|         | type    | gas                 |  | vertical coil       |  |                         |
|         | power   | 75,000 BTU          |  |                     |  | 1/5 hp                  |
|         | year    |                     |  |                     |  |                         |
| 2       | manf    | Trane               |  | Trane               |  | Trane Heat Pump XE 1000 |
|         | model # |                     |  | TWHO24B140A1        |  | TWR024C100A1            |
|         | type    | electric            |  | A type coil         |  |                         |
|         | power   | 1/4 hp              |  | 1/4 hp              |  | 1/8 hp                  |
|         | year    | Feb-96              |  | Feb-96              |  | Aug-94                  |
| 3       | manf    | Trane               |  | (unaccessible)      |  | Trane                   |
|         | model # | BLH100E948H0        |  |                     |  | BTB736A100A4            |
|         | type    | Gas                 |  | vertical            |  |                         |
|         | power   | 100,000 BTU         |  |                     |  | R22 4lbs 6 oz, 1/4 hp   |
|         | year    | 1983                |  |                     |  | Jun-86                  |
| 4       | manf    | Trane               |  | (unaccessible)      |  | Trane                   |
|         | model # | THP100A948A0        |  |                     |  | BTB730A100B0            |
|         | type    | Gas                 |  | Vertical            |  |                         |
|         | power   | 100,000 BTU 1/3 hp  |  |                     |  | R22 3lbs 5 oz. 1/4 hp   |
|         | year    |                     |  |                     |  | Jul-86                  |
| 5       | manf    | (unaccessible)      |  | (unknown)           |  | Trane XL1200            |
|         | model # |                     |  |                     |  | TTX736A100A2            |
|         | type    | gas                 |  |                     |  |                         |
|         | power   |                     |  |                     |  | R22 8lbs 2 oz, 1/5 hp   |
|         | year    |                     |  |                     |  | Mar-89                  |
| 6       | manf    | Essex               |  | General Electric    |  | ARCO Aire               |
|         | model # | SX242NBRF           |  | 5KCP39KG5607S       |  | RCF030GBA               |
|         | type    | gas                 |  | A type coil         |  |                         |
|         | power   |                     |  | 1/3 hp              |  | R22 4lbs 6oz, 1/3 hp    |
|         | year    |                     |  |                     |  |                         |
| 7       | manf    | Magic Chef          |  |                     |  | Amana                   |
|         | model # | G8A125D-9           |  |                     |  | CR3-1                   |
|         | type    | gas                 |  | vertical            |  |                         |
|         | power   | 125,000 BTU         |  |                     |  | R22 24.7 oz             |
|         | year    | 1983                |  |                     |  |                         |
| 8       | manf    | Sears 600 series    |  | Sears               |  | Trane XE900             |
|         | model # | 743812              |  | 814381              |  | TTD730B100A1            |
|         | type    | oil                 |  | A type coil(add on) |  |                         |
|         | power   |                     |  |                     |  | R22 4lbs 5oz, 1/5 hp    |
|         | year    | Jan-53              |  |                     |  | Mar-89                  |

**APPENDIX C**

**RESULTS FOR SAMPLES OF DUST COLLECTED IN THE HAC  
AT NINE STUDY HOMES**

| Test House                                       |                        |                      |
|--|------------------------|----------------------|
| ACS Duct Dust Mass                               |                        |                      |
|  | <u>Pre Cleaning</u>    | <u>Post Cleaning</u> |
|  | <u>g/m<sup>2</sup></u> |                      |
| <b>Supply</b>                                    |                        |                      |
| Main Trunk-Left Back Short of First Feeder Duct  | 0.96                   | 0.47                 |
| Main Trunk-Left Back Just Past First Feeder Duct | 1.81                   | 0.58                 |
| Main Trunk-Right Front Near Third Feeder Duct    | 4.66                   | 1.24                 |
| Main Trunk-Right Front Near Second Feeder Duct   | 3.97                   | 0.78                 |
| Main Trunk-Right Front Near Plenum Box           | 1.80                   | 0.27                 |
| Main Trunk Near Left End Cap                     | 0.80                   | 1.09                 |
|  |                        |                      |
| <b>Avg:</b>                                      | 2.33                   | 0.74                 |
| <b>Standard Deviation</b>                        | 1.61                   | 0.37                 |
|  |                        |                      |
| <b>Duplicates</b>                                |                        |                      |
| Main Trunk Near Left End Cap                     | 1.09                   | 0.79 <sup>a</sup>    |
|  |                        |                      |
|  |                        |                      |
|  |                        |                      |
| a - Sampled with nozzle attachment               |                        |                      |

| House No. 1                       |                           |                      |
|-----------------------------------|---------------------------|----------------------|
| ACS Duct Dust Mass                |                           |                      |
|                                   | <u>Pre Cleaning</u>       | <u>Post Cleaning</u> |
|                                   | g/m <sup>2</sup>          |                      |
| <b>Supply</b>                     |                           |                      |
| Feeder Duct from Family Room      | 2.99                      | 0.25                 |
| Main Trunk Near Right End Cap     | 10.80                     | 0.24                 |
| Feeder Duct to Children's Bedroom | 2.50                      |                      |
| Main Trunk Near Air Handler       | 0.51                      | 0.41                 |
| Feeder Duct to Storage Bedroom    | 26.28                     |                      |
|                                   |                           |                      |
|                                   | <b>Avg:</b>               | 8.62                 |
|                                   | <b>Standard Deviation</b> | 10.62                |
|                                   |                           |                      |
|                                   |                           |                      |
| <b>Return</b>                     |                           |                      |
| At Air Handler                    | 20.17                     | 0.63                 |
| At Kitchen Return Grill           | 26.25                     |                      |
| At Ceiling Return Grill           | 13.07                     | 0.54                 |
|                                   |                           |                      |
|                                   | <b>Avg:</b>               | 19.83                |
|                                   | <b>Standard Deviation</b> | 6.60                 |
|                                   |                           |                      |
|                                   |                           |                      |
| <b>Air Handler</b>                |                           |                      |
| Foil Liner                        | 1.70                      |                      |
| Cooling Coil                      | 2.35                      | 0.29                 |
|                                   |                           |                      |
|                                   |                           |                      |
| <b>Duplicates</b>                 |                           |                      |
| Main Trunk Near Right End Cap     | 11.89                     | 0.25                 |
| Feeder Duct to Storage Bedroom    | 100.72                    |                      |

|                              |                     |                      |
|------------------------------|---------------------|----------------------|
| House No. 2                  |                     |                      |
| ACS Duct Dust Mass           |                     |                      |
|                              | <u>Pre Cleaning</u> | <u>Post Cleaning</u> |
|                              | $g/m^2$             |                      |
| <b>Supply</b>                |                     |                      |
| Main Trunk-Left Center       | 2.22                | 0.18                 |
| Main Trunk-Right Center      | 5.79                | 0.16                 |
| Main Trunk Near Left End Cap | 2.12                | 0.30                 |
|                              |                     |                      |
| <b>Avg:</b>                  | 3.38                | 0.21                 |
| <b>Standard Deviation</b>    | 2.09                | 0.08                 |
|                              |                     |                      |
| <b>Return</b>                |                     |                      |
| At Air Handler               | 7.50                | 0.28                 |
| At Return Grill in Hall      | 40.76               | 0.60                 |
|                              |                     |                      |
| <b>Avg:</b>                  | 24.13               | 0.44                 |
| <b>Standard Deviation</b>    | 23.52               | 0.23                 |
|                              |                     |                      |
| <b>Air Handler</b>           |                     |                      |
| Cooling Coil                 |                     | 0.20                 |
|                              |                     |                      |
| <b>Duplicates</b>            |                     |                      |
| Main Trunk-Left Center       | 2.73                | 0.16                 |

|  |                           |               |
|--|---------------------------|---------------|
| House No. 3  |                           |               |
| ACS Duct Dust Data   |                           |               |
|  | Pre Cleaning              | Post Cleaning |
|  | g/m <sup>2</sup>          |               |
| <b>Supply</b>  |                           |               |
| Main Flexible Trunk  | 3.00                      | 0.19          |
| Galvanized Plenum Box                                      | 2.35                      | 0.35          |
| Flex Duct from Dining Room to Second Galvanized Plenum Box | 1.74                      |               |
| Flex Duct to Living Room                                   | 0.54                      | 0.21          |
|  |                           |               |
|  | <b>Avg:</b>               |               |
|  | <b>Standard Deviation</b> |               |
|  | 1.91                      | 0.25          |
|  | 1.05                      | 0.09          |
| <b>Return</b>  |                           |               |
| Flex Duct at Plenum Box                                    | 7.50                      | 0.23          |
| Flex Duct from Living Room                                 | 13.15                     | 0.42          |
| Flex Duct at Upstairs Return Air Grill                     | 2.62                      | 0.19          |
|  |                           |               |
|  | <b>Avg:</b>               |               |
|  | <b>Standard Deviation</b> |               |
|  | 7.76                      | 0.28          |
|  | 5.27                      | 0.12          |
| <b>Air Handler</b>   |                           |               |
| Foil Liner   | 1.57                      | 0.19          |
| Cooling Coil   | 0.72                      |               |
|  |                           |               |
| <b>Duplicates</b>  |                           |               |
| Main Flexible Trunk  |                           | 0.26          |
| Flex Duct to Living Room                                   | 0.34                      |               |
| Flex Duct from Living Room                                 | 16.54                     | 0.37          |

| House No. 4                                |                  |               |
|--|------------------|---------------|
| ACS Duct Dust Data                         |                  |               |
|  | Pre Cleaning     | Post Cleaning |
|  | g/m <sup>2</sup> |               |
| <b>Supply</b>                              |                  |               |
| Flex Duct to Living Room                   | 1.69             | 0.19          |
| Flex Duct to Second Floor                  | 1.27             | 0.34          |
|  |                  |               |
| <b>Avg:</b>                                | 1.48             | 0.26          |
| <b>Standard Deviation</b>                  | 0.30             | 0.11          |
| <b>Return</b>                              |                  |               |
| Flex Duct from First Floor                 | 6.22             | 0.17          |
| Flex Duct at Upstairs Return Air Grill     | 9.55             | 0.06          |
|  |                  |               |
| <b>Avg:</b>                                | 7.89             | 0.11          |
| <b>Standard Deviation</b>                  | 2.35             | 0.08          |
| <b>Air Handler</b>                         |                  |               |
| Foil Liner                                 | 0.46             |               |
| Cooling Coil                               | 1.81             | 0.12          |
| <b>Duct Liner</b>                          |                  |               |
| Galvanized Plenum Box Duct Liner           | 1.62             | 0.10          |
| Galvanized Plenum Box Duct Liner Duplicate | 1.55             |               |
| <b>Duplicates</b>                          |                  |               |
| Flex Duct to Second Floor                  | 1.47             | 0.12          |
| Flex Duct from First Floor                 | 5.11             |               |

|   |                     |                      |
|---|---------------------|----------------------|
| House No. 5                                 |                     |                      |
| ACS Duct Dust Data                          |                     |                      |
|   | <u>Pre Cleaning</u> | <u>Post Cleaning</u> |
|   | g/m <sup>2</sup>    |                      |
| <b>Supply</b>                               |                     |                      |
| Main Trunk-Right Side                       | 2.62                | 0.32                 |
| Main Trunk-Left Side                        | 1.94                | 0.87                 |
|   |                     |                      |
| <b>Avg:</b>                                 | 2.28                | 0.59                 |
| <b>Standard Deviation</b>                   | 0.48                | 0.39                 |
|   |                     |                      |
| <b>Return</b>                               |                     |                      |
| Galvanized Duct Near Air Handler-Right Side | 11.49               | 1.97                 |
| Galvanized Duct Near Air Handler-Back Side  | 11.19               | 0.25                 |
|   |                     |                      |
| <b>Avg:</b>                                 | 11.34               | 1.11                 |
| <b>Standard Deviation</b>                   | 0.21                | 1.22                 |
|   |                     |                      |
| <b>Air Handler</b>                          |                     |                      |
| Cooling Coil                                | 2.24                | 0.13                 |
|   |                     |                      |
|   |                     |                      |
| <b>Duplicates</b>                           |                     |                      |
| Main Trunk-Right Side                       | 2.52                | 0.23                 |
| Galvanized Duct Near Air Handler-Right Side | 10.47               | 0.59                 |

|                                    |                     |                      |
|------------------------------------|---------------------|----------------------|
|                                    |                     |                      |
| House No. 6                        |                     |                      |
| ACS Duct Dust Data                 |                     |                      |
|                                    | <u>Pre Cleaning</u> | <u>Post Cleaning</u> |
|                                    | g/m <sup>2</sup>    |                      |
| <b>Supply</b>                      |                     |                      |
| Flex Duct in Laundry Room          | 2.45                |                      |
| Main Trunk Near End Cap            | 2.00                | 0.18                 |
| Main Trunk Near Middle             | 2.45                | 0.18                 |
|                                    |                     |                      |
| <b>Avg:</b>                        | 2.30                | 0.18                 |
| <b>Standard Deviation</b>          | 0.26                | 0.00                 |
|                                    |                     |                      |
| <b>Return</b>                      |                     |                      |
| Galvanized Duct Upstream of Filter | 3.62                | 0.19                 |
| Flex Duct Under Stairs             | 5.18                | 0.12                 |
| At Bedroom Return Grill            | 6.99                |                      |
| Galvanized Duct Near Air Handler   |                     | 0.13                 |
|                                    |                     |                      |
| <b>Avg:</b>                        | 5.26                | 0.15                 |
| <b>Standard Deviation</b>          | 1.69                | 0.04                 |
|                                    |                     |                      |
| <b>Duplicates</b>                  |                     |                      |
| Main Trunk Near End Cap            | 2.03                |                      |
| Main Trunk Near Middle             |                     | 0.23                 |
| Galvanized Duct Upstream of Filter | 6.52                |                      |

|  |                     |                      |
|--|---------------------|----------------------|
| House No. 7                                    |                     |                      |
| ACS Duct Dust Data                             |                     |                      |
|  | <u>Pre Cleaning</u> | <u>Post Cleaning</u> |
|  | g/m2                |                      |
| <b>Supply</b>                                  |                     |                      |
| Main Trunk Left at Disconnect                  | 5.93                |                      |
| Main Trunk Left at Disconnect Near Feeder Duct | 2.01                |                      |
| Plenum Box-Right Side                          | 4.22                | 0.44                 |
| Main Trunk Left                                | 2.24                | 0.69                 |
| Main Trunk to Upstairs                         | 1.24                |                      |
| Main Trunk Transition                          | 4.39                | 0.37                 |
|  |                     |                      |
| <b>Avg:</b>                                    | 3.34                | 0.50                 |
| <b>Standard Deviation</b>                      | 1.79                | 0.17                 |
|  |                     |                      |
| <b>Return</b>                                  |                     |                      |
| Galvanized Duct Upstream of Air Handler        | 9.03                | 0.30                 |
| Galvanized Duct at Upstairs Return Air Grill   | 16.78               | 0.34                 |
|  |                     |                      |
| <b>Avg:</b>                                    | 12.91               | 0.32                 |
| <b>Standard Deviation</b>                      | 5.48                | 0.03                 |
|  |                     |                      |
| <b>Air Handler</b>                             |                     |                      |
| Foil Liner                                     | 6.18                | 0.25                 |
| Cooling Coil                                   | 2.38                |                      |
|  |                     |                      |
| <b>Duplicates</b>                              |                     |                      |
| Plenum Box-Right Side                          | 5.07                | 0.80                 |
| Galvanized Duct Upstream of Air Handler        | 11.66               |                      |

|                                |                     |                      |
|--------------------------------|---------------------|----------------------|
| House No. 8                    |                     |                      |
| ACS Duct Dust Data             |                     |                      |
|                                | <u>Pre Cleaning</u> | <u>Post Cleaning</u> |
|                                | g/m2                |                      |
| <b>Supply</b>                  |                     |                      |
| Main Trunk Near End Cap        | 22.81               | 0.44                 |
| Main Trunk Near Center         | 16.39               |                      |
| Main Trunk-Right of Disconnect | 36.07               | 1.13                 |
| Main Trunk-Left of Disconnect  | 28.85               | 0.80                 |
|                                |                     |                      |
| <b>Avg:</b>                    | 26.03               | 0.79                 |
| <b>Standard Deviation</b>      | 8.41                | 0.35                 |
| <b>Return</b>                  |                     |                      |
| At Dining Room Return Grill    | 27.64               | 0.59                 |
| At Air Handler                 | 51.10               | 0.19                 |
| Galvanized Duct-Right Branch   | 26.59               |                      |
|                                |                     |                      |
| <b>Avg:</b>                    | 35.11               | 0.39                 |
| <b>Standard Deviation</b>      | 13.86               | 0.28                 |
| <b>Air Handler</b>             |                     |                      |
| Cooling Coil Upstream          | 5.48                |                      |
| Cooling Coil Downstream        | 0.41                |                      |
|                                |                     |                      |
| <b>Duplicates</b>              |                     |                      |
| Main Trunk-Right of Disconnect | 45.98               | 0.63                 |
| Main Trunk-Left of Disconnect  |                     | 0.65                 |
| At Air Handler                 |                     | 0.26                 |

**APPENDIX D**  
**RESULTS FOR MICROBIOLOGICAL SAMPLES COLLECTED**  
**AT THE NINE STUDY HOMES**

**Description of the Tables**

TSA cassettes and swabs were used for measurement of bacteria concentrations in dust collected from the surfaces of supply and return ducts.

The TSA cassette vacuum method samples and the TSA swab samples were co-located measurements at each location listed in the column "samp loc."

SDA cassettes and swabs were used for measurement of fungi concentrations in dust collected from the surfaces of supply and return ducts.

The SDA cassette vacuum method samples and the SDA swab samples were co-located measurements at each location listed in the column "samp loc."

The SDA-m/g samples listed in the table are the air samples collected for determination of fungi concentrations, reported as cfu/m<sup>3</sup>.

RAWFIELD.XLS Testhouse

|  |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
|--|--------|------------|---------------------|-----------|---------------------|-----------------------|-----------|--------|------------|-----------|-----------|---------------------|
| project: 5973-005  |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| sampling date: 5/27/96   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| description: preclean and postclean counts for sampling test house |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #  | counts | amt plated | total vol           | recip dil | cfu/cm <sup>2</sup> | samp loc              | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| SDA cassettes - preclean   |        |            |                     |           |                     | SDA swabs - preclean  |           |        |            |           |           |                     |
| M8646  | 49     | 0.1        | 5                   | 1000      | 245,000             | sup/fdr #1            | M8665     | 68     | 0.1        | 5         | 100       | 34,000              |
| M8647  | 76     | 0.1        | 5                   | 100       | 38,000              | sup/fdr #10           | M8666     | 147    | 0.1        | 5         | 10        | 7,350               |
| M8648  | 48     | 0.1        | 5                   | 100       | 24,000              | sup/fdr #4            | M8667     | 40     | 0.1        | 5         | 10        | 2,000               |
| M8649  | 26     | 0.1        | 5                   | 100       | 13,000              | sup/fdr #8            |           |        |            |           |           |                     |
| SDA cassettes - postclean  |        |            |                     |           |                     | SDA swabs - postclean |           |        |            |           |           |                     |
| M8650  | 113    | 0.1        | 5                   | 10        | 5,650               | sup/fdr #1            | M8668     | 108    | 0.1        | 5         | 10        | 5,400               |
| M8651  | 138    | 0.1        | 5                   | 10        | 6,900               | sup/fdr #4            | M8669     | 92     | 0.1        | 5         | 1         | 460                 |
| M8652  | 12     | 0.1        | 5                   | 100       | 6,000               | sup/fdr #10           | M8670     | 57     | 0.1        | 5         | 100       | 28,500              |
| M8653  | 161    | 0.1        | 5                   | 1         | 805                 | sup/fdr flx           |           |        |            |           |           |                     |
| rti/emp #  | counts | amt plated | total vol           | recip dil | cfu/cm <sup>2</sup> | samp loc              | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| TSA cassettes - preclean   |        |            |                     |           |                     | TSA swabs - preclean  |           |        |            |           |           |                     |
| M8646  | 20     | 0.1        | 5                   | 1         | 100                 | sup/fdr #1            | M8665     | 0.5    | 0.1        | 5         | 1         | 3                   |
| M8647  | TNTC   | 0.1        | 5                   | 1         | na                  | sup/fdr #10           | M8666     | 0.5    | 0.1        | 5         | 1         | 3                   |
| M8648  | 0.5    | 0.1        | 5                   | 1         | 3                   | sup/fdr #4            | M8667     | 0.5    | 0.1        | 5         | 1         | 3                   |
| M8649  | 0.5    | 0.1        | 5                   | 1         | 3                   | sup/fdr #8            |           |        |            |           |           |                     |
| TSA cassettes - postclean  |        |            |                     |           |                     | TSA swabs - postclean |           |        |            |           |           |                     |
| M8650  | 2      | 0.1        | 5                   | 10        | 100                 | sup/fdr #1            | M8668     | 29     | 0.1        | 5         | 1         | 145                 |
| M8651  | 30     | 0.1        | 5                   | 10        | 1500                | sup/fdr #4            | M8669     | 1      | 0.1        | 5         | 1         | 5                   |
| M8652  | TNTC   | 0.1        | 5                   | 1         | na                  | sup/fdr #10           | M8670     | 2      | 0.1        | 5         | 1         | 10                  |
| M8653  | 0.5    | 0.1        | 5                   | 1         | 3                   | sup/fdr flx           |           |        |            |           |           |                     |
| project: 5973-005  |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| sampling date: 5/27/96   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| description: preclean and postclean counts for sampling test house |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #  | counts | time (min) | m <sup>3</sup> /min | cfu       | cfu/m <sup>3</sup>  |                       |           |        |            |           |           |                     |
| SDA - m/g  |        | preclean   |                     |           |                     |                       |           |        |            |           |           |                     |
| M8660  | 195    | 60         | 0.028               | 3         | 116                 |                       |           |        |            |           |           |                     |
| M8661  | 186    | 60         | 0.028               | 3         | 111                 |                       |           |        |            |           |           |                     |
| M8662  | 668    | 60         | 0.028               | 11        | 398                 |                       |           |        |            |           |           |                     |
| SDA - m/g  |        | postclean  |                     |           |                     |                       |           |        |            |           |           |                     |
| M8697  | 360    | 60         | 0.028               | 6         | 214                 |                       |           |        |            |           |           |                     |
| M8698  | 131    | 60         | 0.028               | 2         | 78                  |                       |           |        |            |           |           |                     |
| M8699  | 183    | 60         | 0.028               | 3         | 109                 |                       |           |        |            |           |           |                     |

