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EFFECTIVENESS OF HVAC SANITATION PROCESSES IN IMPROVING INDOOR AIR QUALITY

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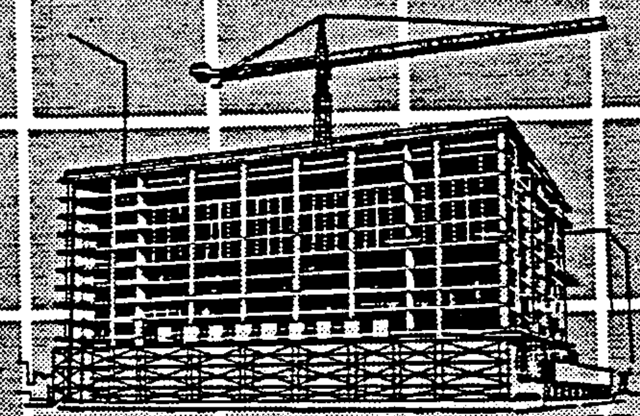

Dr. Irtishad Ahmad, PE
Principal Investigator

Dr. Berrin Tansel, PE
Co-Principal Investigator

Prof. Jose D. Mitrani PE
Co-Principal Investigator

Florida International University
Department of Construction Management
Miami, Florida

1994

Effectiveness of HVAC Sanitation (Duct Cleaning) Processes in Improving Indoor Air Quality

Principal Investigator:
Irtishad Ahmad, Ph.D., P.E.,
Assistant Professor
Department of Construction Management

Co-Principal Investigator:
Berrin Tansel, Ph.D., P.E.,
Assistant Professor
Department of Civil and Environmental Engineering

Co-Principal Investigator:
Jose´ D. Mitrani, P.E.,
Associate Professor and Chairperson
Department of Construction Management
College of Engineering and Design
Florida International University, Miami, Florida

Coordinator:
H. Deane Ellis
Member, Building Construction Industry Advisory Committee, Florida
President, Florida Air Conditioning Contractors Association, Inc.

Overall Guidance and Technical Advise:
H.E. "Barney" Burrroughs
Environmental Design International, Ltd., Atlanta, Georgia

Protocol Development, Training for Microbial Data Collection and Laboratory Analysis:
Larry D. Robertson
Robert A. Garrison
Mycotech Biological, Inc. Jewett, Texas

Technical Guidance on General HVAC Data Collection:
Peter F. Hays
Owens/Corning Fiberglass, Granville, Ohio

Training for Fiber and Dust Data Collection and Laboratory Analysis:
Gregory D. Boothe
Mountain Technical Center, Schuller International, Inc. Littleton, Colorado

Technical Assistance and Supervision:
Charles E. Walker
Climate Control Services, Florida

Duct Cleaning:
Climate Control Services, Florida

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Mr. Larry D. Robertson and **Mr. Robert A. Garrison** of Mycotech Biological, Inc. of Texas developed the study protocol, provided technical guidance and training for bioaerosol sample collection, and performed the subsequent laboratory analysis. Without their contribution this study would not have been possible.

The investigators received technical guidance on general HVAC data collection and visual inspection from **Mr. Peter F. Hays** of Owens/Corning Fiberglass of Ohio, training for fiber and dust data collection, and microscopic analysis from **Mr. Gregory D. Boothe** of Schuller International, Inc. of Colorado, and technical assistance on duct-cleaning and atmospheric data collection from **Mr. Charles E. Walker** of Climate Control Services of Florida. We express our indebtedness to these individuals for their dedicated service.

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Last, but not least, thanks to the eight homeowners who were courageous enough to allow the investigators to use their residences for the purpose of this project. Without their participation, this study would not have been possible.

CLARIFICATION:

Although the word "sanitation" is used in the title of this research project and this report to refer to the cleaning processes, it should be noted that none of the cleaning procedures involved use of any chemicals.