## House 1

|   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
|---|--------|------------|---------------------|-----------|---------------------|-----------------------|-----------|--------|------------|-----------|-----------|---------------------|
| project: 5973-005   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| sampling date: 6/10/96, 6/11/96, 6/13/96                        |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| description: preclean and postclean counts for sampling House 1 |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #   | counts | amt plated | total vol           | recip dil | cfu/cm <sup>2</sup> | samp loc              | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| SDA cassettes - preclean  |        |            |                     |           |                     | SDA swabs - preclean  |           |        |            |           |           |                     |
| M8707   | 50     | 0.1        | 5                   | 1000      | 250000              | sup/fdr #1            | M8732     | 141    | 0.1        | 5         | 10        | 7050                |
| M8708   | 229    | 0.1        | 5                   | 10        | 11450               | sup/trnk #2           | M8733     | 121    | 0.1        | 5         | 10        | 6050                |
| M8709   | 84     | 0.1        | 5                   | 10        | 4200                | sup/trnk #3           | M8734     | 59     | 0.1        | 5         | 10        | 2950                |
| M8710   | 37     | 0.1        | 5                   | 10        | 1850                | sup/trnk #4           | M8735     | 45     | 0.1        | 5         | 10        | 2250                |
| M8711   | 95     | 0.1        | 5                   | 10        | 4750                | return                | M8736     | 10     | 0.1        | 5         | 10        | 500                 |
|   |        |            |                     |           |                     | den diff              | M8742     | 38     | 0.1        | 5         | 1000      | 190000              |
| SDA cassettes - postclean                                       |        |            |                     |           |                     | SDA swabs - postclean |           |        |            |           |           |                     |
| M8712   | 22     | 0.1        | 5                   | 10        | 1100                | sup/fdr #1            | M8737     | 8      | 0.1        | 5         | 1         | 40                  |
| M8713   | 93     | 0.1        | 5                   | 10        | 4650                | sup/trnk #2           | M8738     | 34     | 0.1        | 5         | 10        | 1700                |
| M8714   | 23     | 0.1        | 5                   | 10        | 1150                | sup/trnk #3           | M8739     | 5      | 0.1        | 5         | 1         | 25                  |
| M8715   | 17     | 0.1        | 5                   | 10        | 850                 | sup/trnk #4           | M8740     | 6      | 0.1        | 5         | 1         | 30                  |
| rti/emp #   | counts | amt plated | total vol           | recip dil | cfu/cm <sup>2</sup> | samp loc              | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| TSA cassettes - preclean  |        |            |                     |           |                     | TSA swabs - preclean  |           |        |            |           |           |                     |
| M8707   | 3      | 0.1        | 5                   | 1         | 15                  | sup/fdr #1            | M8732     | 1      | 0.1        | 5         | 1         | 5                   |
| M8708   | 5      | 0.1        | 5                   | 1         | 25                  | sup/trnk #2           | M8733     | 1      | 0.1        | 5         | 1         | 5                   |
| M8709   | 23     | 0.1        | 5                   | 1         | 115                 | sup/trnk #3           | M8734     | 22     | 0.1        | 5         | 10        | 1100                |
| M8710   | 6      | 0.1        | 5                   | 1         | 30                  | sup/trnk #4           | M8735     | 6      | 0.1        | 5         | 1         | 30                  |
| M8711   | 7      | 0.1        | 5                   | 1         | 35                  | return                | M8736     | 0.5    | 0.1        | 5         | 1         | 3                   |
|   |        |            |                     |           |                     | den diff              | M8742     | 13     | 0.1        | 5         | 10        | 650                 |
| TSA cassettes - postclean                                       |        |            |                     |           |                     | TSA swabs - postclean |           |        |            |           |           |                     |
| M8712   | 151    | 0.1        | 5                   | 1         | 755                 | sup/fdr #1            | M8737     | 0.5    | 0.1        | 5         | 1         | 3                   |
| M8713   | 47     | 0.1        | 5                   | 1         | 235                 | sup/trnk #2           | M8738     | 15     | 0.1        | 5         | 10        | 750                 |
| M8714   | 21     | 0.1        | 5                   | 1         | 105                 | sup/trnk #3           | M8739     | 24     | 0.1        | 5         | 1         | 120                 |
| M8715   | 2      | 0.1        | 5                   | 1         | 10                  | sup/trnk #4           | M8740     | 26     | 0.1        | 5         | 1         | 130                 |
| project: 5973-005   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| sampling date: 6/10/96, 6/11/96, 6/13/96                        |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| description: preclean and postclean counts for sampling House 1 |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #   | counts | time (min) | m <sup>3</sup> /min | cfu       | cfu/m <sup>3</sup>  |                       |           |        |            |           |           |                     |
| SDA - m/g   |        | preclean   |                     |           |                     |                       |           |        |            |           |           |                     |
| M8703   | 246    | 60         | 0.028               | 4         | 146                 |                       |           |        |            |           |           |                     |
| M8704   | 276    | 60         | 0.028               | 5         | 164                 |                       |           |        |            |           |           |                     |
| M8705   | 214    | 60         | 0.028               | 4         | 127                 |                       |           |        |            |           |           |                     |
| SDA - m/g   |        | postclean  |                     |           |                     |                       |           |        |            |           |           |                     |
| M8757   | 190    | 60         | 0.028               | 3         | 113                 |                       |           |        |            |           |           |                     |
| M8758   | 149    | 60         | 0.028               | 2         | 89                  |                       |           |        |            |           |           |                     |
| M8759   | 156    | 60         | 0.028               | 3         | 93                  |                       |           |        |            |           |           |                     |

## House 2

|   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
|---|--------|------------|---------------------|-----------|---------------------|-----------------------|-----------|--------|------------|-----------|-----------|---------------------|
| project: 5973-005   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| sampling date: 6/11/96, 6/14/96                                 |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| description: preclean and postclean counts for sampling House 2 |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #   | counts | amt plated | total vol           | recip dil | cfu/cm <sup>2</sup> | samp loc              | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| SDA cassettes - preclean  |        |            |                     |           |                     | SDA swabs - preclean  |           |        |            |           |           |                     |
| M8717   | 64     | 0.1        | 5                   | 1         | 320                 | return #1             | M8743     | 47     | 0.1        | 5         | 1         | 235                 |
| M8718   | 24     | 0.1        | 5                   | 10        | 1200                | sup/trnk #2           | M8744     | 136    | 0.1        | 5         | 10        | 6800                |
| M8719   | 176    | 0.1        | 5                   | 10        | 8800                | sup/trnk #3           | M8745     | 279    | 0.1        | 5         | 10        | 13950               |
| M8720   | 382    | 0.1        | 5                   | 10        | 19100               | sup/trnk #4           | M8746     | 110    | 0.1        | 5         | 10        | 5500                |
| SDA cassettes - postclean                                       |        |            |                     |           |                     | SDA swabs - postclean |           |        |            |           |           |                     |
| M8721   | 9      | 0.1        | 5                   | 1         | 45                  | return #1             | M8747     | 52     | 0.1        | 5         | 1         | 260                 |
| M8722   | 2      | 0.1        | 5                   | 1         | 10                  | sup/trnk #2           | M8748     | 18     | 0.1        | 5         | 1         | 90                  |
| M8723   | 3      | 0.1        | 5                   | 1         | 15                  | sup/trnk #3           | M8749     | 128    | 0.1        | 5         | 1         | 640                 |
| M8724   | 2      | 0.1        | 5                   | 1         | 10                  | sup/trnk #4           | M8750     | 13     | 0.1        | 5         | 1         | 65                  |
|   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
|   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #   | counts | amt plated | total vol           | recip dil | cfu/cm <sup>2</sup> | samp loc              | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| TSA cassettes - preclean  |        |            |                     |           |                     | TSA swabs - preclean  |           |        |            |           |           |                     |
| M8717   | 28     | 0.1        | 5                   | 1         | 140                 | return #1             | M8743     | 65     | 0.1        | 5         | 1         | 325                 |
| M8718   | 9      | 0.1        | 5                   | 1         | 45                  | sup/trnk #2           | M8744     | 9      | 0.1        | 5         | 1         | 45                  |
| M8719   | 2      | 0.1        | 5                   | 1         | 10                  | sup/trnk #3           | M8745     | 4      | 0.1        | 5         | 1         | 20                  |
| M8720   | 11     | 0.1        | 5                   | 1         | 55                  | sup/trnk #4           | M8746     | 8      | 0.1        | 5         | 1         | 40                  |
| TSA cassettes - postclean                                       |        |            |                     |           |                     | TSA swabs - postclean |           |        |            |           |           |                     |
| M8721   | 3      | 0.1        | 5                   | 1         | 15                  | return #1             | M8747     | 5      | 0.1        | 5         | 1         | 25                  |
| M8722   | 1      | 0.1        | 5                   | 1         | 5                   | sup/trnk #2           | M8748     | 19     | 0.1        | 5         | 1         | 95                  |
| M8723   | 1      | 0.1        | 5                   | 1         | 5                   | sup/trnk #3           | M8749     | 9      | 0.1        | 5         | 1         | 45                  |
| M8724   | 0.5    | 0.1        | 5                   | 1         | 3                   | sup/trnk #4           | M8750     | 2      | 0.1        | 5         | 1         | 10                  |
| project: 5973-005   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| sampling date: 6/11/96, 6/14/96                                 |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| description: preclean and postclean counts for sampling House 2 |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #   | counts | time (min) | m <sup>3</sup> /min | cfu       | cfu/m <sup>3</sup>  |                       |           |        |            |           |           |                     |
| SDA - m/g   |        | preclean   |                     |           |                     |                       |           |        |            |           |           |                     |
| M8753   | 1113   | 60         | 0.028               | 19        | 663                 |                       |           |        |            |           |           |                     |
| M8754   | 1030   | 60         | 0.028               | 17        | 613                 |                       |           |        |            |           |           |                     |
| M8755   | 1142   | 60         | 0.028               | 19        | 680                 |                       |           |        |            |           |           |                     |
| SDA - m/g   |        | postclean  |                     |           |                     |                       |           |        |            |           |           |                     |
| M8763   | 196    | 60         | 0.028               | 3         | 117                 |                       |           |        |            |           |           |                     |
| M8764   | 291    | 60         | 0.028               | 5         | 173                 |                       |           |        |            |           |           |                     |
| M8765   | 380    | 60         | 0.028               | 6         | 226                 |                       |           |        |            |           |           |                     |

## House 3

|   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
|---|--------|------------|---------------------|-----------|---------------------|-----------------------|-----------|--------|------------|-----------|-----------|---------------------|
| project: 5973-005   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| sampling date: 6/24/96, 6/25/96, 6/27/96                        |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| description: preclean and postclean counts for sampling House 3 |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #   | counts | amt plated | total vol           | recip dil | cfu/cm <sup>2</sup> | samp loc              | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| SDA cassettes - preclean  |        |            |                     |           |                     | SDA swabs - preclean  |           |        |            |           |           |                     |
| M8773   | 513    | 0.1        | 5                   | 10        | 25650               | ret plenum            | M8797     | 192    | 0.1        | 5         | 10        | 9600                |
| M8774   | 492    | 0.1        | 5                   | 10        | 24600               | ret flex              | M8798     | 312    | 0.1        | 5         | 10        | 15600               |
| M8775   | 154    | 0.1        | 5                   | 10        | 7700                | sup/fdr               | M8799     | 76     | 0.1        | 5         | 10        | 3800                |
| M8776   | 165    | 0.1        | 5                   | 10        | 8250                | sup plenum            | M8800     | 45     | 0.1        | 5         | 1         | 225                 |
| M8777   | 64     | 0.1        | 5                   | 10        | 3200                | sup/fdr               | M8801     | 4      | 0.1        | 5         | 1         | 20                  |
| SDA cassettes - postclean                                       |        |            |                     |           |                     | SDA swabs - postclean |           |        |            |           |           |                     |
| M8778   | 37     | 0.1        | 5                   | 1         | 185                 | ret plenum            | M8802     | 21     | 0.1        | 5         | 10        | 1050                |
| M8779   | 18     | 0.1        | 5                   | 1         | 90                  | ret flex              | M8803     | 32     | 0.1        | 5         | 1         | 160                 |
| M8781   | 34     | 0.1        | 5                   | 10        | 1700                | sup/fdr               | M8804     | 28     | 0.1        | 5         | 10        | 1400                |
| M8780   | 20     | 0.1        | 5                   | 1         | 100                 | sup plenum            | M8805     | 97     | 0.1        | 5         | 10        | 4850                |
| M8782   | 52     | 0.1        | 5                   | 1         | 260                 | sup/fdr               | M8806     | 47     | 0.1        | 5         | 1         | 235                 |
| rti/emp #   | counts | amt plated | total vol           | recip dil | cfu/cm <sup>2</sup> | samp loc              | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| TSA cassettes - preclean  |        |            |                     |           |                     | TSA swabs - preclean  |           |        |            |           |           |                     |
| M8773   | 15     | 0.1        | 5                   | 1         | 75                  | ret plenum            | M8797     | 20     | 0.1        | 5         | 1         | 100                 |
| M8774   | 14     | 0.1        | 5                   | 1         | 70                  | ret flex              | M8798     | 18     | 0.1        | 5         | 1         | 90                  |
| M8775   | 0.5    | 0.1        | 5                   | 1         | 3                   | sup/fdr               | M8799     | 5      | 0.1        | 5         | 1         | 25                  |
| M8776   | 0.5    | 0.1        | 5                   | 1         | 3                   | sup plenum            | M8800     | 17     | 0.1        | 5         | 1         | 85                  |
| M8777   | 1      | 0.1        | 5                   | 1         | 5                   | sup/fdr               | M8801     | 3      | 0.1        | 5         | 1         | 15                  |
| TSA cassettes - postclean                                       |        |            |                     |           |                     | TSA swabs - postclean |           |        |            |           |           |                     |
| M8778   | 3      | 0.1        | 5                   | 1         | 15                  | ret plenum            | M8802     | 6      | 0.1        | 5         | 1         | 30                  |
| M8779   | 0.5    | 0.1        | 5                   | 1         | 3                   | ret flex              | M8803     | 0.5    | 0.1        | 5         | 1         | 3                   |
| M8781   | 4      | 0.1        | 5                   | 1         | 20                  | sup/fdr               | M8804     | 4      | 0.1        | 5         | 1         | 20                  |
| M8780   | 4      | 0.1        | 5                   | 1         | 20                  | sup plenum            | M8805     | 1      | 0.1        | 5         | 1         | 5                   |
| M8782   | 0.5    | 0.1        | 5                   | 1         | 3                   | sup/fdr               | M8806     | 0.5    | 0.1        | 5         | 1         | 3                   |
| project: 5973-005   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| sampling date: 6/24/96, 6/25/96, 6/27/96                        |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| description: preclean and postclean counts for sampling House 3 |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #   | counts | time (min) | m <sup>3</sup> /min | cfu       | cfu/m <sup>3</sup>  |                       |           |        |            |           |           |                     |
| SDA - m/g   |        | preclean   |                     |           |                     |                       |           |        |            |           |           |                     |
| M8769   | 30     | 10         | 0.028               | 3         | 107                 |                       |           |        |            |           |           |                     |
| M8770   | 49     | 10         | 0.028               | 5         | 175                 |                       |           |        |            |           |           |                     |
| M8771   | 45     | 10         | 0.028               | 5         | 161                 |                       |           |        |            |           |           |                     |
| SDA - m/g   |        | postclean  |                     |           |                     |                       |           |        |            |           |           |                     |
| M8822   | 26     | 10         | 0.028               | 3         | 93                  |                       |           |        |            |           |           |                     |
| M8823   | 28     | 10         | 0.028               | 3         | 100                 |                       |           |        |            |           |           |                     |
| M8824   | 30     | 10         | 0.028               | 3         | 107                 |                       |           |        |            |           |           |                     |

## House 4

|   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
|---|--------|------------|---------------------|-----------|---------------------|-----------------------|-----------|--------|------------|-----------|-----------|---------------------|
| project: 5973-005   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| sampling date: 6/25/96, 6/28/96                                 |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| description: preclean and postclean counts for sampling House 4 |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #   | counts | amt plated | total vol           | recip dil | cfu/cm <sup>2</sup> | samp loc              | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| SDA cassettes - preclean  |        |            |                     |           |                     | SDA swabs - preclean  |           |        |            |           |           |                     |
| M8783   | 14     | 0.1        | 5                   | 1         | 700                 | ret/flx               | M8807     | 24     | 0.1        | 5         | 1         | 1200                |
| M8784   | 13     | 0.1        | 5                   | 1         | 650                 | ret/plenum            | M8808     | 8      | 0.1        | 5         | 1         | 400                 |
| M8785   | 10     | 0.1        | 5                   | 1         | 500                 | sup/fdr               | M8809     | 90     | 0.1        | 5         | 1         | 4500                |
| M8786   | 324    | 0.1        | 5                   | 10        | 162000              | sup/plenum            | M8810     | 347    | 0.1        | 5         | 10        | 173500              |
| M8787   | 184    | 0.1        | 5                   | 10        | 92000               | sup/fdr               | M8811     | 228    | 0.1        | 5         | 10        | 114000              |
| SDA cassettes - postclean                                       |        |            |                     |           |                     | SDA swabs - postclean |           |        |            |           |           |                     |
| M8788   | 0.5    | 0.1        | 5                   | 10        | 250                 | ret/flx               | M8812     | 12     | 0.1        | 5         | 1         | 600                 |
| M8789   | 2      | 0.1        | 5                   | 10        | 1000                | ret/plenum            | M8813     | 13     | 0.1        | 5         | 1         | 650                 |
| M8790   | 71     | 0.1        | 5                   | 10        | 35500               | sup/fdr               | M8814     | 15     | 0.1        | 5         | 10        | 7500                |
| M8791   | 60     | 0.1        | 5                   | 10        | 30000               | sup/plenum            | M8815     | 35     | 0.1        | 5         | 10        | 17500               |
| M8792   | 99     | 0.1        | 5                   | 1         | 4950                | sup/fdr               | M8816     | 19     | 0.1        | 5         | 1         | 950                 |
|   |        |            |                     |           |                     | kitchen reg           | M8821     | 17     | 0.1        | 5         | 1         | 850                 |
| rti/emp #   | counts | amt plated | total vol           | recip dil | cfu/cm <sup>2</sup> | samp loc              | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| TSA cassettes - preclean  |        |            |                     |           |                     | TSA swabs - preclean  |           |        |            |           |           |                     |
| M8783   | 21     | 0.1        | 5                   | 1         | 1050                | ret/flx               | M8807     | 45     | 0.1        | 5         | 1         | 2250                |
| M8784   | 6      | 0.1        | 5                   | 1         | 300                 | ret/plenum            | M8808     | 16     | 0.1        | 5         | 1         | 800                 |
| M8785   | 0.5    | 0.1        | 5                   | 1         | 25                  | sup/fdr               | M8809     | 7      | 0.1        | 5         | 1         | 350                 |
| M8786   | 2      | 0.1        | 5                   | 1         | 100                 | sup/plenum            | M8810     | 16     | 0.1        | 5         | 1         | 800                 |
| M8787   | 0.5    | 0.1        | 5                   | 1         | 25                  | sup/fdr               | M8811     | 2      | 0.1        | 5         | 1         | 100                 |
| TSA cassettes - postclean                                       |        |            |                     |           |                     | TSA swabs - postclean |           |        |            |           |           |                     |
| M8788   | 0.5    | 0.1        | 5                   | 1         | 25                  | ret/flx               | M8812     | 1      | 0.1        | 5         | 1         | 50                  |
| M8789   | 0.5    | 0.1        | 5                   | 1         | 25                  | ret/plenum            | M8813     | 4      | 0.1        | 5         | 1         | 200                 |
| M8790   | 0.5    | 0.1        | 5                   | 1         | 25                  | sup/fdr               | M8814     | 6      | 0.1        | 5         | 1         | 300                 |
| M8791   | 5      | 0.1        | 5                   | 1         | 250                 | sup/plenum            | M8815     | 4      | 0.1        | 5         | 1         | 200                 |
| M8792   | 1      | 0.1        | 5                   | 1         | 50                  | sup/fdr               | M8816     | 23     | 0.1        | 5         | 1         | 1150                |
|   |        |            |                     |           |                     | kitchen reg           | M8821     | 1      | 0.1        | 5         | 1         | 50                  |
| project: 5973-005   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| sampling date: 6/25/96, 6/28/96                                 |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| description: preclean and postclean counts for sampling House 4 |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #   | counts | time (min) | m <sup>3</sup> /min | cfu       | cfu/m <sup>3</sup>  |                       |           |        |            |           |           |                     |
| SDA - m/g   |        | preclean   |                     |           |                     |                       |           |        |            |           |           |                     |
| M8817   | 55     | 10         | 0.028               | 6         | 196                 |                       |           |        |            |           |           |                     |
| M8818   | 84     | 10         | 0.028               | 8         | 300                 |                       |           |        |            |           |           |                     |
| M8819   | 34     | 10         | 0.028               | 3         | 121                 |                       |           |        |            |           |           |                     |
| SDA - m/g   |        | postclean  |                     |           |                     |                       |           |        |            |           |           |                     |
| M8828   | 88     | 10         | 0.028               | 9         | 314                 |                       |           |        |            |           |           |                     |
| M8829   | 84     | 10         | 0.028               | 8         | 300                 |                       |           |        |            |           |           |                     |
| M8830   | 63     | 10         | 0.028               | 6         | 225                 |                       |           |        |            |           |           |                     |

## House 5

| project: 5973-005   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
|---|--------|------------|---------------------|-----------|---------------------|-----------------------|-----------|--------|------------|-----------|-----------|---------------------|
| sampling date: 7/15/96, 7/16/96, 7/18/96                        |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| description: preclean and postclean counts for sampling House 5 |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
|   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #   | counts | amt plated | total vol           | recip dil | cfu/cm <sup>2</sup> | samp loc              | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| SDA cassettes - preclean  |        |            |                     |           |                     | SDA swabs - preclean  |           |        |            |           |           |                     |
| M8838   | 17     | 0.1        | 5                   | 1         | 85                  | return flex           | M8863     | 5      | 0.1        | 5         | 1         | 25                  |
| M8839   | 18     | 0.1        | 5                   | 1         | 90                  | ret plenum            | M8864     | 6      | 0.1        | 5         | 1         | 30                  |
| M8840   | 22     | 0.1        | 5                   | 1         | 110                 | sup plenum            | M8866     | 4      | 0.1        | 5         | 1         | 20                  |
| M8841   | 1      | 0.1        | 5                   | 1         | 5                   | sup/fdr #4            | M8867     | 0.5    | 0.1        | 5         | 1         | 3                   |
|   |        |            |                     |           |                     | fan blade             | M8865     | 21     | 0.1        | 5         | 10        | 1050                |
| SDA cassettes - postclean                                       |        |            |                     |           |                     | SDA swabs - postclean |           |        |            |           |           |                     |
| M8842   | 3      | 0.1        | 5                   | 1         | 15                  | return flex           | M8868     | 10     | 0.1        | 5         | 1         | 50                  |
| M8843   | 16     | 0.1        | 5                   | 1         | 80                  | ret plenum            | M8869     | 27     | 0.1        | 5         | 1         | 135                 |
| M8844   | 9      | 0.1        | 5                   | 1         | 45                  | sup plenum            | M8871     | 24     | 0.1        | 5         | 1         | 120                 |
| M8845   | 3      | 0.1        | 5                   | 1.0E+0    | 1.5E+1              | sup/fdr #4            | M8872     | 1      | 0.1        | 5         | 1         | 5                   |
|   |        |            |                     |           |                     | fan blade             | M8870     | 0.5    | 0.1        | 5         | 1         | 3                   |
|   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
|   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #   | counts | amt plated | total vol           | recip dil | cfu/cm <sup>2</sup> | samp loc              | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| TSA cassettes - preclean  |        |            |                     |           |                     | TSA swabs - preclean  |           |        |            |           |           |                     |
| M8838   | 6      | 0.1        | 5                   | 1         | 30                  | return flex           | M8863     | 12     | 0.1        | 5         | 1         | 60                  |
| M8839   | 2      | 0.1        | 5                   | 1         | 10                  | ret plenum            | M8864     | 1      | 0.1        | 5         | 1         | 5                   |
| M8840   | 3      | 0.1        | 5                   | 1         | 15                  | sup plenum            | M8866     | 6      | 0.1        | 5         | 10        | 300                 |
| M8841   | 1      | 0.1        | 5                   | 1         | 5                   | sup/fdr #4            | M8867     | 1      | 0.1        | 5         | 1         | 5                   |
|   |        |            |                     |           |                     | fan blade             | M8865     | 20     | 0.1        | 5         | 10        | 1000                |
| TSA cassettes - postclean                                       |        |            |                     |           |                     | TSA swabs - postclean |           |        |            |           |           |                     |
| M8842   | 0.5    | 0.1        | 5                   | 1         | 3                   | return flex           | M8868     | 6      | 0.1        | 5         | 1         | 30                  |
| M8843   | 1      | 0.1        | 5                   | 1         | 5                   | ret plenum            | M8869     | 2      | 0.1        | 5         | 1         | 10                  |
| M8844   | 2      | 0.1        | 5                   | 1         | 10                  | sup plenum            | M8871     | 12     | 0.1        | 5         | 1         | 60                  |
| M8845   | 0.5    | 0.1        | 5                   | 1         | 3                   | sup/fdr #4            | M8872     | 1      | 0.1        | 5         | 1         | 5                   |
|   |        |            |                     |           |                     | fan blade             | M8870     | 2      | 0.1        | 5         | 1         | 10                  |
|   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| project: 5973-005   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| sampling date: 7/15/96  |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| description: preclean and postclean counts for sampling House 5 |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
|   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #   | counts | time (min) | m <sup>3</sup> /min | cfu       | cfu/m <sup>3</sup>  |                       |           |        |            |           |           |                     |
| SDA - m/g   |        | preclean   |                     |           |                     |                       |           |        |            |           |           |                     |
| M8834   | 63     | 60         | 0.028               | 1         | 38                  |                       |           |        |            |           |           |                     |
| M8835   | 24     | 60         | 0.028               | 0         | 14                  |                       |           |        |            |           |           |                     |
| M8836   | 107    | 60         | 0.028               | 2         | 64                  |                       |           |        |            |           |           |                     |
| SDA - m/g   |        | postclean  |                     |           |                     |                       |           |        |            |           |           |                     |
| M8891   | 89     | 60         | 0.028               | 1         | 53                  |                       |           |        |            |           |           |                     |
| M8892   | 3      | 60         | 0.028               | 0         | 2                   |                       |           |        |            |           |           |                     |
| M8893   | 179    | 60         | 0.028               | 3         | 107                 |                       |           |        |            |           |           |                     |

## House 6

|   |        |            |           |           |                     |                            |           |        |            |           |           |                     |
|---|--------|------------|-----------|-----------|---------------------|----------------------------|-----------|--------|------------|-----------|-----------|---------------------|
| project: 5973-005   |        |            |           |           |                     |                            |           |        |            |           |           |                     |
| sampling date: 7/16/96, 7/17/96, 7/19/96                        |        |            |           |           |                     |                            |           |        |            |           |           |                     |
| description: preclean and postclean counts for sampling House 6 |        |            |           |           |                     |                            |           |        |            |           |           |                     |
| rti/emp #   | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> | samp loc                   | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| SDA cassettes - preclean  |        |            |           |           |                     | SDA swabs - preclean       |           |        |            |           |           |                     |
| M8846   | 4      | 0.1        | 5         | 1         | 20                  | return #1                  | M8873     | 51     | 0.1        | 5         | 10        | 2550                |
| M8847   | 24     | 0.1        | 5         | 1         | 120                 | ret/flx #2                 | M8874     | 35     | 0.1        | 5         | 1         | 175                 |
| M8848   | 21     | 0.1        | 5         | 1         | 105                 | return #3                  | M8875     | 13     | 0.1        | 5         | 10        | 650                 |
| M8849   | 10     | 0.1        | 5         | 1         | 50                  | sup/fdr #4                 | M8876     | 3      | 0.1        | 5         | 1         | 15                  |
| M8850   | 32     | 0.1        | 5         | 1         | 160                 | sup/fdr #5                 | M8877     | 10     | 0.1        | 5         | 1         | 50                  |
| M8851   | 29     | 0.1        | 5         | 1         | 145                 | sup/trnk #6                | M8878     | 50     | 0.1        | 5         | 1         | 250                 |
| SDA cassettes - postclean                                       |        |            |           |           |                     | SDA swabs - postclean      |           |        |            |           |           |                     |
| M8854   | 26     | 0.1        | 5         | 1         | 130                 | sup/trnk #6                | M8881     | 18     | 0.1        | 5         | 1         | 90                  |
| M8855   | 0.5    | 0.1        | 5         | 1         | 3                   | sup/fdr #5                 | M8882     | 4      | 0.1        | 5         | 1         | 20                  |
| M8857   | 3      | 0.1        | 5         | 1         | 15                  | return #3                  | M8888     | 1      | 0.1        | 5         | 1         | 5                   |
| M8858   | 1      | 0.1        | 5         | 1         | 5                   | ret/flx #2                 | M8889     | 0.5    | 0.1        | 5         | 1         | 3                   |
| M8859   | 0.5    | 0.1        | 5         | 1         | 3                   | return #1                  | M8890     | 1      | 0.1        | 5         | 1         | 5                   |
| SDA cassettes - after air wash                                  |        |            |           |           |                     | SDA swabs - after air wash |           |        |            |           |           |                     |
| M8852   | 10     | 0.1        | 5         | 1         | 50                  | sup/trnk #6                | M8879     | 8      | 0.1        | 5         | 1         | 40                  |
| M8853   | 2      | 0.1        | 5         | 1         | 10                  | sup/fdr #5                 | M8880     | 5      | 0.1        | 5         | 1         | 25                  |
| M8856   | 10     | 0.1        | 5         | 1         | 50                  | return #3                  | M8887     | 5      | 0.1        | 5         | 1         | 25                  |
| rti/emp #   | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> | samp loc                   | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| TSA cassettes - preclean  |        |            |           |           |                     | TSA swabs - preclean       |           |        |            |           |           |                     |
| M8846   | 1      | 0.1        | 5         | 1         | 5                   | return #1                  | M8873     | 29     | 0.1        | 5         | 1         | 145                 |
| M8847   | 9      | 0.1        | 5         | 1         | 45                  | ret/flx #2                 | M8874     | 39     | 0.1        | 5         | 1         | 195                 |
| M8848   | 38     | 0.1        | 5         | 1         | 190                 | return #3                  | M8875     | 54     | 0.1        | 5         | 1         | 270                 |
| M8849   | 2      | 0.1        | 5         | 1         | 10                  | sup/fdr #4                 | M8876     | 2      | 0.1        | 5         | 1         | 10                  |
| M8850   | 0.5    | 0.1        | 5         | 1         | 3                   | sup/fdr #5                 | M8877     | 1      | 0.1        | 5         | 1         | 5                   |
| M8851   | 6      | 0.1        | 5         | 1         | 30                  | sup/trnk #6                | M8878     | 5      | 0.1        | 5         | 1         | 25                  |
| TSA cassettes - postclean                                       |        |            |           |           |                     | TSA swabs - postclean      |           |        |            |           |           |                     |
| M8854   | 21     | 0.1        | 5         | 1         | 105                 | sup/trnk #6                | M8881     | 28     | 0.1        | 5         | 1         | 140                 |
| M8855   | 1      | 0.1        | 5         | 1         | 5                   | sup/fdr #5                 | M8882     | 7      | 0.1        | 5         | 1         | 35                  |
| M8857   | 1      | 0.1        | 5         | 1         | 5                   | return #3                  | M8888     | 0.5    | 0.1        | 5         | 1         | 3                   |
| M8858   | 0.5    | 0.1        | 5         | 1         | 3                   | ret/flx #2                 | M8889     | 1      | 0.1        | 5         | 1         | 5                   |
| M8859   | 1      | 0.1        | 5         | 1         | 5                   | return #1                  | M8890     | 4      | 0.1        | 5         | 1         | 20                  |
| TSA cassettes - after air wash                                  |        |            |           |           |                     | TSA swabs - after air wash |           |        |            |           |           |                     |
| M8852   | 1      | 0.1        | 5         | 1         | 5                   | sup/trnk #6                | M8879     | 5      | 0.1        | 5         | 1         | 25                  |
| M8853   | 2      | 0.1        | 5         | 1         | 10                  | sup/fdr #5                 | M8880     | 1      | 0.1        | 5         | 1         | 5                   |
| M8856   | 0.5    | 0.1        | 5         | 1         | 3                   | return #3                  | M8887     | 6      | 0.1        | 5         | 1         | 30                  |

House 6

|   |        |            |                     |     |                    |  |  |  |  |  |  |  |  |  |
|---|--------|------------|---------------------|-----|--------------------|--|--|--|--|--|--|--|--|--|
| project: 5973-005   |        |            |                     |     |                    |  |  |  |  |  |  |  |  |  |
| sampling date: 7/16/96, 7/19/96                                 |        |            |                     |     |                    |  |  |  |  |  |  |  |  |  |
| description: preclean and postclean counts for sampling House 6 |        |            |                     |     |                    |  |  |  |  |  |  |  |  |  |
|   |        |            |                     |     |                    |  |  |  |  |  |  |  |  |  |
| rti/emp #   | counts | time (min) | m <sup>3</sup> /min | cfu | cfu/m <sup>3</sup> |  |  |  |  |  |  |  |  |  |
| SDA - m/g   |        | preclean   |                     |     |                    |  |  |  |  |  |  |  |  |  |
| M8883   | 152    | 60         | 0.028               | 3   | 90                 |  |  |  |  |  |  |  |  |  |
| M8884   | 108    | 60         | 0.028               | 2   | 64                 |  |  |  |  |  |  |  |  |  |
| M8885   | 120    | 60         | 0.028               | 2   | 71                 |  |  |  |  |  |  |  |  |  |
| SDA - m/g   |        | postclean  |                     |     |                    |  |  |  |  |  |  |  |  |  |
| M8897   | 156    | 60         | 0.028               | 3   | 93                 |  |  |  |  |  |  |  |  |  |
| M8898   | 95     | 60         | 0.028               | 2   | 57                 |  |  |  |  |  |  |  |  |  |
| M8899   | 101    | 60         | 0.028               | 2   | 60                 |  |  |  |  |  |  |  |  |  |

## House 7

|   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
|---|--------|------------|---------------------|-----------|---------------------|-----------------------|-----------|--------|------------|-----------|-----------|---------------------|
| project: 5973-005   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| sampling date: 7/30/96  |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| description: preclean and postclean counts for sampling House 7 |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #   | counts | amt plated | total vol           | recip dil | cfu/cm <sup>2</sup> | samp loc              | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| SDA cassettes - preclean  |        |            |                     |           |                     | SDA swabs - preclean  |           |        |            |           |           |                     |
| M8963   | 12     | 0.1        | 5                   | 1         | 60                  | ret plenum            | M8993     | 3      | 0.1        | 5         | 1         | 15                  |
| M8964   | 48     | 0.1        | 5                   | 10        | 2400                | return #2             | M8994     | 4      | 0.1        | 5         | 100       | 2000                |
| M8965   | 22     | 0.1        | 5                   | 1         | 110                 | sup/fdr #3            | M8995     | 3      | 0.1        | 5         | 1         | 15                  |
| M8966   | 29     | 0.1        | 5                   | 100       | 14500               | sup plenum            | M8996     | 86     | 0.1        | 5         | 100       | 43000               |
| M8967   | 77     | 0.1        | 5                   | 10        | 3850                | sup/trnk #5           | M8997     | 65     | 0.1        | 5         | 1         | 325                 |
| SDA cassettes - postclean                                       |        |            |                     |           |                     | SDA swabs - postclean |           |        |            |           |           |                     |
| M8968   | 86     | 0.1        | 5                   | 1         | 430                 | ret plenum            | M8998     | 4      | 0.1        | 5         | 1         | 20                  |
| M8969   | 8      | 0.1        | 5                   | 1         | 40                  | return #2             | M8999     | 0.5    | 0.1        | 5         | 1         | 3                   |
| M8970   | 3      | 0.1        | 5                   | 1         | 15                  | sup/fdr #3            | M9000     | 2      | 0.1        | 5         | 1         | 10                  |
| M8971   | 2      | 0.1        | 5                   | 1         | 10                  | sup plenum            | M9001     | 3      | 0.1        | 5         | 1         | 15                  |
| M8972   | 3      | 0.1        | 5                   | 10        | 150                 | sup/trnk #5           | M9002     | 4      | 0.1        | 5         | 1         | 20                  |
|   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
|   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #   | counts | amt plated | total vol           | recip dil | cfu/cm <sup>2</sup> | samp loc              | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| TSA cassettes - preclean  |        |            |                     |           |                     | TSA swabs - preclean  |           |        |            |           |           |                     |
| M8963   | 5      | 0.1        | 5                   | 1         | 25                  | ret plenum            | M8993     | 9      | 0.1        | 5         | 10        | 450                 |
| M8964   | 4      | 0.1        | 5                   | 10        | 200                 | return #2             | M8994     | 11     | 0.1        | 5         | 1         | 55                  |
| M8965   | 5      | 0.1        | 5                   | 1         | 25                  | sup/fdr #3            | M8995     | 11     | 0.1        | 5         | 10        | 550                 |
| M8966   | 0.5    | 0.1        | 5                   | 1         | 3                   | sup plenum            | M8996     | 16     | 0.1        | 5         | 10        | 800                 |
| M8967   | 48     | 0.1        | 5                   | 1         | 240                 | sup/trnk #5           | M8997     | 16     | 0.1        | 5         | 10        | 800                 |
| TSA cassettes - postclean                                       |        |            |                     |           |                     | TSA swabs - postclean |           |        |            |           |           |                     |
| M8968   | 37     | 0.1        | 5                   | 10        | 1850                | ret plenum            | M8998     | 41     | 0.1        | 5         | 10        | 2050                |
| M8969   | 0.5    | 0.1        | 5                   | 1         | 3                   | return #2             | M8999     | 11     | 0.1        | 5         | 10        | 550                 |
| M8970   | 5      | 0.1        | 5                   | 10        | 250                 | sup/fdr #3            | M9000     | 11     | 0.1        | 5         | 1         | 55                  |
| M8971   | 1      | 0.1        | 5                   | 10        | 50                  | sup plenum            | M9001     | 9      | 0.1        | 5         | 10        | 450                 |
| M8972   | 0.5    | 0.1        | 5                   | 1         | 3                   | sup/trnk #5           | M9002     | 6      | 0.1        | 5         | 1         | 30                  |
|   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| project: 5973-005   |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| sampling date: 7/29/96, 8/1/96                                  |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| description: preclean and postclean counts for sampling House 7 |        |            |                     |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #   | counts | time (min) | m <sup>3</sup> /min | cfu       | cfu/m <sup>3</sup>  |                       |           |        |            |           |           |                     |
| SDA - m/g   |        | preclean   |                     |           |                     |                       |           |        |            |           |           |                     |
| M8903   | 215    | 60         | 0.028               | 4         | 128                 |                       |           |        |            |           |           |                     |
| M8904   | 92     | 60         | 0.028               | 2         | 55                  |                       |           |        |            |           |           |                     |
| M8961   | 73     | 60         | 0.028               | 1         | 43                  |                       |           |        |            |           |           |                     |
| SDA - m/g   |        | postclean  |                     |           |                     |                       |           |        |            |           |           |                     |
| M9021   | 117    | 60         | 0.028               | 2         | 70                  |                       |           |        |            |           |           |                     |
| M9022   | 97     | 60         | 0.028               | 2         | 58                  |                       |           |        |            |           |           |                     |
| M9023   | 18     | 60         | 0.028               | 0         | 11                  |                       |           |        |            |           |           |                     |

## House 8

| project: 5973-005   |        |            |           |           |                     |                       |           |        |            |           |           |                     |
|---|--------|------------|-----------|-----------|---------------------|-----------------------|-----------|--------|------------|-----------|-----------|---------------------|
| sampling date: 7/30/96, 7/31/96                                 |        |            |           |           |                     |                       |           |        |            |           |           |                     |
| description: preclean and postclean counts for sampling House 8 |        |            |           |           |                     |                       |           |        |            |           |           |                     |
| rti/emp #   | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> | samp loc              | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| SDA cassettes - preclean  |        |            |           |           |                     | SDA swabs - preclean  |           |        |            |           |           |                     |
| M8973   | 41     | 0.1        | 5         | 1         | 205                 | return #1             | M9003     | 15     | 0.1        | 5         | 1         | 75                  |
| M8974   | 16     | 0.1        | 5         | 1         | 80                  | sup/trnk #2           | M9004     | 6      | 0.1        | 5         | 1         | 30                  |
| M8975   | 35     | 0.1        | 5         | 1         | 175                 | return #3             | M9005     | 63     | 0.1        | 5         | 1         | 315                 |
| M8976   | 34     | 0.1        | 5         | 1         | 170                 | sup/trnk #4           | M9006     | 7      | 0.1        | 5         | 1         | 35                  |
| M8977   | 7      | 0.1        | 5         | 1         | 35                  | sup/trnk #5           | M9007     | 5      | 0.1        | 5         | 1         | 25                  |
|   |        |            |           |           |                     | coil drain            | M9008     | 13     | 0.1        | 5         | 10        | 650                 |
|   |        |            |           |           |                     | coil                  | M9009     | 32     | 0.1        | 5         | 10        | 1600                |
| SDA cassettes - postclean                                       |        |            |           |           |                     | SDA swabs - postclean |           |        |            |           |           |                     |
| M8978   | 0.5    | 0.1        | 5         | 1         | 3                   | return #1             | M9010     | 3      | 0.1        | 5         | 1         | 15                  |
| M8979   | 0.5    | 0.1        | 5         | 1         | 3                   | sup/trnk #2           | M9011     | 1      | 0.1        | 5         | 1         | 5                   |
| M8980   | 0.5    | 0.1        | 5         | 1         | 3                   | return #3             | M9012     | 3      | 0.1        | 5         | 1         | 15                  |
| M8981   | 0.5    | 0.1        | 5         | 1         | 3                   | sup/trnk #4           | M9017     | 1      | 0.1        | 5         | 1         | 5                   |
| M8982   | 3      | 0.1        | 5         | 1         | 15                  | sup/trnk #5           | M9018     | 0.5    | 0.1        | 5         | 1         | 3                   |
|   |        |            |           |           |                     | coil drain            | M9019     | 14     | 0.1        | 5         | 1         | 70                  |
|   |        |            |           |           |                     | coil                  | M9020     | 1      | 0.1        | 5         | 1         | 5                   |
| rti/emp #   | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> | samp loc              | rti/emp # | counts | amt plated | total vol | recip dil | cfu/cm <sup>2</sup> |
| TSA cassettes - preclean  |        |            |           |           |                     | TSA swabs - preclean  |           |        |            |           |           |                     |
| M8973   | 2      | 0.1        | 5         | 10        | 100                 | return #1             | M9003     | 3      | 0.1        | 5         | 10        | 150                 |
| M8974   | 3      | 0.1        | 5         | 10        | 150                 | sup/trnk #2           | M9004     | 3      | 0.1        | 5         | 10        | 150                 |
| M8975   | 0.5    | 0.1        | 5         | 1         | 3                   | return #3             | M9005     | 15     | 0.1        | 5         | 1         | 75                  |
| M8976   | 1      | 0.1        | 5         | 10        | 50                  | sup/trnk #4           | M9006     | 0.5    | 0.1        | 5         | 1         | 3                   |
| M8977   | 5      | 0.1        | 5         | 1         | 25                  | sup/trnk #5           | M9007     | 0.5    | 0.1        | 5         | 1         | 3                   |
|   |        |            |           |           |                     | coil drain            | M9008     | 2      | 0.1        | 5         | 10        | 100                 |
|   |        |            |           |           |                     | coil                  | M9009     | 6      | 0.1        | 5         | 10        | 300                 |
| TSA cassettes - postclean                                       |        |            |           |           |                     | TSA swabs - postclean |           |        |            |           |           |                     |
| M8978   | 0.5    | 0.1        | 5         | 1         | 3                   | return #1             | M9010     | 2      | 0.1        | 5         | 10        | 100                 |
| M8979   | 0.5    | 0.1        | 5         | 1         | 3                   | sup/trnk #2           | M9011     | 8      | 0.1        | 5         | 1         | 40                  |
| M8980   | 0.5    | 0.1        | 5         | 1         | 3                   | return #3             | M9012     | 2      | 0.1        | 5         | 10        | 100                 |
| M8981   | 3      | 0.1        | 5         | 1         | 15                  | sup/trnk #4           | M9017     | 4      | 0.1        | 5         | 10        | 200                 |
| M8982   | 0.5    | 0.1        | 5         | 1         | 3                   | sup/trnk #5           | M9018     | 1      | 0.1        | 5         | 10        | 50                  |
|   |        |            |           |           |                     | coil drain            | M9019     | 3      | 0.1        | 5         | 10        | 150                 |
|   |        |            |           |           |                     | coil                  | M9020     | 1      | 0.1        | 5         | 10        | 50                  |