EFFECTIVENESS OF HVAC SANITATION (DUCT CLEANING) PROCESSES IN IMPROVING INDOOR AIR QUALITY

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EFFECTIVENESS OF HVAC SANITATION (DUCT CLEANING) PROCESSES IN IMPROVING INDOOR AIR QUALITY

EXECUTIVE SUMMARY

This project was initiated by the Building Construction Industry Advisory Committee (BCIAC) as a part of their continuing effort to aid the construction industry and the public in the state of Florida. Indoor air quality of residential buildings can deteriorate due to many reasons. Sick building syndrome, originating from improper installation and maintenance of HVAC system and ductwork, is one of them. HVAC units can become sources of mold, fungi and other microbial pollutants. Air duct cleaning has often been recommended and may be carried out to maintain the good quality of indoor air in residences. There are, however, several methods available in the market for air duct cleaning. The effectiveness of these methods are not known due to a lack of established data and investigation.

This research project was undertaken to determine the effectiveness of three commercial HVAC duct cleaning processes in reducing the level of airborne particulate matter and viable bioaerosols. Eight identical homes were selected in a single neighborhood. Two homes were cleaned using each procedure. Two were used as study controls. Data and samples were collected both indoors and outdoors before, during and after cleaning.

The three procedures under investigation were: (1) Contact method, in which conventional vacuum cleaning of interior duct surfaces was performed; (2) Air sweep method, in which compressed air is introduced into the duct for dislodging dirt and debris, which, becoming airborne, are drawn downstream through the duct and out of the system by the vacuum collection equipment; and (3) Mechanical brush method, in which a rotary brush is inserted into the ductwork to agitate and dislodge the debris, that as with the air sweep method, are drawn through the duct out of the system by the vacuum collection equipment.

Airborne particulate matter readings were obtained using Met-One particle analyzer. NIOSH 7400 and 0500 procedures were employed to collect fiber count readings and total nuisance dust readings, respectively. Viable

bioaerosol concentrations were obtained using Andersen biological sampler, HVAC biological sampler, and Burkard procedure.

We found that knowledge regarding the effect and extent of air pollution that can be attributed to a lack of effective HVAC duct cleaning is almost nonexistent. Homeowners and occupants need answers to a variety of questions, both technical and procedural, regarding HVAC duct cleaning. We found that while the houses are normally kept clean, occupants, in general, are ignorant about the cleanliness of their HVAC units and ductwork. We observed very dirty air handling units, drain pans with full of water and debris, and almost clogged filters that have not been replaced on time.

It was found that both particle count readings and bioaerosol concentrations were higher when cleaning was being performed than before or after cleaning. This observation suggests dirt, debris and other pollutant may become airborne as a result of disturbances caused by the cleaning processes.

In most cases, indoor particle counts were found to be higher than corresponding outdoor readings. Readings at 0.3 micron level are found to have increased due to cigarette smoking. Particle counts at 1.0 micron level were shown to have been reduced due to HVAC cleaning.

Cleaning procedures were not found to have contributed to a higher indoor fiber count. Thus the concern that cleaning of fiberglass ductwork might increase the amount of fiber in the house is not supported by the findings of this study.

Major types of microbial contaminants were found to be Cladosporium, Penicillium, Sterile Hyphae, Yeast, and Bacteria.

Post-level bioaerosol concentrations, taken two days after cleaning, were found, in most cases, to be lower than the pre-level concentrations. This observation suggests that cleaning procedures are effective in reducing microbial contamination. All three analytical procedures indicated this effect.

Homes cleaned with the Air Sweep procedure showed the highest amount of reduction in bioaerosol concentration according to the Andersen procedure.

Except for a few cases, results obtained from the HVAC sampling procedure were found to be in agreement with those obtained from the Andersen procedure.

The investigators recommend:

that the findings of this report be considered as case studies and should not be used to generalize or to draw definite conclusions without further investigation;

[The budget and time constraint prevented the researchers from investigating the long-term effects of the duct cleaning procedures and from conducting investigations on a sufficient number of homes for statistical analysis. Accordingly, at this point, definite conclusions can not be drawn on the degree of relative effectiveness of the cleaning processes in reducing indoor air pollutants. Findings of this research study, however, will help identify the specific parameters for further investigation and will lead to more elaborate research studies. BCIAC and NAIMA have just funded a phase II study of this project, in which two homes will be studied for a year to determine the long-term effectiveness of HVAC cleaning.]

that measures be taken to increase public awareness regarding the importance of maintaining good indoor air quality;

that steps be taken to certify and regulate companies that are engaged in commercial duct-cleaning business;

that specific guidelines for duct-cleaning be developed, disseminated and enforced;

that further investigations be carried out to determine the relative effectiveness of the duct cleaning procedures.