House 8

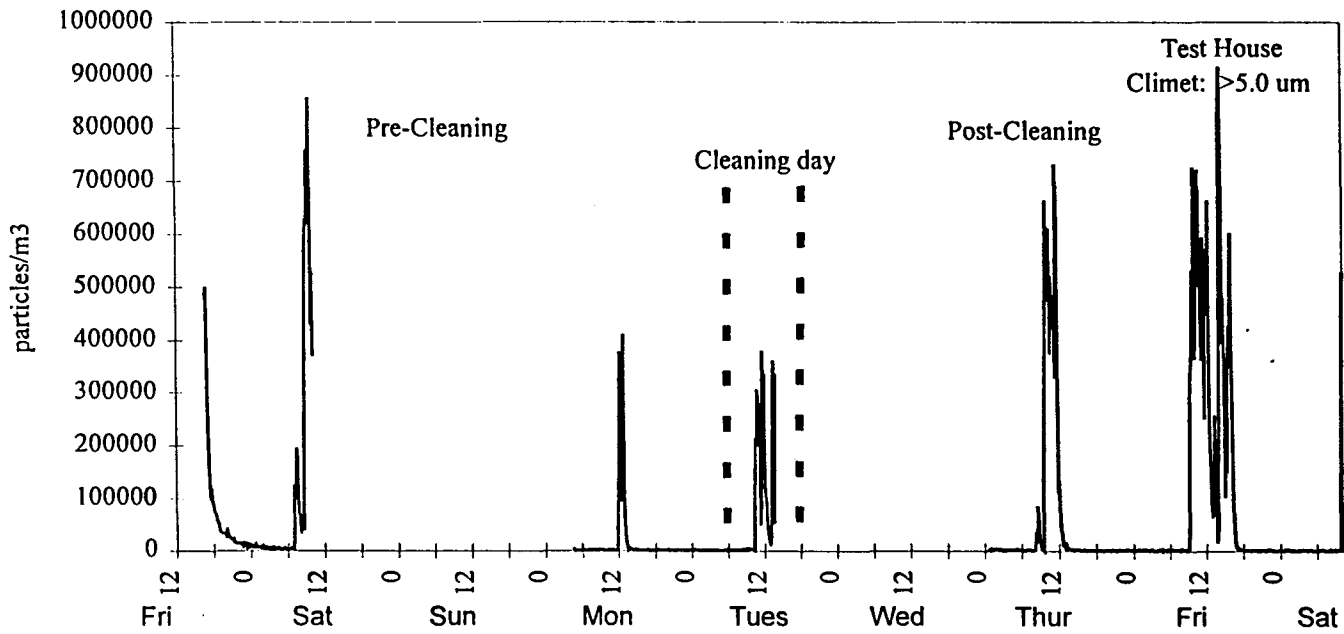
| project: 5973-005   |        |            |                     |     |                    |  |  |  |  |  |  |  |  |  |  |
|---|--------|------------|---------------------|-----|--------------------|--|--|--|--|--|--|--|--|--|--|
| sampling date: 7/30/96, 8/2/96                                  |        |            |                     |     |                    |  |  |  |  |  |  |  |  |  |  |
| description: preclean and postclean counts for sampling House 8 |        |            |                     |     |                    |  |  |  |  |  |  |  |  |  |  |
|   |        |            |                     |     |                    |  |  |  |  |  |  |  |  |  |  |
| rti/emp #   | counts | time (min) | m <sup>3</sup> /min | cfu | cfu/m <sup>3</sup> |  |  |  |  |  |  |  |  |  |  |
| SDA - m/ preclean   |        |            |                     |     |                    |  |  |  |  |  |  |  |  |  |  |
| M9013   | 131    | 60         | 0.028               | 2   | 78                 |  |  |  |  |  |  |  |  |  |  |
| M9014   | 116    | 60         | 0.028               | 2   | 69                 |  |  |  |  |  |  |  |  |  |  |
| M9015   | 134    | 60         | 0.028               | 2   | 80                 |  |  |  |  |  |  |  |  |  |  |
| SDA - m/g postclean   |        |            |                     |     |                    |  |  |  |  |  |  |  |  |  |  |
| M9027   | 117    | 60         | 0.028               | 2   | 70                 |  |  |  |  |  |  |  |  |  |  |
| M9028   | 138    | 60         | 0.028               | 2   | 82                 |  |  |  |  |  |  |  |  |  |  |
| M9029   | 144    | 60         | 0.028               | 2   | 86                 |  |  |  |  |  |  |  |  |  |  |

## APPENDIX E

### CLIMET MEASUREMENT RESULTS FOR PARTICLES IN THE SIZE FRACTION > 5.0 $\mu\text{m}$ DIAMETER

#### Note

Data were not downloaded from the Climet for the > 5.0  $\mu\text{m}$  size fraction at Houses 1 and 2



Airborne particle concentrations in the >5.0 um size fraction at Test House

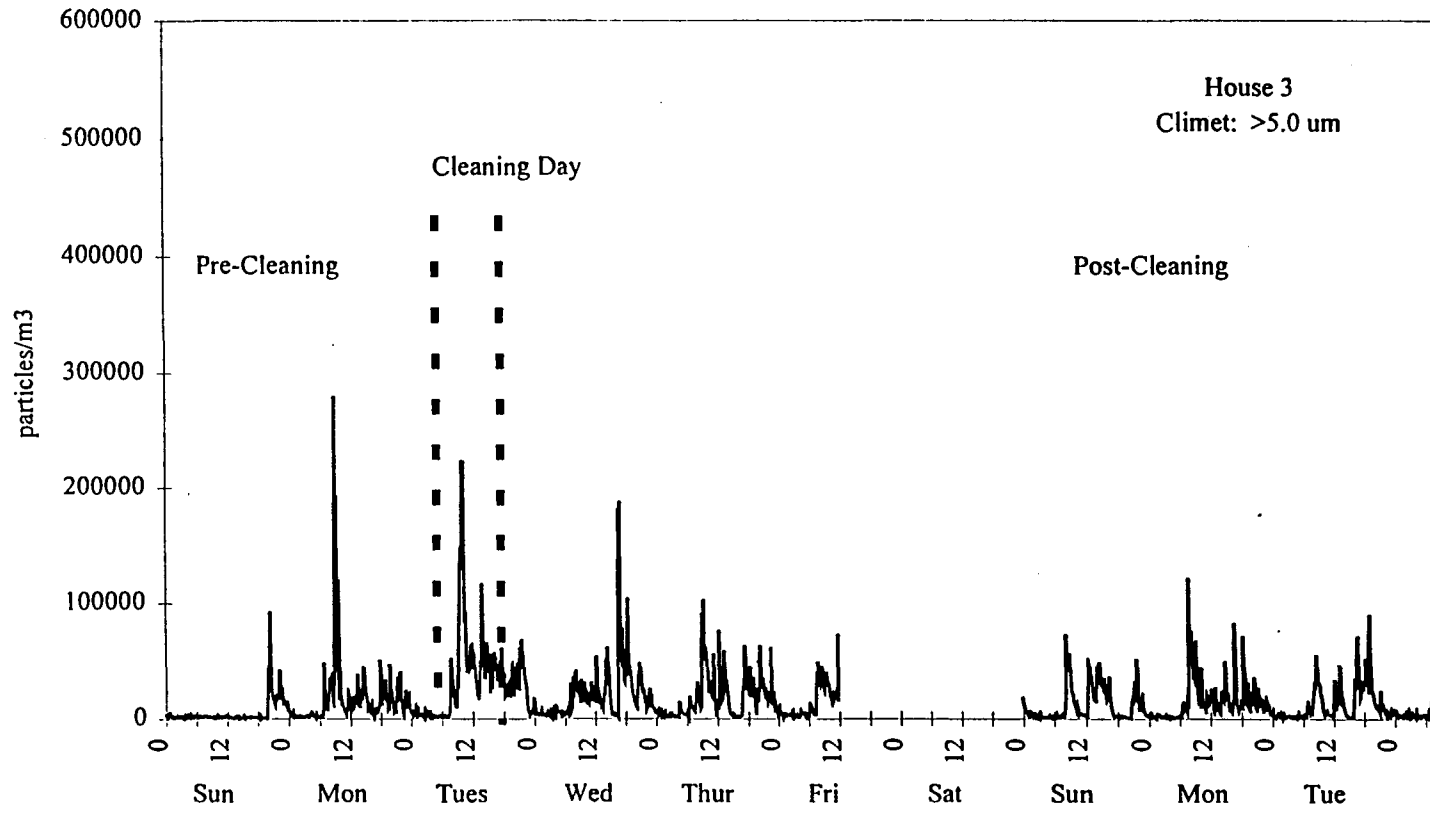


Figure 5-4 . Airborne particle concentrations in the >5.0 um size fraction at House 3

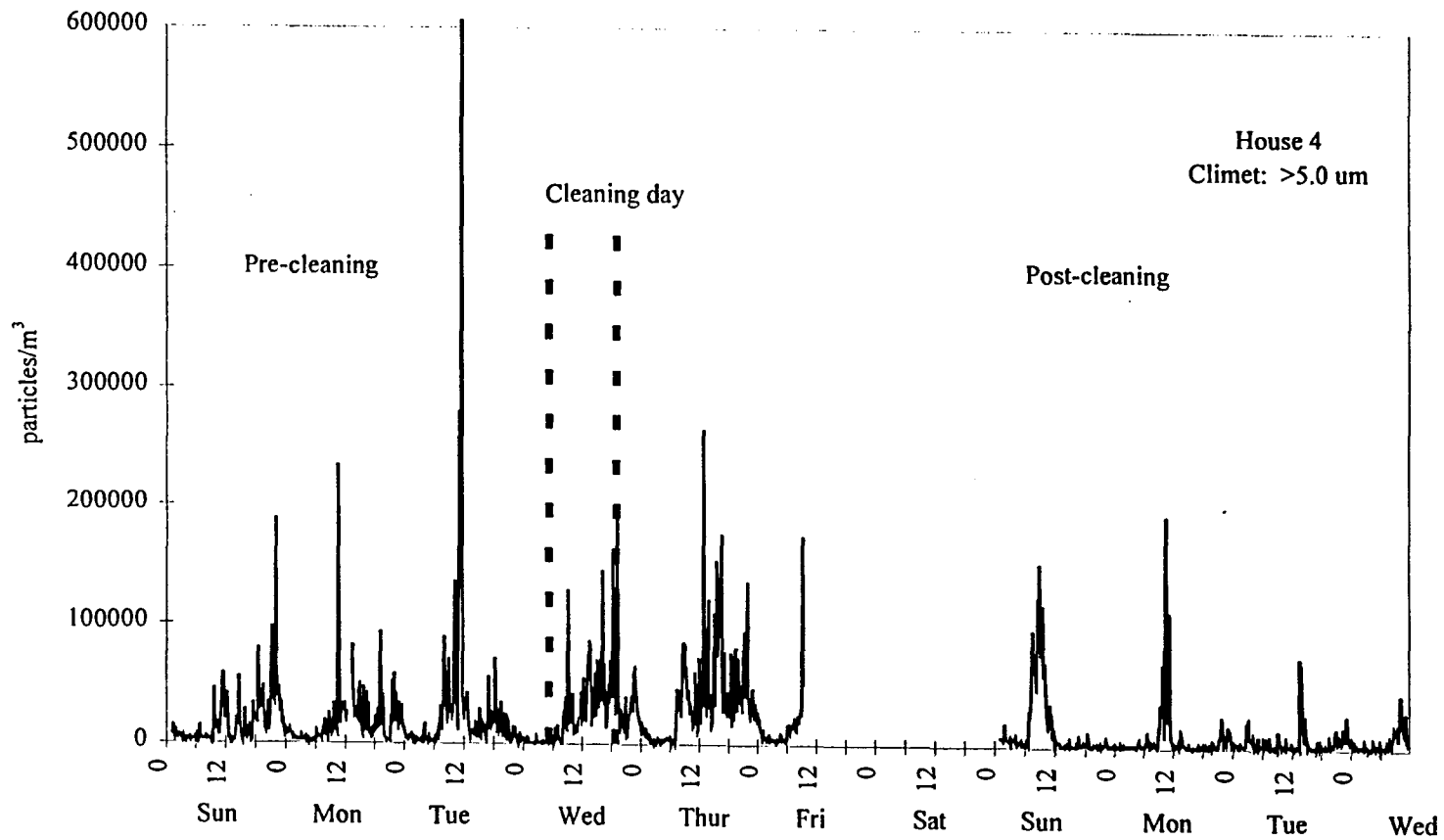
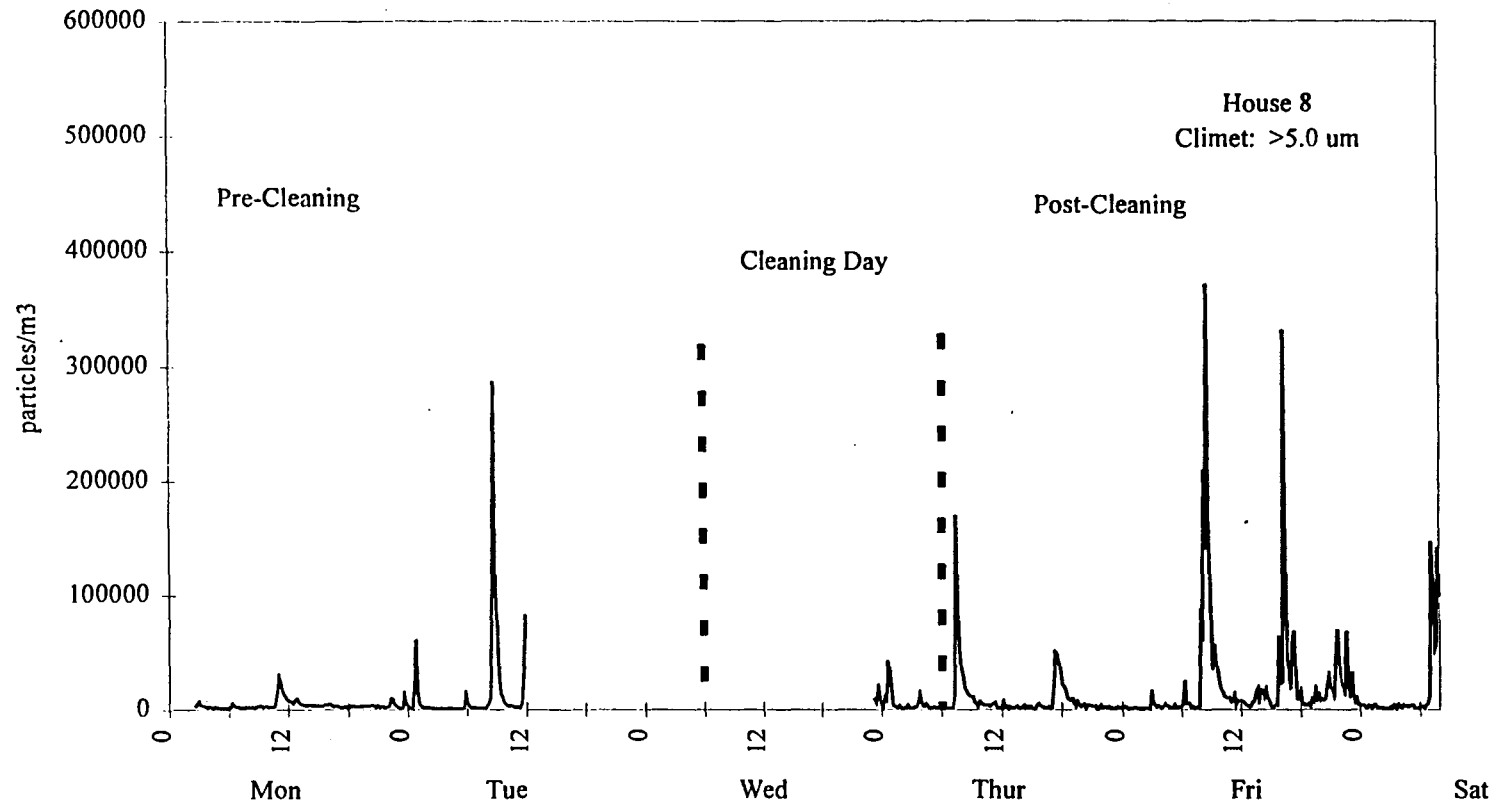


Figure 5-10. Airborne particle concentrations in the >5.0 um size fraction at House 4









Airborne particle concentrations in the >5.0 um size fraction at House 8

APPENDIX F

MEAN CONCENTRATIONS OF PARTICLES IN 16 SIZE FRACTIONS MEASURED WITH THE LAS-X PRE- AND POST-HAC CLEANING

|            |          | Lasx Data                                   |           |           |           |           |           |           |           |          |         |         |         |         |         |         |       |
|------------|----------|---|-----------|-----------|-----------|-----------|-----------|-----------|-----------|----------|---------|---------|---------|---------|---------|---------|-------|
|            |          | particles X 10 <sup>3</sup> /m <sup>3</sup> |           |           |           |           |           |           |           |          |         |         |         |         |         |         |       |
|            |          | Microns                                     |           |           |           |           |           |           |           |          |         |         |         |         |         |         |       |
| Test House |          | 0.10-0.12                                   | 0.12-0.16 | 0.16-0.20 | 0.20-0.25 | 0.25-0.35 | 0.35-0.45 | 0.45-0.80 | 0.60-0.75 | 0.75-1.0 | 1.0-1.5 | 1.5-2.0 | 2.0-3.0 | 3.0-4.5 | 4.5-6.0 | 6.0-7.5 | ≥7.5  |
| Test House | Pre Avg: | 106.145                                     | 129.053   | 134.802   | 64.111    | 54.205    | 20.719    | 7.399     | 0.144     | 0.075    | 0.040   | 0.010   | 0.007   | 0.003   | 0.001   | 0.000   | 0.001 |
|            | Std Dev: | 6.564                                       | 1.967     | 2.588     | 2.321     | 2.511     | 0.845     | 0.656     | 0.016     | 0.017    | 0.016   | 0.005   | 0.005   | 0.001   | 0.000   | 0.000   | 0.000 |
|            | post/pre | 0.168                                       | 0.177     | 0.160     | 0.203     | 0.163     | 0.607     | 1.077     | 10.300    | 3.560    | 1.860   | 2.901   | 1.388   | 3.388   | 7.877   | 6.804   | 8.271 |
| House 1    | Pre Avg: | 38.411                                      | 32.686    | 33.165    | 15.512    | 12.966    | 3.471     | 0.777     | 0.066     | 0.059    | 0.047   | 0.021   | 0.019   | 0.011   | 0.005   | 0.002   | 0.007 |
|            | Std Dev: | 40.521                                      | 29.975    | 24.803    | 10.492    | 8.572     | 3.299     | 0.721     | 0.064     | 0.076    | 0.073   | 0.037   | 0.035   | 0.020   | 0.008   | 0.004   | 0.013 |
|            | post/pre | 0.319                                       | 0.344     | 0.326     | 0.398     | 0.330     | 0.428     | 0.821     | 0.328     | 0.229    | 0.187   | 0.192   | 0.312   | 0.224   | 0.203   | 0.211   | 0.188 |
| House 2    | Pre Avg: | 24.910                                      | 42.531    | 45.502    | 30.405    | 17.247    | 17.017    | 10.070    | 2.393     | 0.979    | 0.649   | 0.503   | 0.204   | 0.206   | 0.046   | 0.014   | 0.031 |
|            | Std Dev: | 16.468                                      | 30.160    | 38.995    | 31.261    | 20.696    | 27.755    | 23.572    | 7.359     | 3.197    | 2.161   | 1.758   | 0.728   | 0.801   | 0.150   | 0.027   | 0.048 |
|            | post/pre | 1.481                                       | 1.263     | 1.076     | 1.121     | 1.281     | 1.484     | 1.371     | 0.638     | 0.266    | 0.137   | 0.102   | 0.119   | 0.130   | 0.298   | 0.534   | 0.583 |
| House 3    | Pre Avg: | 123.530                                     | 137.292   | 159.743   | 79.464    | 85.326    | 45.405    | 24.849    | 1.198     | 0.576    | 0.163   | 0.034   | 0.023   | 0.012   | 0.005   | 0.002   | 0.008 |
|            | Std Dev: | 56.438                                      | 58.894    | 65.471    | 26.877    | 24.808    | 15.409    | 9.129     | 0.516     | 0.263    | 0.073   | 0.026   | 0.023   | 0.014   | 0.006   | 0.003   | 0.013 |
|            | post/pre | 1.364                                       | 1.484     | 1.678     | 1.648     | 1.890     | 1.272     | 0.980     | 0.707     | 0.710    | 0.673   | 1.430   | 1.446   | 1.806   | 1.577   | 1.611   | 1.688 |
| House 4    | Pre Avg: | 34.752                                      | 50.684    | 44.570    | 24.587    | 13.841    | 15.265    | 8.826     | 1.185     | 0.228    | 0.095   | 0.055   | 0.025   | 0.031   | 0.015   | 0.007   | 0.023 |
|            | Std Dev: | 24.155                                      | 32.115    | 23.389    | 9.517     | 4.442     | 5.045     | 3.582     | 0.603     | 0.175    | 0.122   | 0.099   | 0.051   | 0.069   | 0.034   | 0.013   | 0.034 |
|            | post/pre | 1.819                                       | 1.881     | 2.088     | 2.167     | 2.018     | 1.870     | 0.829     | 0.709     | 0.707    | 0.749   | 0.837   | 0.822   | 0.918   | 1.121   | 1.237   |       |
| House 5    | Pre Avg: | 7.475                                       | 13.418    | 13.074    | 7.578     | 4.245     | 3.855     | 1.340     | 0.186     | 0.060    | 0.041   | 0.030   | 0.017   | 0.019   | 0.011   | 0.007   | 0.024 |
|            | Std Dev: | 1.730                                       | 3.202     | 4.599     | 4.088     | 2.434     | 2.173     | 0.652     | 0.104     | 0.047    | 0.039   | 0.032   | 0.019   | 0.023   | 0.014   | 0.010   | 0.038 |
|            | post/pre | 4.138                                       | 3.267     | 3.163     | 3.382     | 3.111     | 2.881     | 3.062     | 2.766     | 3.181    | 2.322   | 1.688   | 1.394   | 1.338   | 1.189   | 1.038   | 0.789 |
| House 6    | Pre Avg: | 81.954                                      | 85.807    | 96.175    | 48.507    | 48.033    | 18.861    | 8.472     | 0.420     | 0.339    | 0.226   | 0.082   | 0.062   | 0.029   | 0.012   | 0.006   | 0.018 |
|            | Std Dev: | 48.754                                      | 45.522    | 45.064    | 21.687    | 22.646    | 10.230    | 4.779     | 0.470     | 0.443    | 0.333   | 0.137   | 0.116   | 0.049   | 0.020   | 0.011   | 0.036 |
|            | post/pre | 1.194                                       | 1.104     | 1.068     | 1.203     | 1.180     | 1.012     | 0.763     | 0.587     | 0.686    | 0.697   | 0.614   | 0.670   | 0.725   | 0.882   | 0.897   | 0.824 |
| House 7    | Pre Avg: | -   | -         | -         | -         | -         | -         | -         | -         | -        | -       | -       | -       | -       | -       | -       | -     |
|            | Std Dev: | -   | -         | -         | -         | -         | -         | -         | -         | -        | -       | -       | -       | -       | -       | -       | -     |
|            | post/pre | 107.759                                     | 105.165   | 119.209   | 60.113    | 64.423    | 31.612    | 9.376     | 0.610     | 0.370    | 0.187   | 0.055   | 0.037   | 0.018   | 0.007   | 0.003   | 0.007 |
| House 8    | Pre Avg: | 44.572                                      | 81.820    | 61.567    | 32.585    | 19.775    | 19.948    | 8.195     | 0.961     | 0.157    | 0.055   | 0.025   | 0.010   | 0.010   | 0.005   | 0.003   | 0.008 |
|            | Std Dev: | 26.472                                      | 36.367    | 27.897    | 17.925    | 11.486    | 10.895    | 4.380     | 0.832     | 0.127    | 0.043   | 0.020   | 0.010   | 0.013   | 0.007   | 0.004   | 0.013 |
|            | post/pre | 1.241                                       | 1.038     | 1.334     | 1.141     | 1.144     | 0.953     | 0.948     | 0.996     | 2.594    | 4.078   | 6.096   | 6.576   | 6.719   | 3.559   | 2.682   | 2.644 |

Note: Pre-cleaning is entire period prior to 0600 on cleaning day, while post-cleaning is entire period from 0600 on day following cleaning to end of day.

a - Data lost due to power failure and technician error

**APPENDIX G**

**RESULTS OF SCANNING ELECTRON MICROSCOPY ANALYSES OF SAMPLES  
COLLECTED AT THE NINE STUDY HOMES**

Log of SEM Samples

| <u>House</u> | <u>Pre-Cleaning Sample</u> | <u>Post-Cleaning Sample</u> |
|--------------|----------------------------|-----------------------------|
| TH           | AEFIB0021                  | AEFIB0033                   |
| 1            | AEFIB0049                  | AEFIB0059                   |
| 2            | AEFIB0055                  | AEFIB0063                   |
| 3            | AEFIB0072                  | AEFIB0080                   |
| 4            | AEFIB0077                  | AEFIB0081                   |
| 5            | AEFIB0097                  | AEFIB0100                   |
| 6            | AEFIB0108                  | AEFIB0109                   |
| 7            | AEFIB0125                  | AEFIB0127                   |
| 8            | AEFIB0133                  | AEFIB0136                   |

# RJ LeeGroup, Inc.

350 Hochberg Road • Monroeville, PA 15146  
412/325-1776 • FAX 412/733-1799

June 17, 1996

Mr. Cary P. Gentry  
Acurex Environmental, Inc.  
P.O. Box 13109  
Research Triangle Park, NC 27709

RE: Analysis of MCE Filters  
RJ Lee Group Project No. AOW605190

Dear Mr. Gentry:

Enclosed are the results of the analyses of the two MCE filters which we received on June 3, 1996 (reference your Chain of Custody dated May 31, 1996). The samples were identified by you as AEFIB0021 and AEFIB0033 and were assigned RJ Lee Group Sample Nos. 609237 and 609238, respectively.

The purpose of this investigation was to characterize the air filter particulate paying particular attention to the fibrous material. Manual scanning electron microscopy (SEM) was the method used. The as-received samples were previewed using a stereo optical microscope. One half of each filter was attached to an SEM stub using carbon tape and given a thin coating of carbon by evaporative deposition to prevent charging during analysis.

## Sample AEFIB0021 (RJ Lee Group Sample No.609237)

### Light Microscopy - General Appearance

The cassette contained an MCE filter with a moderate loading (heavier loading toward the center) of brown-to-black particulate.

### MSEM Evaluation

| <u>Particle Type</u> | <u>Comments</u>   | <u>Estimated Contribution*</u> |
|----------------------|---|--------------------------------|
| Si/Al-rich particles | Clay minerals (some associated with Ca/S-rich or Fe-rich particles) | Major                          |
| Cu-rich particles    | 1-4 $\mu\text{m}$ , commonly spheres                                | Moderate                       |
| Si-rich particles    | Quartz (2-10 $\mu\text{m}$ )  | Minor                          |
| Ca/S-rich particles  |   |                                |
| Fe-rich particles    |   |                                |
| Cellulose            |   | Trace                          |
| Fibrous glass        | 1 observed (50 $\mu\text{m}$ x 1 $\mu\text{m}$ )                    | Trace                          |

\* Definitions for acronyms, "Estimated Contribution" and the elemental names for the symbols listed in this report can be found on the page 3.

Sample AEFIB0033 (RJ Lee Group Sample No.609238)

Light Microscopy - General Appearance

The cassette contained an MCE filter with heavy loading of brown-to-black particulate.

MSEM Evaluation

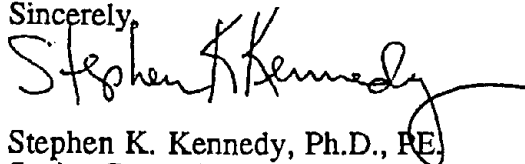
| <u>Particle Type</u> | <u>Comments</u>  | <u>Estimated Contribution</u> |
|----------------------|--|-------------------------------|
| Si/Al-rich particles | Clay minerals (some associated with Fe-rich particles up to 25 $\mu\text{m}$ .) A few spheres were observed. | Major                         |
| C-rich particles     | Blocky in shape (up to 10 $\mu\text{m}$ ). A few spheres and 1 skin flake was observed.                      | Moderate                      |
| Cellulose            |  | Trace                         |
| Ca/S-rich particles  | 2-5 $\mu\text{m}$  | Trace                         |
| Fe-rich particles    | 2-5 $\mu\text{m}$  | Trace                         |
| Ti-rich particles    | 2 $\mu\text{m}$  | Trace                         |
| Pb                   | 1 particle observed (1 $\mu\text{m}$ )   | Trace                         |
| Cu                   |  | Trace                         |

The overall composition of the two samples was similar, but Sample AEFIB0033 was considerably heavier in loading and consisted of larger particulate (up to 25  $\mu\text{m}$  was common). The major component in both samples was Si/Al-rich particles (see Figure 1). Copper particles were commonly observed in AEFIB0021 but were rarely observed in sample AEFIB0033 (see Figure 2). Representative images of Si-rich and Ca/S-rich particles are shown in Figures 3 and 4, respectively. Other than cellulose, fibers were not common in either sample but one fibrous glass was observed in sample AEFIB0021 (see Figure 5), and a rock wool and manmade fiber were observed in AEFIB0033.

These results are submitted pursuant to RJ Lee Group's current terms and conditions of sale, including the company's standard warranty and limitation of liability provisions. No responsibility or liability is assumed for the manner in which the results are used or interpreted. Unless notified to return the samples covered by this report, RJ Lee Group will store them for a period of thirty (30) days before discarding.

Should you have any questions regarding this information, please do not hesitate to contact me.

Sincerely,



Stephen K. Kennedy, Ph.D., PE  
Senior Geologist  
Environmental Services

SKK:dls  
Attachments

## Definitions

### Acronyms

|      |                                     |
|------|-------------------------------------|
| EDS  | Energy dispersive spectroscopy      |
| MSEM | Manual scanning electron microscopy |
| µm   | Micrometers                         |

### Chemical Elements

|    |          |
|----|----------|
| Al | Aluminum |
| C  | Carbon   |
| Ca | Calcium  |
| Cu | Copper   |
| Fe | Iron     |
| Pb | Lead     |
| S  | Sulfur   |
| Si | Silicon  |
| Ti | Titanium |

## Estimated Contribution

|          |   |
|----------|---|
| Major    | Estimated to comprise > 40 percent of the sample by number              |
| Moderate | Estimated to comprise between 20 and 40 percent of the sample by number |
| Minor    | Estimated to comprise between 5 and 20 percent of the sample by number  |
| Trace    | Estimated to comprise < 5 percent of the sample by number               |

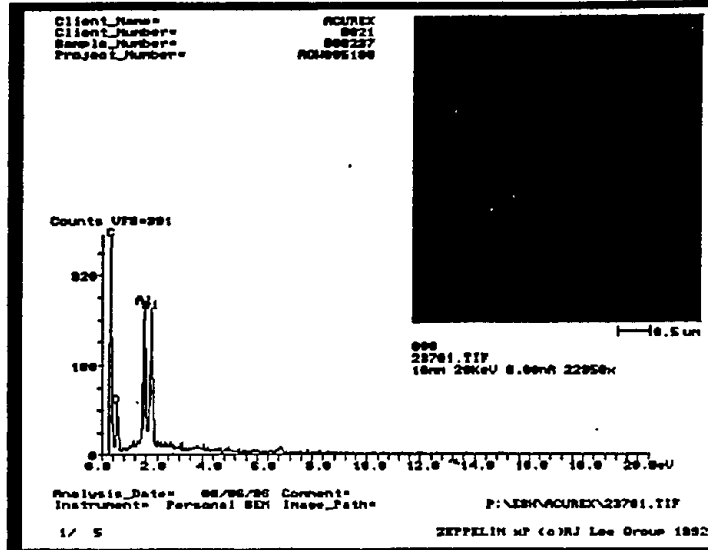


Figure 1. Representative backscattered electron image and EDS spectrum of Si/Al-rich particle

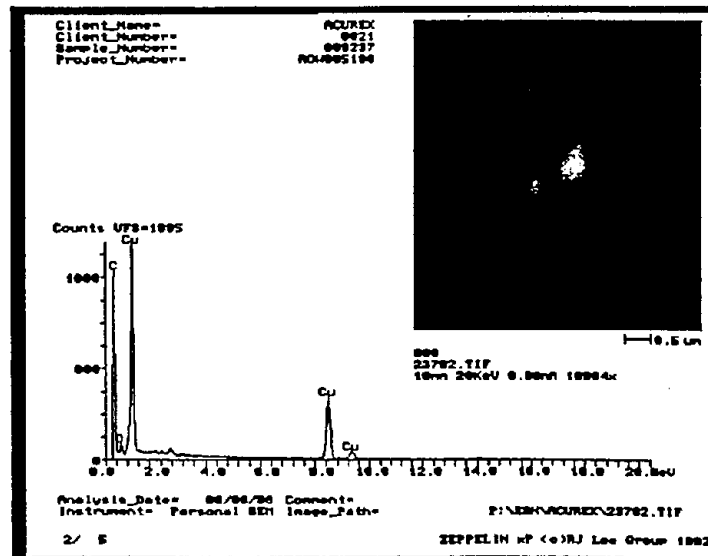


Figure 2. Representative backscattered electron image and EDS spectrum of Cu particle

ACUREX ENVIRONMENTAL, INC.  
RJ Lee Group Project No. AOW605190

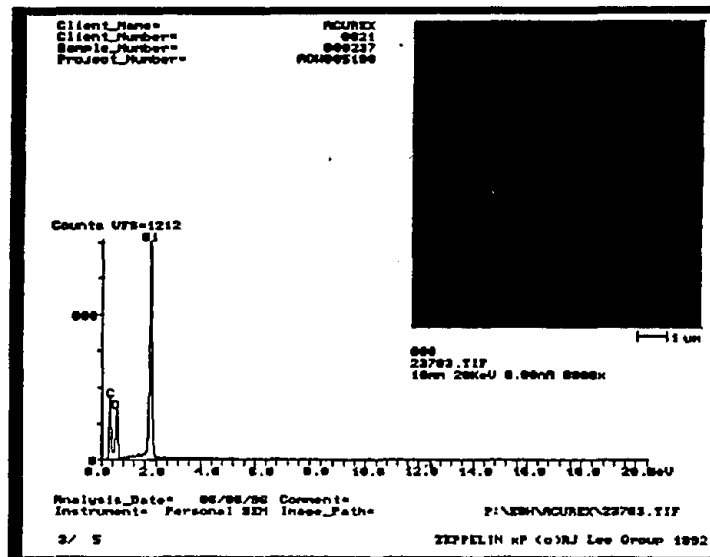


Figure 3. Representative backscattered electron image and EDS spectrum of Si-rich particle

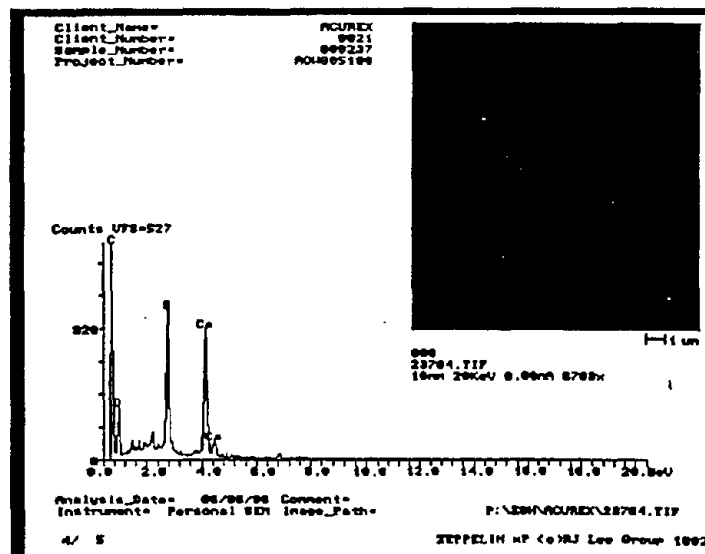


Figure 4. Representative backscattered electron image and EDS spectrum of Ca/S-rich particle

ACUREX ENVIRONMENTAL, INC.  
RJ Lee Group Project No. AOW605190

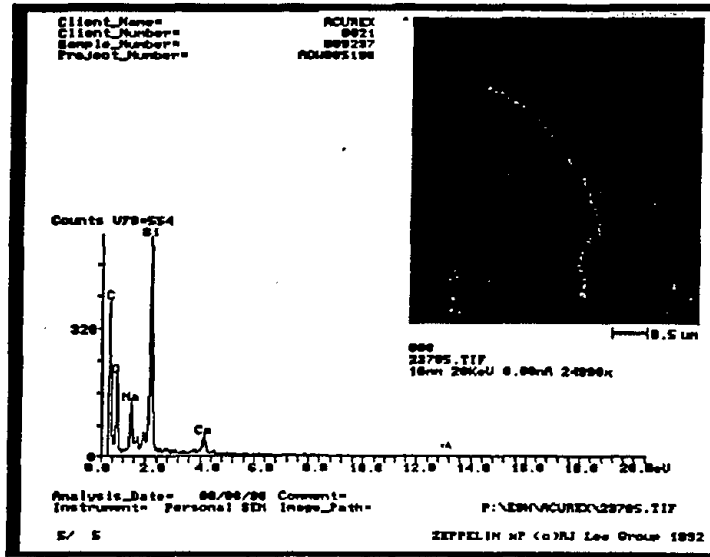


Figure 5. Representative backscattered electron image and EDS spectrum of fibrous glass

# RJ LeeGroup, Inc.

350 Hochberg Road • Monroeville, PA 15146  
412/325-1776 • FAX 412/733-1799

June 27, 1996

Mr. Gary Gentry  
Acurex Environmental, Inc.  
P.O. Box 13109  
Research Triangle Park, NC 27709

RE: Characterization of Four Polycarbonate Filter Samples  
RJ Lee Group Project No. AOW606118

Dear Mr. Gentry:

Enclosed you will find a summary of the analytical results for the four air samples that you recently sent us (reference your Laboratory Request dated June 21, 1996). The samples were identified as follows:

| <u>Acurex Environmental<br/>Sample ID</u> | <u>RJ Lee Group<br/>Sample No.</u> |
|---|------------------------------------|
| 49  | 609343                             |
| 55  | 609344                             |
| 59  | 609345                             |
| 63  | 609346                             |

The purpose of this investigation was to characterize material collected on the sampling cassettes by manual scanning electron microscopy (MSEM). MSEM distinguishes among different particle types based on morphology and elemental composition utilizing backscattered electron imaging (BSI) and energy dispersive spectroscopy (EDS). In the BSI mode, higher atomic number elements generate more backscattered electrons than do lower atomic number elements resulting in a brighter image for heavier materials. Elemental composition of each species can be obtained utilizing (EDS) techniques. Sample preparation involved mounting a portion of the filter onto an SEM stub and coating it with a thin layer of carbon by evaporative deposition under vacuum.

## Acurex Environmental Sample No. 49 (RJ Lee Group Sample No.609343)

| <u>Particle Type</u> | <u>Comments</u>         | <u>Estimated Contribution</u> |
|----------------------|-------------------------|-------------------------------|
| C-rich particles     | Combustion Material     | 85%                           |
| Si/Al-rich           | Feldspar                | 10%                           |
| Miscellaneous        | Earth Crustal Materials | 5%                            |

The bulk of the particulate on the filters was carbon-rich particles. These particles were dominantly spheres <1  $\mu\text{m}$  in diameter. Minor sulfur was associated with these spheres suggesting formation from a combustion source (see Figure 1). Feldspars were present as >2  $\mu\text{m}$  particles and miscellaneous particulate consisted of earth crustal materials (see Figures 2 and 3).

**Acurex Environmental Sample No. 55 (RJ Lee Group Sample No.609344)**

| <u>Particle Type</u> | <u>Comments</u>        | <u>Estimated Contribution</u> |
|----------------------|------------------------|-------------------------------|
| C-rich particles     | Carbonaceous Fragments | 100%                          |

Only carbonaceous particles were present on this filter. The sample was composed of particles similar to plant and insect fragments (see Figures 4 and 5), a few less than 1  $\mu\text{m}$  spheres, and miscellaneous carbon particles. Carbonaceous spheres (<1  $\mu\text{m}$ ) consisted of approximately 5% of the bulk particulate. This sample also contained the lightest particle loading of the four samples.

**Acurex Environmental Sample No. 59 (RJ Lee Group Sample No. 609345)**

| <u>Particle Type</u> | <u>Comments</u>        | <u>Estimated Contribution</u> |
|----------------------|------------------------|-------------------------------|
| C-rich particles     | Carbonaceous Fragments | 100%                          |

Sample 609245 contained carbon-rich particles consisting of plant and animal fragments and other miscellaneous carbon particles. Figures 6 and 7 show the typical carbonaceous fragments observed within the sample. A few carbon spheres without sulfur were observed.

**Acurex Environmental Sample No. 63 (RJ Lee Group Sample No.609346)**

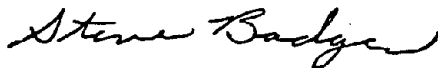
| <u>Particle Type</u> | <u>Comments</u>         | <u>Estimated Contribution</u> |
|----------------------|-------------------------|-------------------------------|
| C-rich particles     | Combustion Material     | 95%                           |
| Miscellaneous        | Earth Crustal Materials | 5%                            |

The majority of this sample consisted of >1  $\mu\text{m}$  spheres with minor sulfur contents suggesting a combustion source. Figure 8 shows a cellulose particle (left) and a wood fragment (right). Figure 9 is a carbon-rich phase abundant within the carbon-rich particles. Miscellaneous particles consisted of feldspars and other earth crustal particles.

These results are submitted pursuant to RJ Lee Group's current terms of sale, including the company's standard warranty and limitation of liability provisions and no responsibility or liability is assumed for the manner in which the results are used or interpreted.

Should you have any questions regarding this information, please do not hesitate to contact John Johns before 3:00 p.m. or me after 3:00 p.m.