A copy of this report may be obtained by contacting:
Executive Secretary, BCIAC
M.E. Rinker, Sr., School of Building Construction
FAC 101 - University of Florida, Gainesville, Florida 32611

EFFECTIVENESS OF HVAC SANITATION (DUCT CLEANING) PROCESSES IN IMPROVING INDOOR AIR QUALITY

FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

Findings

Indoor air quality of residential houses can become a significant problem and is perhaps responsible for several kind of allergic and respiratory diseases of occupants. Improper design, installation and maintenance of Heating, Ventilation and Air Conditioning (HVAC) systems and ductwork can contribute to this problem. HVAC units can become sources of mold, fungi and other microbial pollutants. Dirt, dust and fibrous material can accumulate inside the ductwork. One way of keeping the indoor air quality of a residential house is to clean its HVAC unit, and the ductwork.

Several methods for HVAC duct cleaning are available in the market. The efficacy of these methods are not known due to a lack of established data and investigation. Unscrupulous commercial vendors might be taking advantage of this situation by capitalizing on public concerns regarding indoor air quality of residential houses. Investigations should be carried out in an attempt to help establish the proper cleaning procedures and to formulate certification guidelines of HVAC duct cleaning companies.

This research project was undertaken to determine the effectiveness of three commercial HVAC duct cleaning processes in reducing airborne contamination of residential homes. Eight identical homes in the same neighborhood were selected to monitor the level of airborne particulate matter and viable bioaerosols before, during and after cleaning. Two homes were cleaned using each procedure, and two were used as study controls. Relevant outdoor data were also collected.

The three procedures were: (1) Contact method, in which conventional vacuum cleaning of interior duct surfaces was performed; (2) Air sweep method, in which compressed air is introduced into the duct for dislodging dirt and debris, which, becoming airborne, are drawn downstream through the duct and out of the system by the vacuum collection equipment; and (3) Mechanical brush method, in which a rotary brush is inserted into the ductwork to agitate and dislodge the debris, that as with the air sweep method, are drawn through the duct out of the system by the vacuum collection equipment.

Airborne particulate matter readings were obtained using Met-One particle analyzer. NIOSH 7400 and 0500 procedures were employed to collect fiber count readings and total nuisance dust readings, respectively. Viable bioaerosol concentrations were obtained using Andersen biological sampler, HVAC biological sampler, and Burkard procedure.

The major findings of this research study are summarized in the following.

- Knowledge regarding the effect and extent of air pollution that can be attributed to a lack of effective HVAC duct cleaning is almost nonexistent. There exists a great need for information and knowledge regarding effectiveness of air duct cleaning procedures for residential homes. Homeowners need answers to a variety of technical and procedural questions regarding HVAC duct cleaning. The questions, include but are not limited to, (1) What is the best method of duct cleaning? (2) How effective is the method? (3) Are the companies that perform duct cleaning certified? and, (4) How often one should clean the system and ductwork?

- The interest generated by this research and recent media attentions suggest that public concerns regarding indoor air quality of residential buildings are growing.

- The HVAC units of the houses (built in 1986) that were selected for this study were, in most cases, found very dirty. None of the houses had their ductwork professionally cleaned before. Almost all the condensate drain pans were full with dirty water, some were rusted and some had floating clumps of debris. Heavy accumulations were observed in the air handling unit, on the surface of the blower cage. The side walls were wet. Seven out of eight homes were using spun fiberglass disposable type filters. Some of the filters observed were clogged with dirt. Accumulations of dirt and debris were also found in the interior of the ductwork of most of the homes.

- The readings obtained from Met-One particle analyzer suggest that the concentration of particles are higher during the cleaning process than either before of after cleaning. This is perhaps due to disturbances caused by cleaning procedures employed. The same phenomenon was also observed with the NIOSH 7400 total fiber counting procedure.

- Met-One readings obtained at 0.3 microns-level were found to have been affected by cigarette smoking, the readings obtained were much higher when smoking took place. Smoking did not have much affect on the readings at 1.0 micron-level.

- Except for a few anomalous cases, indoor Met-One readings were found to be higher than corresponding outdoor particle counts.

- Met-One readings taken two days after cleaning do not show substantial reduction from the pre-cleaning readings at 0.3 micron level, but indicate significant reduction (ranging from 9% to 60%) at 1.0 micron level. Both AirSweep and MechBrush homes indicated a reduction at this level. One of the Contact homes showed reduction while the other experienced an increase.

- The two control homes do not show much difference in the fiber counts taken two days apart. Both Contact homes indicate slight increase in post and during fiber counts from the corresponding pre-level counts. Post-level fiber counts for the AirSweep and the MechBrush homes were found to be lower than or equal to either pre or during counts. The findings suggest that cleaning procedures do not increase the amount of fiber inside the house. Some individuals' concern that cleaning of fiberglass ductwork may increase the amount of fiber in the house and thus may create a potential health-hazard is not supported by the findings of this study.

- Both Andersen and HVAC biological sampling procedures revealed that the major types of microbial contaminants are Cladosporium, Penicillium, Sterile Hyphae, Yeast, and Bacteria.

- Findings of Andersen procedure suggest that bioaerosol concentrations, in cfu's/m^3, during cleaning were higher than the pre-level concentrations. Post-level concentrations, taken two days after, were found to be lower than the pre-level readings with the exception of two homes. The extent of reduction was ranging from 45% to 73%, although the two control homes experienced an increase from pre- to post-level cfu's/m^3. This observation suggest that, cleaning procedures are, in general, effective in reducing microbial contaminants.

- Homes cleaned with the Air Sweep method showed the highest amount of reduction according to the Andersen procedure.

- HVAC sampling procedure indicated substantial reduction in bioaerosol concentration, in terms of cfu's/sample, from pre- to post-level. The range is varying from 79% to 92%. Only one home, cleaned with the Air Sweep method indicated a rise in microbial concentration according to this procedure. Except for a few cases, results obtained from the HVAC procedure are in agreement with those obtained from the Andersen procedure.

- According to the Burkard procedure, post-level bioaerosol concentrations are lower than the corresponding pre-level concentrations. Results, expressed in terms of spore/m3, are generally in agreement with the results of Andersen and HVAC procedures. The extent of reduction was varying from 22% to 91%. Both Air Sweep homes indicated a reduction of about 85% according to the Burkard procedure.

Conclusions and Recommendations

The scope of this research study was limited by many constraints, time and budget were the two major ones. It was not possible to collect enough data necessary for any statistical analysis. The results, reported herein, should be considered as case studies and the investigators are aware of the danger of generalizing these results. We believe, however, that findings of this study are very valuable and will provide important insight regarding the effects of HVAC cleaning on indoor air quality of residential buildings.

The following conclusions and recommendations are outlined on the basis of the findings of this study:

- People, in general, are not quite familiar with the commercial air duct cleaning procedures. Measures should be taken to increase public awareness regarding the importance of maintaining good quality of indoor air. Cleaning of HVAC system and ductwork may be of value but it should be performed by professional duct cleaning specialists. Steps should be taken to certify and regulate companies and individuals that are engaged in commercial duct-cleaning business.

- Results of this and similar studies should be utilized to develop specific guidelines for duct-cleaning. These guidelines should include information regarding the effectiveness of these procedures, frequency of cleaning, and steps that can be followed to keep level of pollution at a minimum.

- The results of this study suggest that if proper cleaning methods are used fiberglass ductwork do not pose any special problem. The concern that cleaning procedures may dislodge fibrous material that might become airborne, thus creating a potential health-hazard, was found not to be true.