Sincerely,



Steve Badger  
Project Manager  
Environmental Services

SB:dls  
Attachments

Figure 1

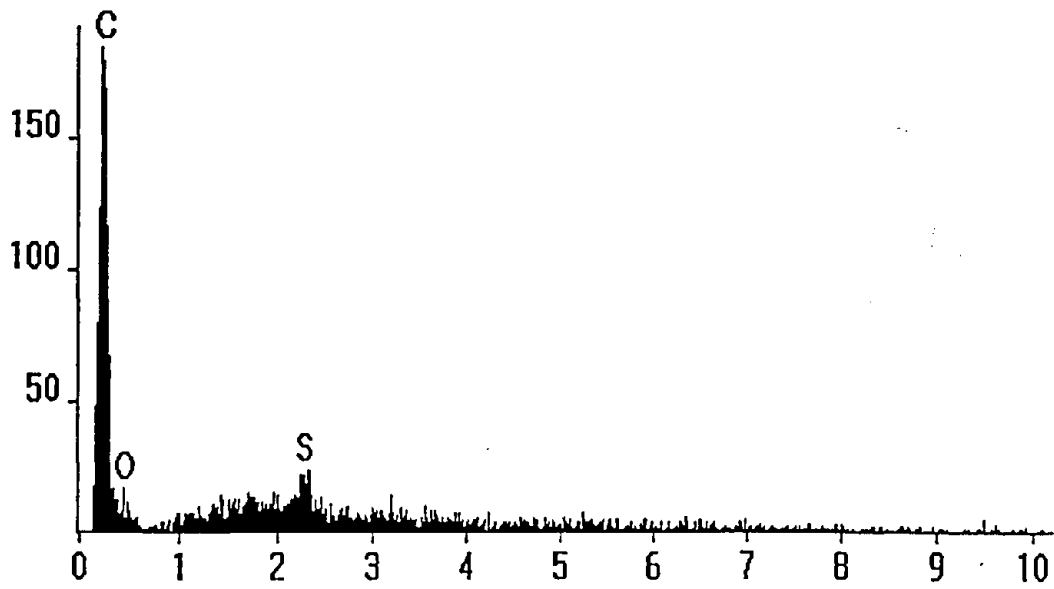
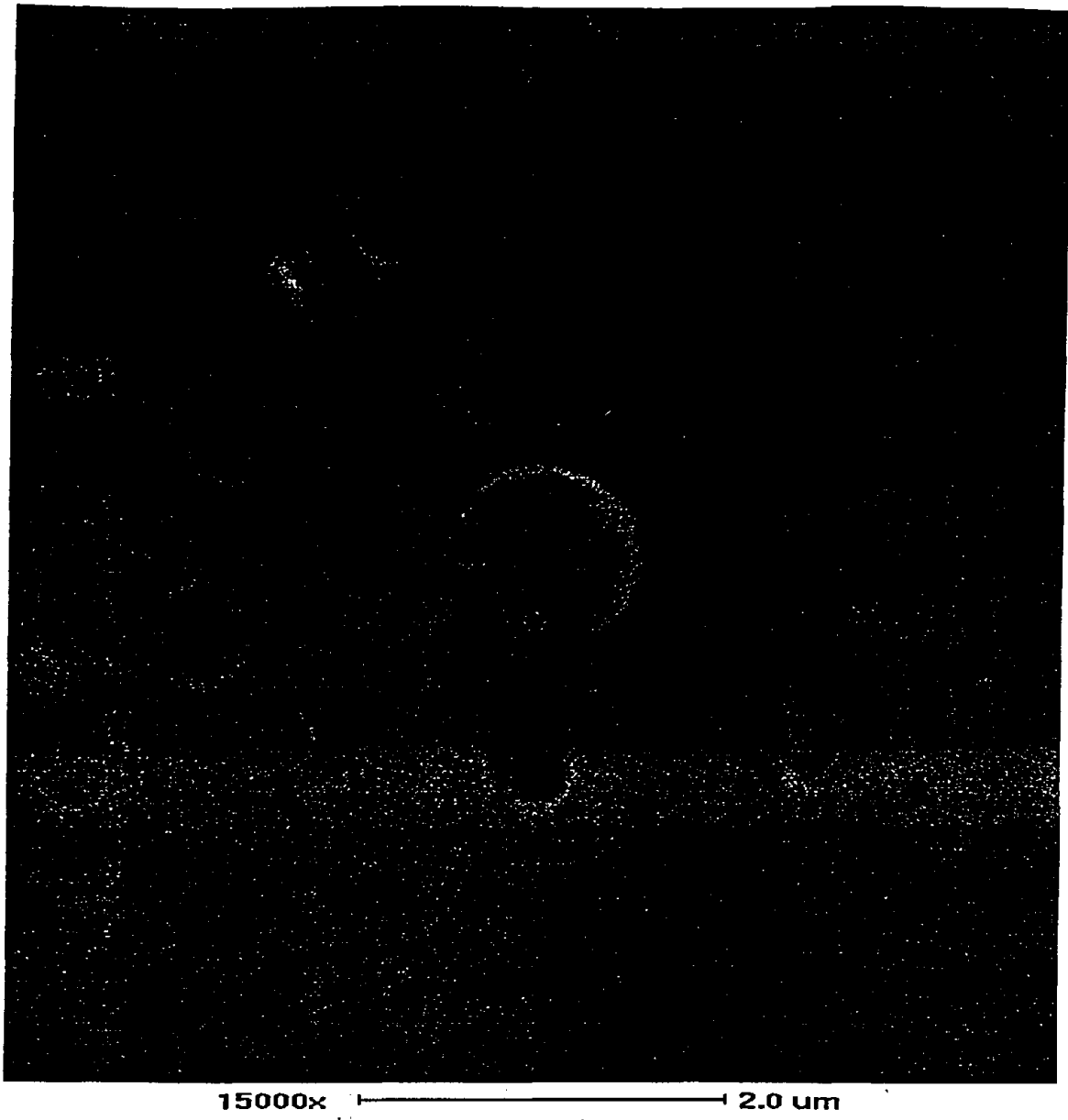


Figure 2 (EDS of right particle)

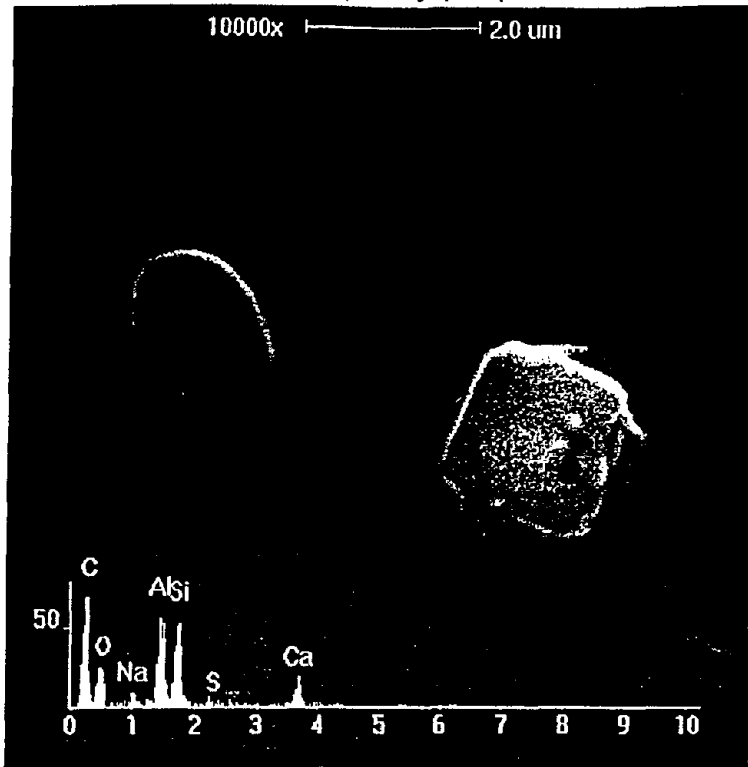


Figure 3

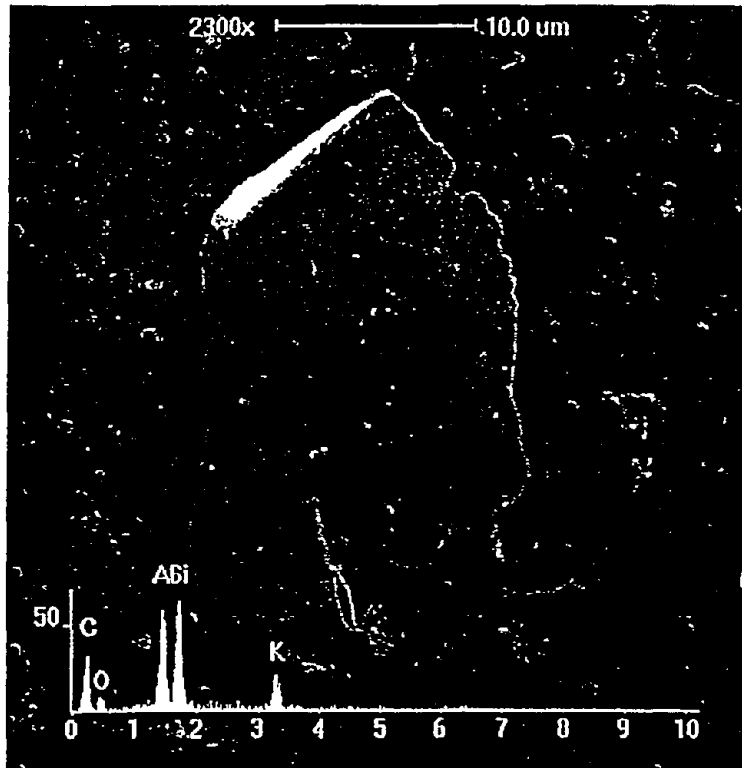


Figure 4

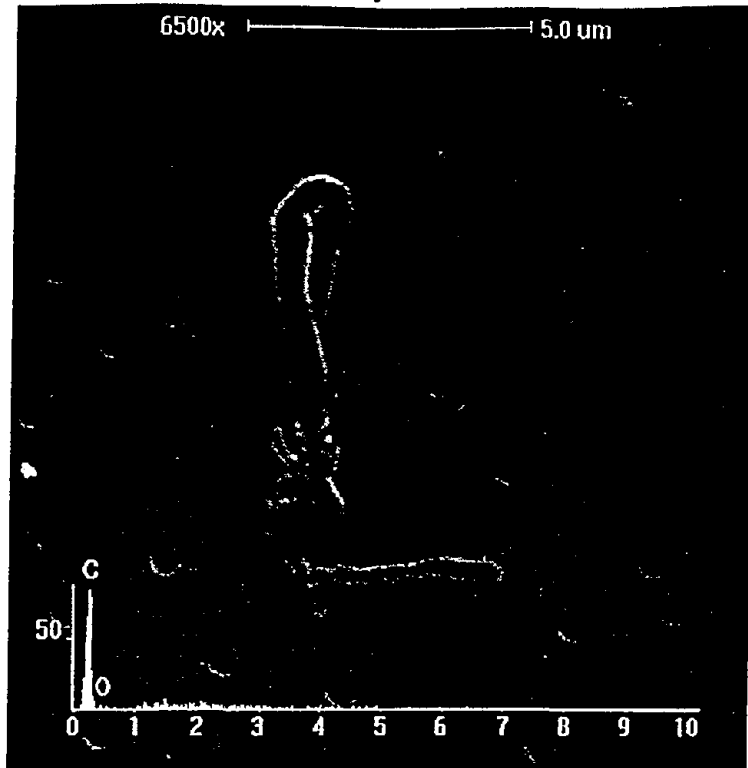


Figure 5

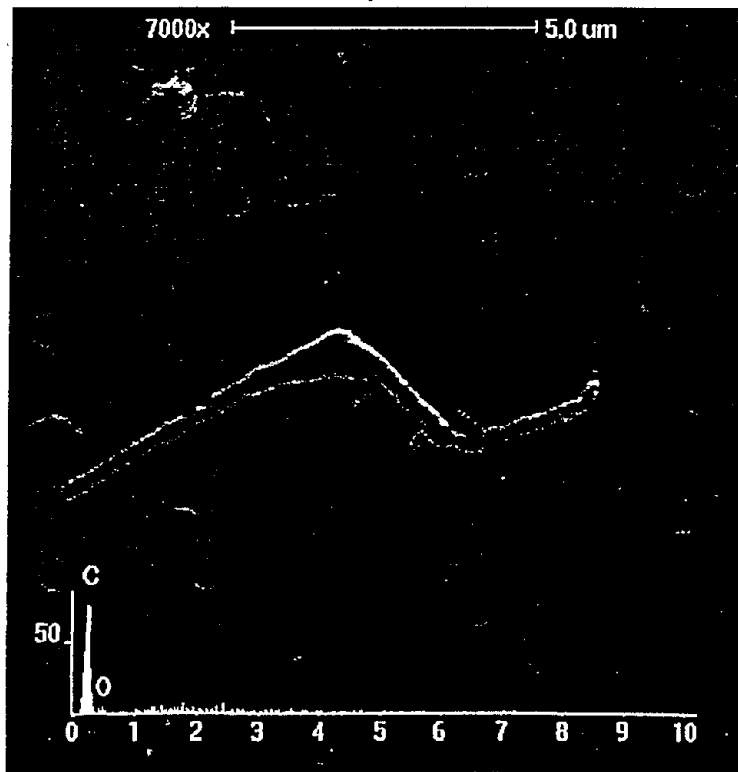


Figure 6

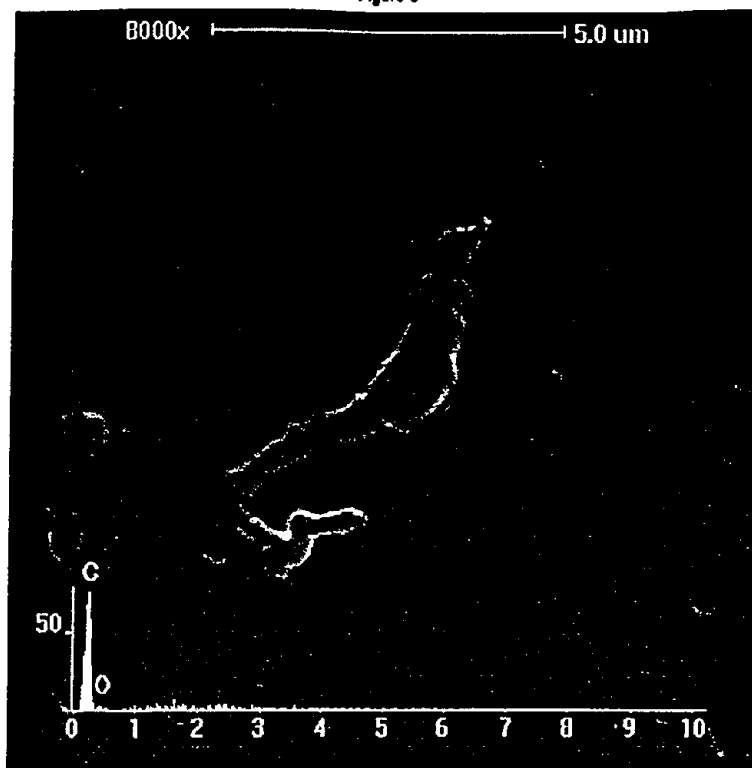


Figure 7

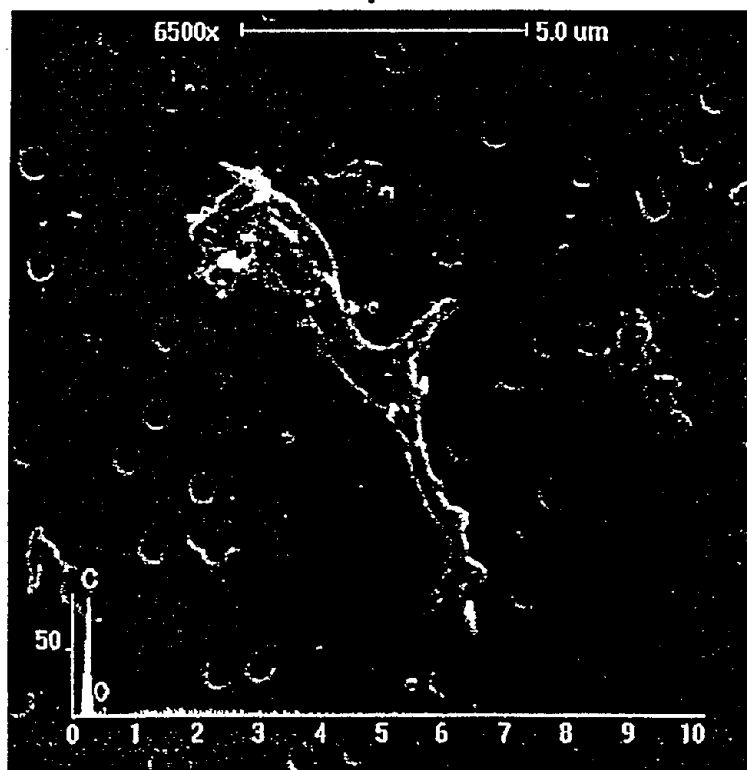


Figure 8

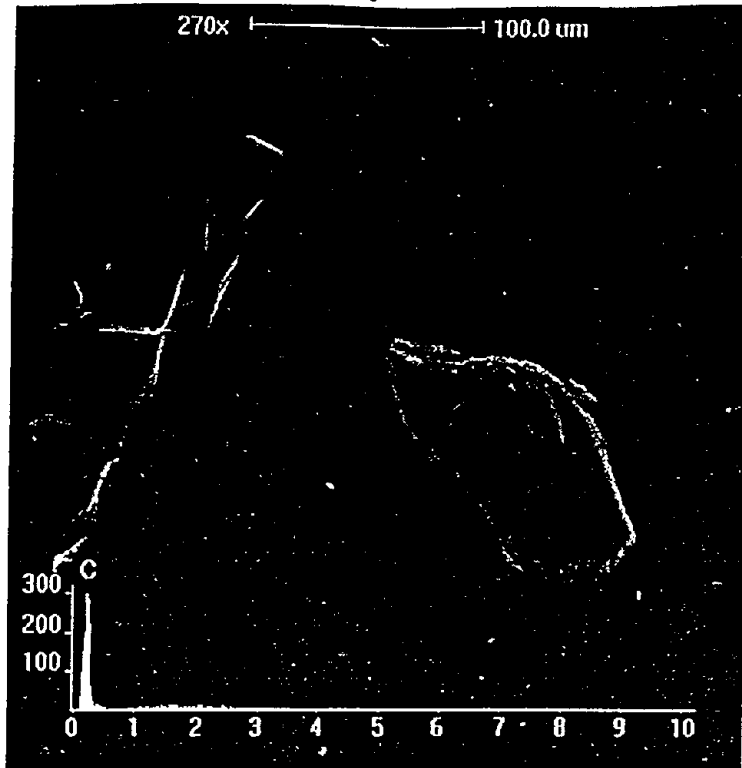
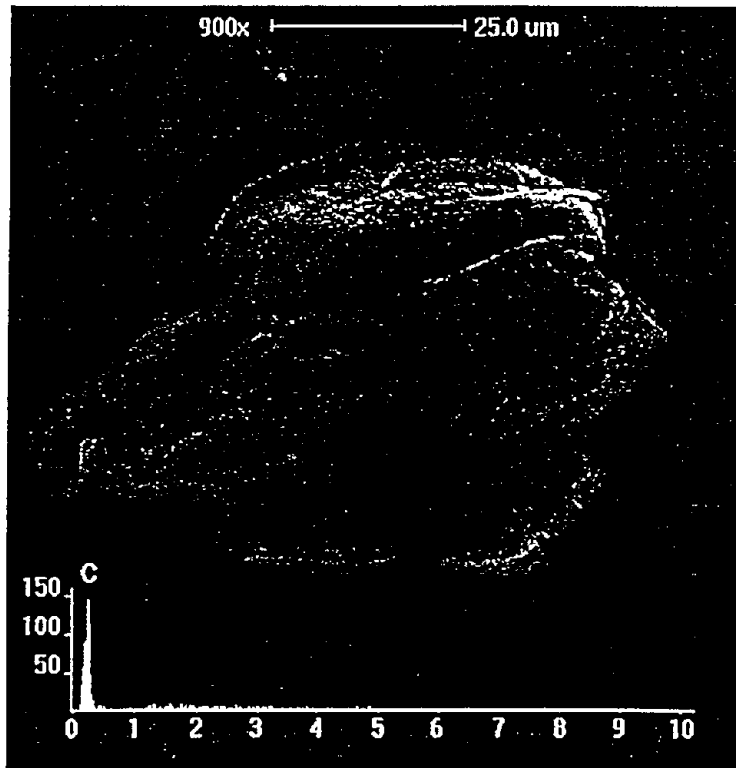


Figure 9



# RJ LeeGroup, Inc.

350 Hochberg Road • Monroeville, PA 15146  
412/325-1776 • FAX 412/733-1799

July 15, 1996

Mr. Gary Gentry  
Acurex Environmental, Inc.  
4915 Prospectus Dr.  
Durham, NC 27713

RE: Characterization of Four Air Samples  
RJ Lee Group Project No. AOW607044

Dear Mr. Gentry:

Enclosed you will find a summary of the analytical results for the filter samples that you recently sent us (reference your Laboratory Request dated July 8, 1996). The samples were identified as follows:

| <u>Acurex<br/>Sample ID</u> | <u>RJ Lee Group<br/>Sample No.</u> |
|-----------------------------|------------------------------------|
| AEFIB0077                   | 609423                             |
| AEFIB0081                   | 609424                             |
| AEFIB0072                   | 609425                             |
| AEFIB0080                   | 609426                             |

The purpose of this investigation was to characterize material collected on four 37 mm polycarbonate filters by manual scanning electron microscopy (MSEM). MSEM distinguishes among different particle types based on morphology and elemental composition utilizing backscattered electron imaging (BSI) and energy dispersive spectroscopy (EDS). In the BSI mode, higher atomic number elements generate more backscattered electrons than do lower atomic number elements resulting in a brighter image for heavier materials. Elemental composition of each species can be obtained utilizing (EDS) techniques. Sample preparation involved mounting a portion of the filter onto an SEM stub and also by shaking fine particulate matter and fibers from the filter onto carbon tape which was attached to a SEM stub. The stubs were coated with a thin layer of carbon by evaporative deposition under vacuum.

## Sample ID AEFIB0077 (RJ Lee Group Sample ID 609423)

| <u>Particle Type</u> | <u>Comments</u>   | <u>Estimated Contribution*</u> |
|----------------------|-------------------|--------------------------------|
| C-rich               | Flakes, Cellulose | Major                          |
| Si-rich              | Quartz            | Minor                          |
| Si/Al-rich           | Feldspar          | Trace                          |
| C-rich               | Plant Fragments   | Trace                          |
| C-rich               | Pollen            | Trace                          |
| C-rich               | Mold              | Trace                          |

\* Definitions for acronyms, "Estimated Contribution" and the elemental names for the symbols listed in this report can be found on page 4.

The majority of the particulate on this filter was carbon-rich. These carbon-rich particles were dominantly flakes with a morphology similar to that of skin (see Figure 1). Cellulose fibers typically possessed lengths of less than 40  $\mu\text{m}$ . Earth crustal materials such as quartz (see Figure 2) and feldspar particles were less than 10  $\mu\text{m}$  in diameter. Carbon spheres of less than 3  $\mu\text{m}$  were observed in trace amounts and resembled mold.

**Sample ID AEFIB0081 (RJ Lee Group Sample ID 609424)**

| <u>Particle Type</u> | <u>Comments</u>   | <u>Estimated Contribution</u> |
|----------------------|-------------------|-------------------------------|
| C-rich               | Flakes, Cellulose | Major                         |
| Si/Al-rich           | Feldspar          | Moderate                      |
| Si-rich              | Quartz            | Minor                         |
| Ca-rich              |                   | Trace                         |

Carbonaceous particles composed the majority of this sample and earth crustal particles were found in moderate concentrations in the less than 5  $\mu\text{m}$  sized particles. Si-rich particles were less than 10  $\mu\text{m}$  in size. Pollen and mold particles were not observed on this sample.

**Sample ID AEFIB0072 (RJ Lee Group Sample ID 609425)**

| <u>Particle Type</u> | <u>Comments</u>                      | <u>Estimated Contribution</u> |
|----------------------|--------------------------------------|-------------------------------|
| C-rich               | Flakes, Cellulose                    | Major                         |
| Si/Al-rich           | Feldspar                             | Minor                         |
| Si-rich              | Quartz                               | Minor                         |
| C-rich               | Pollen                               | Trace                         |
| C-rich               | Mold                                 | Trace                         |
| C/S/Ca-rich          | <3 $\mu\text{m}$ Spherical Particles | Trace                         |
| Ca/S-rich            |                                      | Trace                         |
| Fe-rich              |                                      | Trace                         |
| Al/P/Cl-rich         |                                      | Trace                         |

The majority of this filter consisted of carbonaceous particles with a minor amount of earth crustal particles (Si/Al-rich and Si-rich particle types).