- Airborne particulate matter and bioaerosol concentrations are usually higher during when cleaning is carried out. Occupants should not stay home during the cleaning procedure and the cleaning crew should wear masks for protection from breathing polluted air. Met-One readings taken two days after cleaning did not show substantial drop at 0.3 micron level. Whether these readings will drop further or go up, could not be known, since only one post-level reading was collected. To understand the long-term effect of cleaning on the level of pollution further readings must be taken at different points in time. This would provide information regarding how long the effectiveness of a certain cleaning procedure lasts.

- Post level bioaerosol concentrations were found to be lower than the pre-level concentrations in most cases. Generally speaking, all three analytical procedures indicated this effect. Based on the observations obtained in this study, Air Sweep method indicated the best results in reducing bioaerosol concentrations. Definite conclusions cannot be drawn on the degree of relative effectiveness of the cleaning procedures. Additional information must be gathered to determine the relative strengths and weaknesses of a particular method over another. It should be noted that findings reported herein are based on an insufficient number of data and should be considered as such.

- Results obtained from HVAC sampling procedure are, in general, comparable with those obtained from the Andersen and Burkard procedures. Although a numerical comparison was not possible, the nature of the results were found similar. It is a relatively inexpensive procedure. This procedure can be used as a screening method for limited purposes, such as, to decide if further investigation is necessary.

- A research project should be undertaken to investigate long-term effects of cleaning methods employed. Questions such as how long the effectiveness of cleaning lasts, and how often ductwork should be cleaned need to be answered. To obtain dependable answers to questions such as these, one needs to know how the concentration levels of various pollutants vary with time. It should be mentioned here that the Building Construction Industry Advisory Committee (BCIAC) along with the North American Insulation Manufacturer's Association (NAIMA) has awarded a phase II research project to the investigators of this study. In the phase II project, two homes will be studied for a year to investigate the long-term effect of duct-cleaning. The findings of the current project constituted the basis of the phase II study.

Chapter 1

INTRODUCTION

1.1 The Problem Statement

People may become extremely sick by being exposed to airborne particulate matter or other aeroallergens if they work or stay in buildings with contaminated indoor air. People may develop symptoms of illnesses such as sleeping problems, headaches, watery eyes, nausea, skin disorders, and fatigue.

Inadequate or ineffective HVAC (Heating, Ventilation and Air Conditioning) duct-cleaning processes may be responsible for both causing and enhancing these sick building problems. Pearts and Cook[1] reported that many residential buildings have sick building syndrome. Sick building syndrome is a recently recognized phenomenon. As noted by Ellis[2], when a significant number of building occupants experience symptoms that do not fit the pattern of any particular illness and are difficult to trace to any specific source, the problem may be "sick building syndrome."

Recently, numerous articles have been published in national and local newspapers, and trade journals and magazines on the problems originating from sick buildings. School buildings, offices and residential

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[1] Peart, V.M. and Cook, G.D. "Sick Buildings: Moisture and Mildew, Correlation and Prevention," *ASC (Associated Schools of Construction) Proceedings*, April 1990, Charleston, South Carolina.

[2] Ellis, H.D., "What You Should Know About Indoor Air Quality But Were Afraid to Ask," Handout by Climate Control Services, 1993.

houses are being scrutinized for detecting the causes of contaminated indoor air.

Various sources suggest that the root cause of contaminated indoor air is improperly designed and maintained HVAC system. Good ventilation can be both a prevention and a cure. A National Institute On Safety and Health study, reported in Architectural Trendletter[1], indicated that more than half of reported cases of "sick building syndrome" stemmed from problems with the HVAC systems.

In tightly sealed buildings, a legacy of the 1970's oil embargo, a large portion of inside air is recycled[2]. Indoor air may become contaminated due to many reasons. A lack of proper cleaning of the HVAC system might be one of them. Other reasons might include poor filtration, poor outdoor air, poor maintenance, etc. Household activities and habits of occupants may also add to contamination. Whatever might be the reason, however, contamination persists because of recycling. A primary means of transportation of airborne pollutants is the central air conditioning system. Stewart[3] concluded, based on the findings of a case study, that improper maintenance of the HVAC system components may be contributing to the accumulation of contaminants within the HVAC system and plenums. Since people spend most of

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[1] "Preventing Sick Building Syndrome," *Architectural Trendletter*, Genflex Roofing Systems, July/August 1993.