**Sample ID AEFIB0080 (RJ Lee Group Sample ID 609426)**

| <u>Particle Type</u> | <u>Comments</u>     | <u>Estimated Contribution</u> |
|----------------------|---------------------|-------------------------------|
| C-rich               | Flakes, Cellulose   | Major                         |
| Si/Al-rich           | Feldspar            | Moderate                      |
| C-rich               | Pollen              | Trace                         |
| C-rich               | Mold                | Trace                         |
| C-rich               | Possible Toner Dust | Trace                         |
| Si/Mg-rich           |                     | Trace                         |
| Si/Ca-rich           |                     | Trace                         |
| Si-rich              |                     | Trace                         |
| Ca/Mg-rich           |                     | Trace                         |

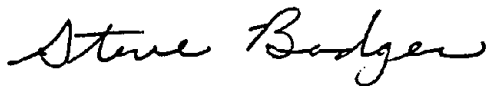
Mr. Gary Gentry  
RJ Lee Group Project No. AOW607044  
July 15, 1996  
Page 3

Carbon-rich particles were the major particle type observed on this filter and consisted dominantly of flakes (see Figure 3). Feldspars were found in moderate concentrations and were less than 10  $\mu\text{m}$  in diameter. Nearly spherical pollen grains were in the less than 12  $\mu\text{m}$  particle fraction and less than 5  $\mu\text{m}$  carbon-rich particles were molds (see Figure 4).

These results are submitted pursuant to RJ Lee Group's current terms and conditions of sale, including the company's standard warranty and limitation of liability provisions. No responsibility or liability is assumed for the manner in which the results are used or interpreted. Unless notified in writing to return the samples covered by this report, RJ Lee Group will store the samples for a period of thirty (30) days before discarding.

Should you have any questions regarding this information, please do not hesitate to contact John Johns or me.

Sincerely,



Steve Badger  
Project Manager  
Environmental Services

SRB:dls

c: J. C. Johns

### Definitions

#### Acronyms

|      |                                     |
|------|-------------------------------------|
| EDS  | Energy dispersive spectroscopy      |
| MSEM | Manual scanning electron microscopy |
| µm   | Micrometers                         |

#### Chemical Elements

|    |             |
|----|-------------|
| Al | Aluminum    |
| C  | Carbon      |
| Ca | Calcium     |
| Cl | Chlorine    |
| Fe | Iron        |
| Mg | Magnesium   |
| P  | Phosphorous |
| S  | Sulfur      |
| Si | Silicon     |

#### Estimated Contribution

|          |   |
|----------|---|
| Major    | Estimated to comprise > 40 percent of the sample by number              |
| Moderate | Estimated to comprise between 20 and 40 percent of the sample by number |
| Minor    | Estimated to comprise between 5 and 20 percent of the sample by number  |
| Trace    | Estimated to comprise < 5 percent of the sample by number               |

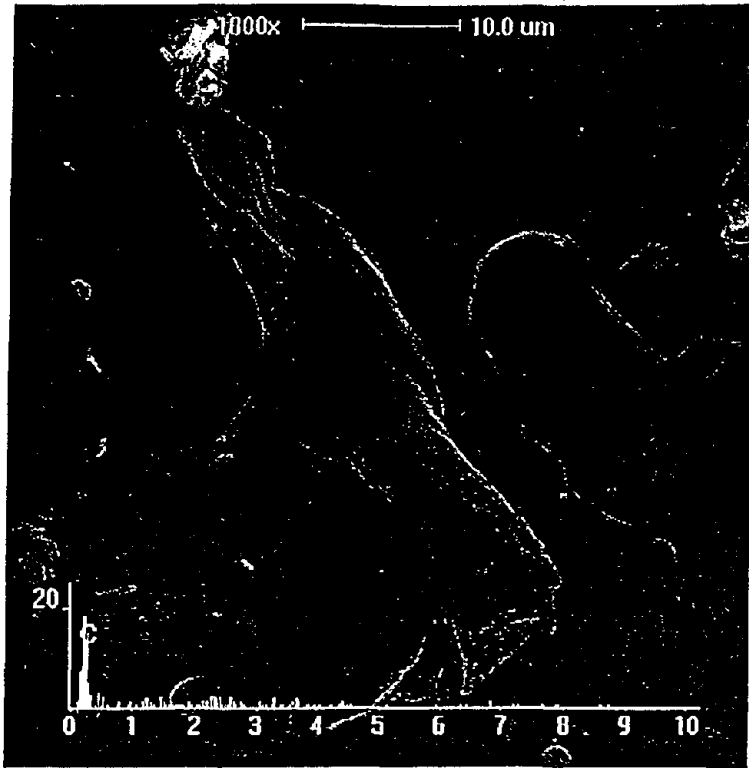


Figure 1

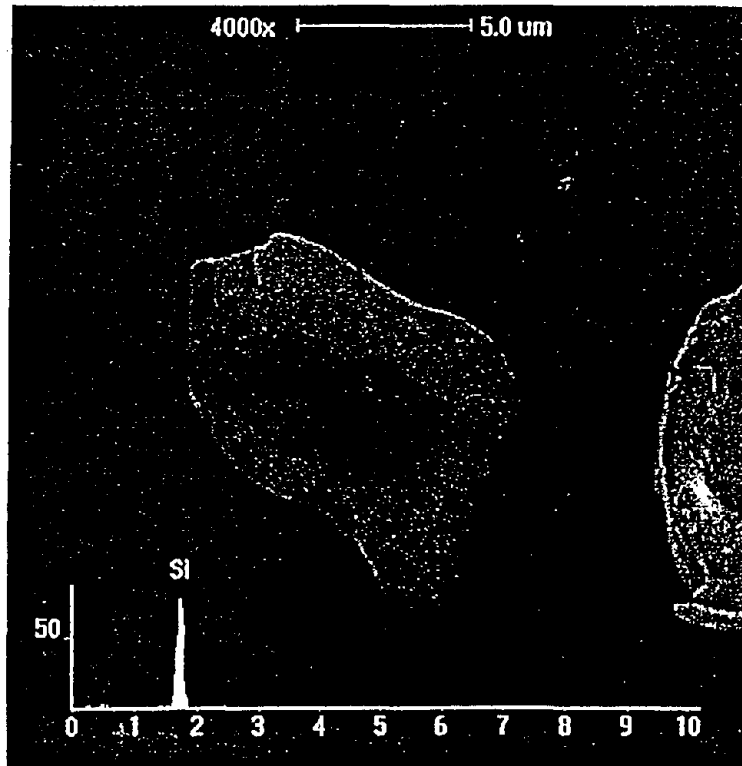


Figure 2

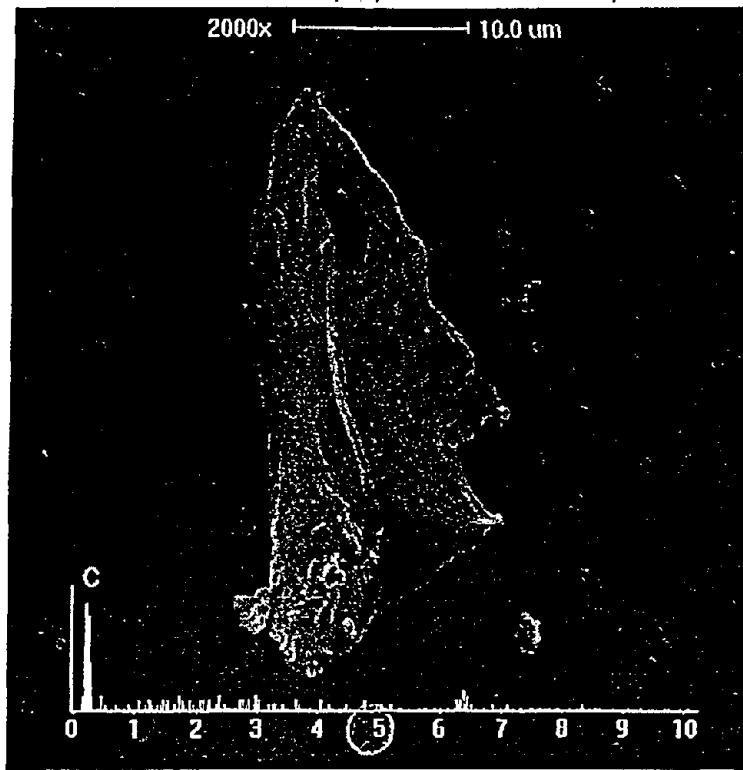


Figure 3

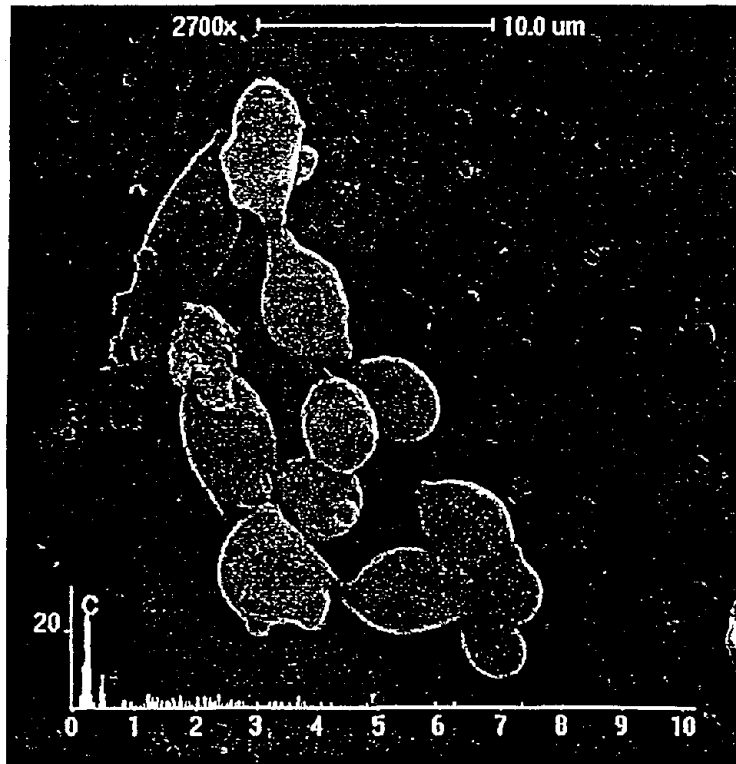


Figure 4

# RJ LeeGroup, Inc.

August 7, 1996

350 Hochberg Road • Monroeville, PA 15146  
412/325-1776 • FAX 412/733-1799

Mr. Gary Gentry  
Acurex Environmental, Inc.  
P.O. Box 13109  
Research Triangle Park, NC 27709

RE: Characterization of four polycarbonate filter samples  
RJ Lee Group Project No. AOW607198

Dear Mr. Gentry:

Enclosed you will find a summary of the analytical results for the air samples that you recently sent us (reference your Laboratory Request dated July 30, 1996). The samples were identified as follows:

| <u>Acurex Environmental Sample ID</u> | <u>RJ Lee Group Sample ID</u> |
|---------------------------------------|-------------------------------|
| 0097                                  | 609667                        |
| 0100                                  | 609668                        |
| 0108                                  | 609669                        |
| 0109                                  | 609670                        |

The purpose of this investigation was to characterize material collected on the polycarbonate filters by manual scanning electron microscopy (MSEM). MSEM distinguishes among different particle types based on morphology and elemental composition utilizing secondary electron imaging (SEI), backscattered electron imaging (BEI) and energy dispersive spectroscopy (EDS). SEI is used to obtain a three dimensional image of the specimen. In the BEI mode, higher atomic number elements generate more backscattered electrons than do lower atomic number elements resulting in a brighter image for heavier materials. Elemental composition of each species can be obtained utilizing (EDS) techniques. Sample preparation involved mounting a portion of the filter onto an SEM stub and coating it with a thin layer of carbon by evaporative deposition under vacuum.

Acurex Environmental, Inc. No. 0097 (RJ Lee Group Sample No. 609667)

| <u>Particle Type</u> | <u>Comments</u>                     | <u>Estimated Contribution</u> |
|----------------------|-------------------------------------|-------------------------------|
| C-rich flakes        | Skin Flakes                         | Major                         |
| C-rich fibers        | Cellulose                           | Minor                         |
| Si/Al-rich           | Earth Crustal (Feldspars and Clays) | Minor                         |
| Si-rich              | Quartz                              | Trace                         |
| Ca/S-rich            | Gypsum                              | Trace                         |
| C-rich               | Wood                                | Trace                         |
| K/Cl-rich            | Salt                                | Trace                         |
| Fe-rich              |                                     | Trace                         |

The majority of the particulate on the filter was carbon-rich particles. These particles were dominantly skin flakes with diameters typically less than 50 microns and cellulose (see Figure 1). Earth crustal particles were typically less than 15 microns in diameter. Ca/S-rich particles were less than 5 microns in diameter and were likely gypsum, a common building material.

Acurex Environmental, Inc. No. 0100 (RJ Lee Group Sample No. 609668)

| <u>Particle Type</u> | <u>Comments</u>                   | <u>Estimated Contribution</u> |
|----------------------|-----------------------------------|-------------------------------|
| C-rich flakes        | Skin Flakes                       | Major                         |
| C-rich fibers        | Cellulose                         | Minor                         |
| Si/Al-rich           | Earth Crustal (Feldspar and Clay) | Minor                         |
| Si-rich              | Quartz                            | Trace                         |
| Ca-rich              |                                   | Trace                         |

The dominant particle types on this filter were skin flakes, cellulose, and earth crustal particles. The skin flakes were typically less than 50 microns in diameter and earth crustal particles were less than 15 microns in diameter. Trace amounts of pollen (12-15 micron diameters) were identified as spherical carbon-rich particles.

Acurex Environmental, Inc. No. 0108 (RJ Lee Group Sample No. 609669)

| <u>Particle Type</u> | <u>Comments</u>                   | <u>Estimated Contribution</u> |
|----------------------|-----------------------------------|-------------------------------|
| C-rich flakes        | Skin Flakes                       | Major                         |
| C-rich fibers        | Cellulose                         | Minor                         |
| Si/Al-rich           | Earth Crustal (Feldspar and Clay) | Minor                         |
| Si/Mg-rich           |                                   | Minor                         |
| Al/P/Cl-rich         |                                   | Minor                         |
| Si-rich              | Quartz                            | Trace                         |
| Ca/S-rich            | Gypsum                            | Trace                         |
| C-rich               | Pollens                           | Trace                         |
| Fe-rich              |                                   | Trace                         |

The particulate on this filter was dominantly skin flakes. Si/Mg-rich (Figure 2) and Al/P/Cl-rich particles (Figure 3) were not found on the filters 0097 and 0100. Also, Al/P/Cl-rich particles were not found on any of the other filters. The Si/Mg-rich particles were less than 30 microns in diameter and the Al/P/Cl-rich particles were less than 15 microns in diameter. The origin the Si/Mg-rich and Al/P/Cl-rich particles is unknown.

Acurex Environmental Inc. No. 0109 (RJ Lee Group Sample No. 609670)

| <u>Particle Type</u> | <u>Comments</u>                   | <u>Estimated Contribution</u> |
|----------------------|-----------------------------------|-------------------------------|
| C-rich flake         | Skin Flake                        | Major                         |
| C-rich fiber         | Cellulose                         | Minor                         |
| Si/Al-rich           | Earth Crustal (Feldspar and Clay) | Minor                         |
| Si/Mg-rich           |                                   | Minor                         |
| Si-rich              | Quartz                            | Trace                         |
| C-rich               | Pollen                            | Trace                         |
| C-rich               | Mold                              | Trace                         |
| Fe-rich              |                                   | Trace                         |

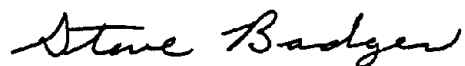
The majority of this sample consisted of skin flakes. Si/Mg rich particles were less than 30 microns in diameter. Pollen particles (Figure 4) were 10 to 14 microns in diameter.

Mr. Gary Gentry  
RJ Lee Group Project No. AOW607198  
August 7, 1996  
Page 3

These results are submitted pursuant to RJ Lee Group's current terms of sale, including the company's standard warranty and limitation of liability provisions and no responsibility or liability is assumed for the manner in which the results are used or interpreted.

Should you have any questions regarding this information, please do not hesitate to contact me.

Sincerely,



Steve Badger  
Project Manager  
Environmental Services

SB:skd  
Attachments

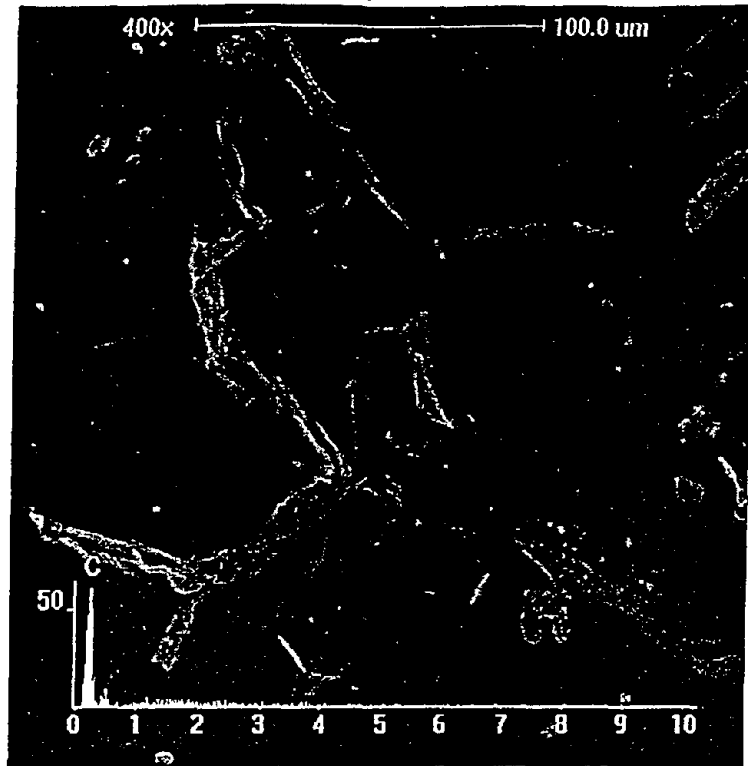


Figure 1

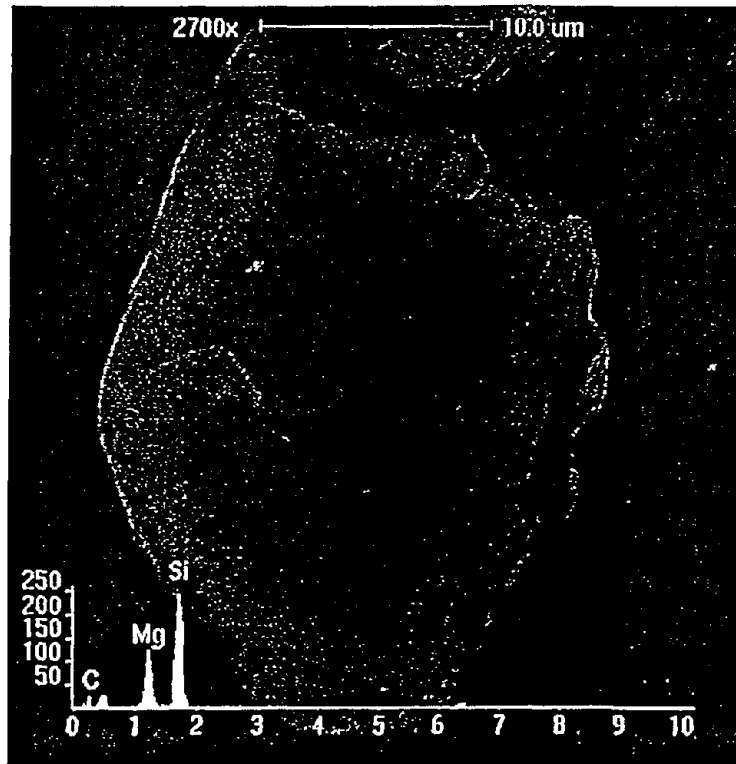


Figure 2

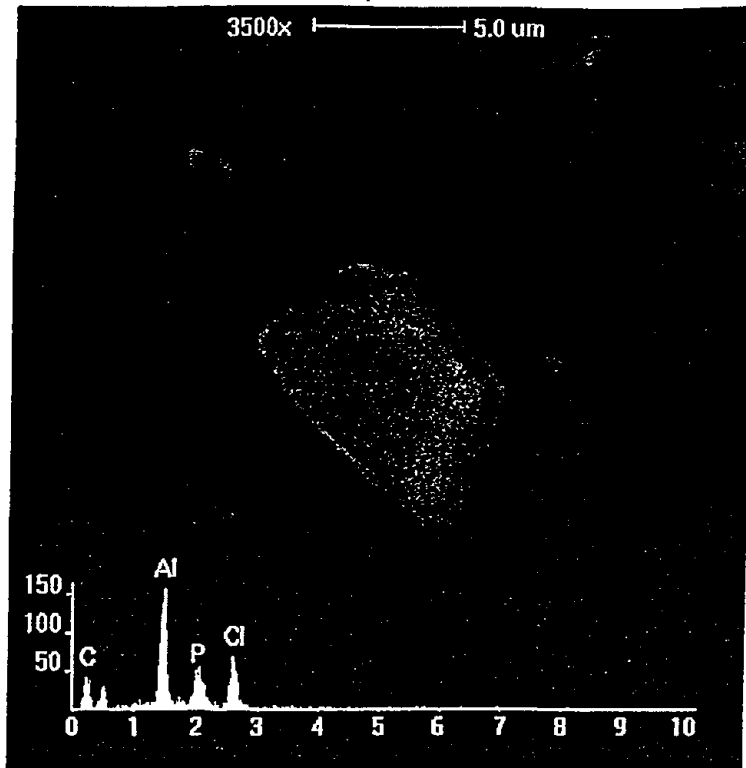


Figure 3

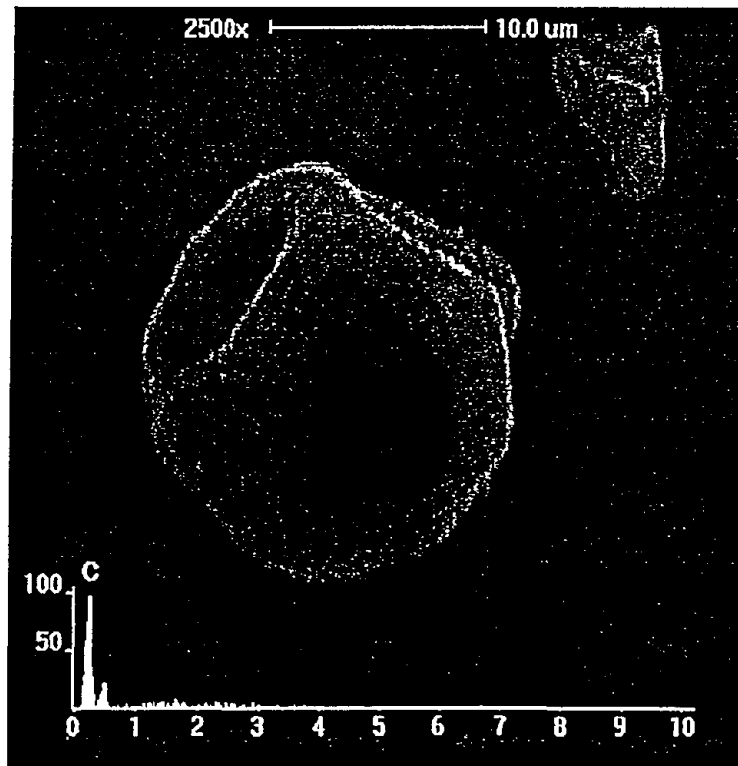


Figure 4

# RJ Lee Group, Inc.

350 Hochberg Road • Monroeville, PA 15146  
412/325-1776 • FAX 412/733-1799

August 20, 1996

Mr. Gary Gentry  
Acurex Environmental, Inc.  
P.O. Box 13109  
Research Triangle Park, NC 27709

RE: Characterization of Four Polycarbonate Filter Samples  
RJ Lee Group Project No. AOW608055

Dear Mr. Gentry:

Enclosed you will find a summary of the analytical results for the four air samples that you recently sent us (reference your Laboratory Request dated August 6, 1996). The samples were identified as follows:

| <u>Acurex<br/>Sample ID</u> | <u>RJ Lee Group<br/>Sample No.</u> |
|-----------------------------|------------------------------------|
| AEFIB0133                   | 609689                             |
| AEFIB0125                   | 609690                             |
| AEFIB0127                   | 609691                             |
| AEFIB0136                   | 609692                             |

The purpose of this investigation was to characterize material collected on the polycarbonate filters by manual scanning electron microscopy (MSEM). MSEM distinguishes among different particle types based on morphology and elemental composition utilizing secondary electron imaging (SEI), backscattered electron imaging (BEI) and energy dispersive spectroscopy (EDS). SEI is used to obtain a three dimensional image of the specimen. In the BEI mode, higher atomic number elements generate more backscattered electrons than do lower atomic number elements resulting in a brighter image for heavier materials. Elemental composition of each species can be obtained utilizing (EDS) techniques. Sample preparation involved mounting a portion of the filter onto an SEM stub and coating it with a thin layer of carbon by evaporative deposition under vacuum.

Acurex Sample ID: AEFIB0133 (RJ Lee Group Sample No.609689)

| <u>Particle Type</u>   | <u>Comments</u>                  | <u>Estimated Contribution</u> |
|------------------------|----------------------------------|-------------------------------|
| Si/Mg-rich flakes      | Talc                             | Major                         |
| C-rich flakes          | Skin flakes/animal dander        | Moderate                      |
| Si/Al-rich particles   | Earth crustal (feldspar & clays) | Minor                         |
| Si-rich fibers         | Glass fibers                     | Trace                         |
| Ca/S-rich particles    | Gypsum (<10 $\mu$ m)             | Trace                         |
| Al/P/Cl-rich particles | <3 $\mu$ m in size               | Trace                         |
| Ca-rich particles      | <5 $\mu$ m in size               | Trace                         |
| Cu-rich particles      | <3 $\mu$ m in size               | Trace                         |
| Fe-rich particles      | <5 $\mu$ m in size               | Trace                         |

The majority of the particulate matter detected on this sample were Si/Mg-rich flakes predominantly 10 to 20  $\mu\text{m}$  in size. The element chemistry and flake-like morphology is similar to that of talc (see Figure 1). A moderate amount of carbon-rich flakes with a size ranging from 20 to 50  $\mu\text{m}$  were observed and were identified as skin flakes/animal dander (see Figure 2). Earth crustal particles were detected in minor amounts and were less than 10  $\mu\text{m}$  in size.

Acurex Sample ID: AEFIB0125 (RJ Lee Group Sample No.609690)

| <u>Particle Type</u>   | <u>Comments</u>                  | <u>Estimated Contribution</u> |
|------------------------|----------------------------------|-------------------------------|
| C-rich particles       | Skin flakes/animal dander        | Major                         |
| Si/Al-rich particles   | Earth crustal (feldspar & clays) | Minor                         |
| C-rich particles       | Cellulose                        | Minor                         |
| Si/Al-rich spheres     | Fly ash                          | Trace                         |
| C-rich particles       | Pollen                           | Trace                         |
| K/Cl-rich particles    | Salt                             | Trace                         |
| Cr-rich particles      | ~20 $\mu\text{m}$ in size        | Trace                         |
| Fe-rich particles      | ~10 $\mu\text{m}$ in size        | Trace                         |
| Ca/Si-rich particles   | ~5 $\mu\text{m}$ in size         | Trace                         |
| Al/P/Cl-rich particles | ~10 $\mu\text{m}$ in size        | Trace                         |
| Fe/Zn-rich particles   | ~5 $\mu\text{m}$ in size         | Trace                         |

The majority of the particulate matter associated with this sample were skin flakes/animal dander with a size range from 10 to 80  $\mu\text{m}$ . A minor amount of earth crustal material with a size of less than 10  $\mu\text{m}$  was detected. A minor amount of cellulose material was observed and was approximately 20 to 30  $\mu\text{m}$  in size.

Acurex Sample ID: AEFIB0127 (RJ Lee Group Sample No.609691)

| <u>Particle Type</u> | <u>Comments</u>                  | <u>Estimated Contribution</u> |
|----------------------|----------------------------------|-------------------------------|
| C-rich flakes        | Skin flakes/animal dander        | Moderate                      |
| Si/Al-rich particles | Earth crustal (feldspar & clays) | Moderate                      |
| C-rich particles     | Cellulose                        | Minor                         |
| Cu-rich particles    | <1 $\mu\text{m}$ in size         | Minor                         |
| C-rich particles     | Pollen                           | Trace                         |
| Si-rich particles    | ~10 $\mu\text{m}$ in size        | Trace                         |
| Ca-rich particles    | <5 $\mu\text{m}$ in size         | Trace                         |
| Fe-rich particles    | <5 $\mu\text{m}$ in size         | Trace                         |

This sample contained a moderate amount of skin flakes/animal dander which ranged from 20 to 80  $\mu\text{m}$  in size. A moderate amount of earth crustal material was also detected. These particles were predominately less than 10  $\mu\text{m}$  in size (see Figure 3). Cellulose fibers and flakes of various sizes (possibly paper) were observed. A minor amount of copper-rich particles with a somewhat spherical morphology and less than 1  $\mu\text{m}$  in size were also detected.

Mr. Gary Gentry  
RJ Lee Group Project No. AOW608055  
August 20, 1996  
Page 3

Acurex Sample ID: AEFIB0136 (RJ Lee Group Sample No.609692)

| <u>Particle Type</u> | <u>Comments</u>                  | <u>Estimated Contribution</u> |
|----------------------|----------------------------------|-------------------------------|
| Si/Mg-rich flakes    | Talc                             | Moderate                      |
| C-rich flakes        | Skin flakes/animal dander        | Moderate                      |
| Si/Al-rich particles | Earth crustal (feldspar & clays) | Minor                         |
| C-rich particles     | Pollens                          | Trace                         |
| Ca-rich particles    | ~10 $\mu\text{m}$ in size        | Trace                         |
| Cu-rich particles    | <1 $\mu\text{m}$ in size         | Trace                         |

The sample contained a moderate amount of Si/Mg-rich flakes with a size range of 10 to 30  $\mu\text{m}$ . The flake-like morphology and elemental chemistry suggests talc particles. Skin flakes/animal dander were also observed in moderate amounts ranging from 20 to 75  $\mu\text{m}$  in size.

These results are submitted pursuant to RJ Lee Group's current terms of sale, including the company's standard warranty and limitation of liability provisions and no responsibility or liability is assumed for the manner in which the results are used or interpreted.

Should you have any questions regarding this information, please do not hesitate to contact Steve Badger or me.

Sincerely,



John C. Johns  
Project Manager  
Environmental Services

JCJ:dls  
Attachments

## Definitions

### Acronyms

|      |                                     |
|------|-------------------------------------|
| EDS  | Energy dispersive spectroscopy      |
| MSEM | Manual scanning electron microscopy |
| µm   | Micrometers                         |

### Chemical Elements

|    |            |
|----|------------|
| Al | Aluminum   |
| C  | Carbon     |
| Ca | Calcium    |
| Cl | Chlorine   |
| Cr | Chromium   |
| Cu | Copper     |
| Fe | Iron       |
| K  | Potassium  |
| Mg | Magnesium  |
| P  | Phosphorus |
| S  | Sulfur     |
| Si | Silicon    |
| Zn | Zinc       |

### Estimated Contribution

|          |   |
|----------|---|
| Major    | Estimated to comprise > 40 percent of the sample by number              |
| Moderate | Estimated to comprise between 20 and 40 percent of the sample by number |
| Minor    | Estimated to comprise between 5 and 20 percent of the sample by number  |
| Trace    | Estimated to comprise < 5 percent of the sample by number               |

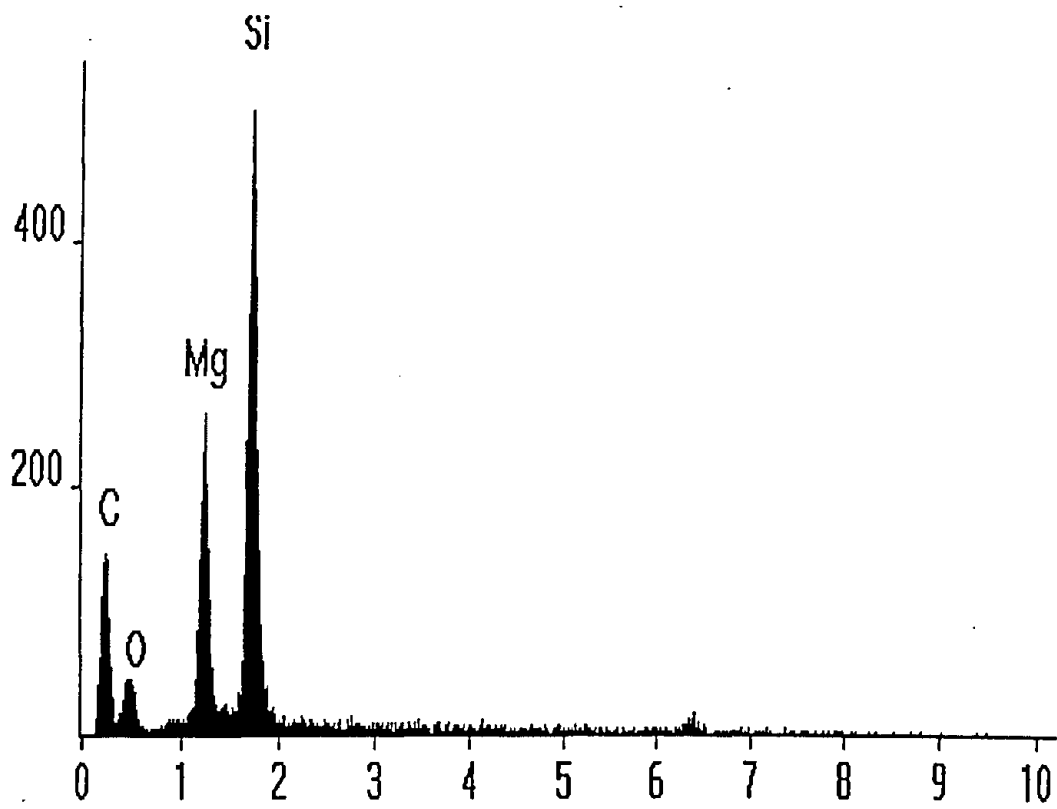
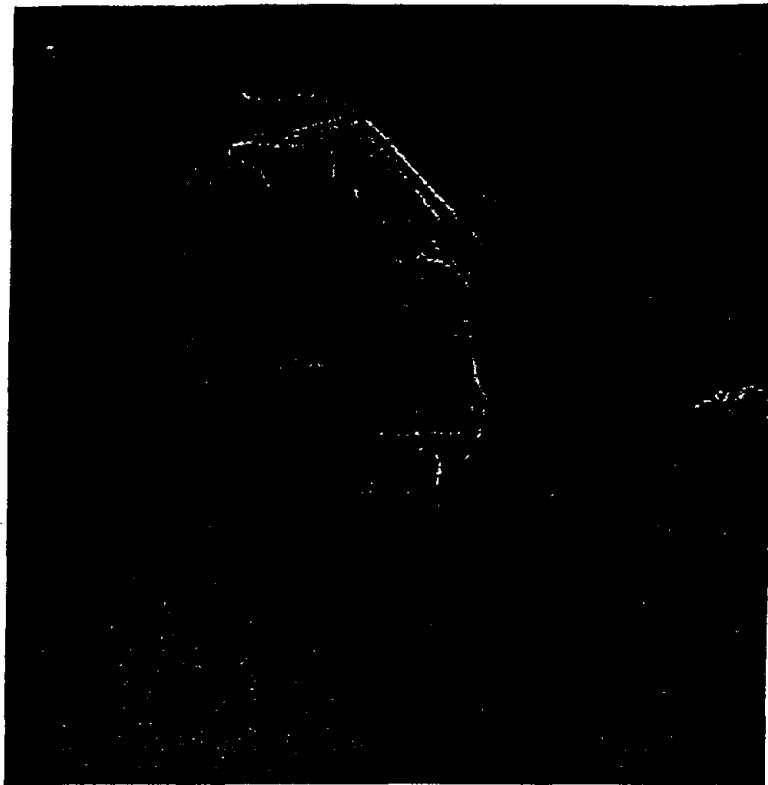
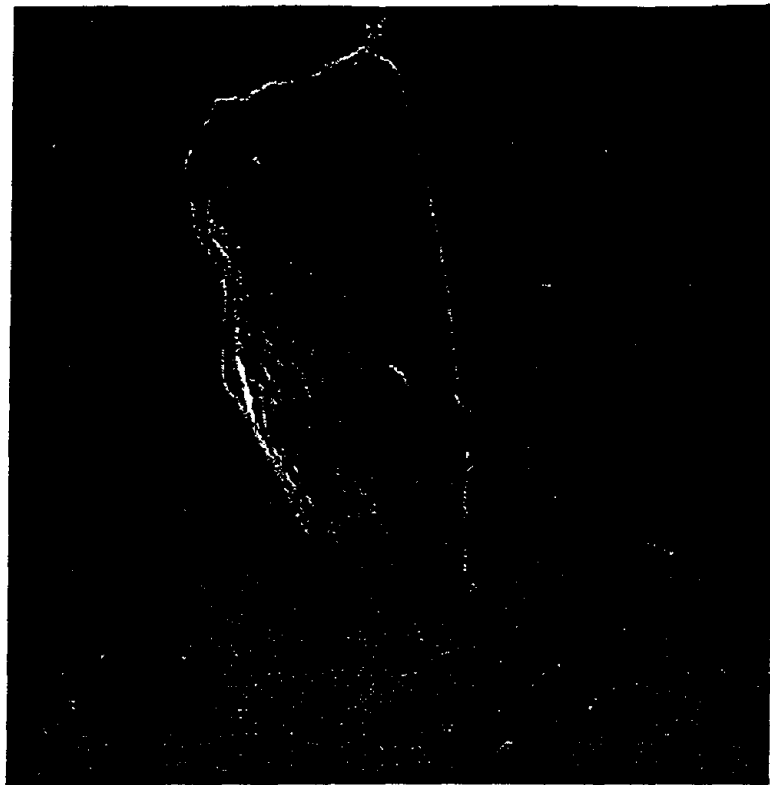


Figure 1



2500x |-----| 10.0  $\mu$ m

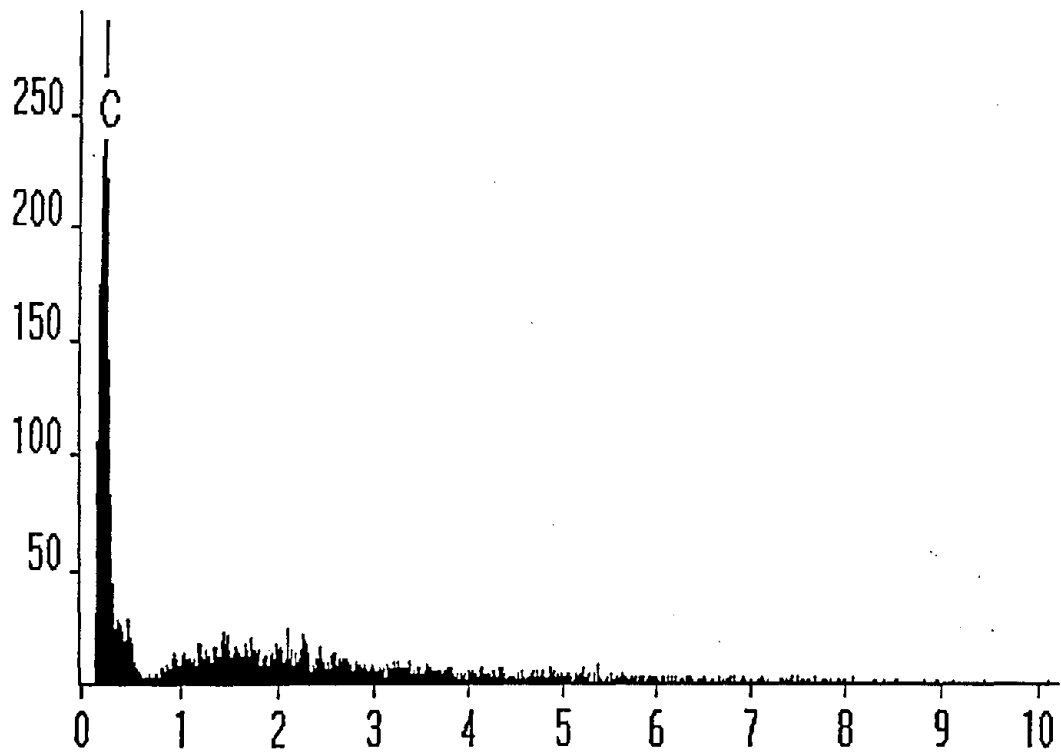
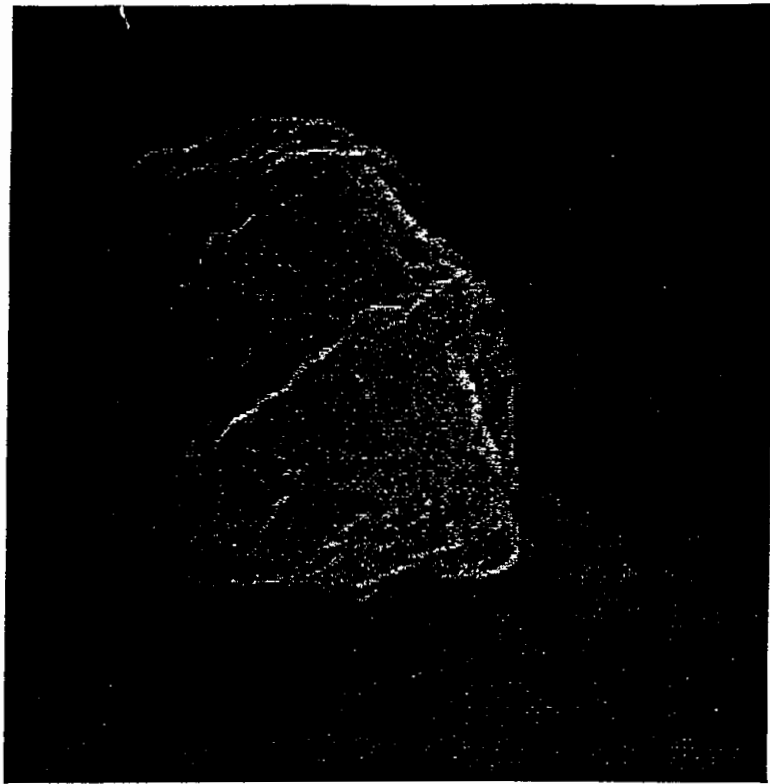


Figure 2



6000x |-----| 5.0 um

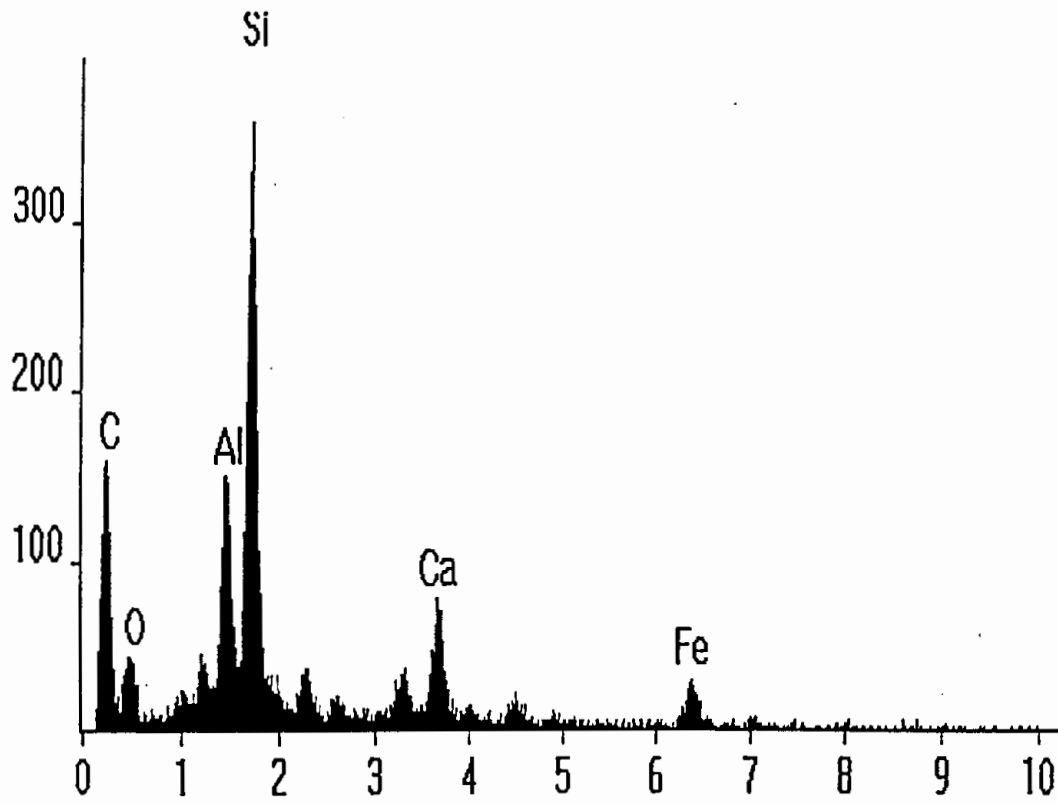


Figure 3