[2] Ellis, H.D., Ibid.

[3] Stewart, S.M., "Reaching Agreements on Indoor Air Quality," *ASHRAE Journal*, August 1992, p. 28- 32.

their time indoors, (about 90%, of which 65% is at home), it is important that indoor air of residences be kept free from pollution.

1.2. HVAC Ductwork Cleaning

The EPA (Environmental Protection Agency) states that some hazardous pollutants in indoor air have been proven to be up to 70 times greater than the outdoor air[1]. Fungi, which abound in nature, enter the air handling system from outdoors through the fresh air intakes, windows, doors, etc. These fungi find the dark, moist areas of the air handling units (AHU's) and ductwork to be well-suited environments to flourish[2]. Ellis[3] noted, most bacterial growth originates in the condensate drain pan and cooling coil, from where it moves to the remainder of the air handler and duct work.

It has been claimed that proper design, operation, and maintenance of a building's air handling system can significantly improve indoor air quality. Krell[4] concluded, regular cleaning of heating and cooling coils, drain pans, fans, filters, and other related hardware not only limits subsequent contamination, it saves on operating expenses by allowing HVAC system to operate at

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[1] Ellis, H.D., Ibid.

[2] Krell, B. "Who Needs Air Duct Cleaning?" *Indoor Air Review*, August 1991, p. 29.

[3] Ellis, H.D., Ibid.

[4] Krell, B., Ibid.

maximum efficiency.

The National Air Duct Cleaners Association (NADCA), a non-profit trade organization of air duct cleaning professionals endorse source removal air duct cleaning, whereby high-powered vacuum units, compressed air, specially designed brushes and other tools are employed to physically remove dust and debris from air duct systems.[1]

North American Insulation Manufacturers Association (NAIMA) has published guidelines for cleaning ductwork made of fibrous glass material[2]. In this research study NAIMA-recommended methods were employed for duct-cleaning.

1.3 Justification for Investigation

Knowledge regarding the effect and extent of air pollution that can be attributed to a lack of effective HVAC sanitation or duct cleaning is almost nonexistent. A lack of information is a major obstacle in solving the problem of sick buildings. Questions such as the followings need to be answered:

- What are the methods available for cleaning ductwork?
- Which methods are effective and to what degree are they effective, in reducing the level of fungal aeroallergens and other airborne particulate matter?

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[1] "The NADCA Standard - A Preview, Air Duct Cleaning," *Indoor Air Review*, August 1991, p.29.

[2] "Cleaning Fibrous-glass insulated ducts," North American Insulation Manufacturers Association.

• How often ductwork and the system be cleaned?

The past ten to twelve years has seen a dramatic increase in the number of air duct cleaning firms. Unfortunately many of these companies have failed to keep pace with improvements in duct cleaning methods and technology. Inadequate and ineffective cleaning of HVAC ductwork may cause and enhance indoor air quality related illnesses among the occupants.

Due to a lack of reliable data and knowledge some unscrupulous commercial sanitation/duct cleaning vendors might be taking advantage of the public concern by leading them into unnecessary expenses. There is a great need to make people aware of the dangers of contaminated indoor air and to provide guidance for improving the quality of indoor air of residences.

Chapter 2
OBJECTIVES AND SCOPE OF RESEARCH

2.1 Objective

The main objective of this research project is to evaluate the three duct cleaning processes, described in detail in section 3.3, regarding their effectiveness in reducing total airborne particulate and viable bioaerosols in residential homes.

In specific terms, the following tasks will be accomplished in this project:

a) Investigate different types of duct cleaning processes and conduct studies to determine the ones that are effective in reducing the level of airborne pollutants.

b) Develop a list of recommendations on the basis of the findings of the study.

2.2 Scope of the Project

The residential homes selected for this study were furnished with fiberglass duct material. Accordingly, findings of this study may not be applicable to metal ductwork. No chemicals have been used for sanitizing the ductwork before, during or after cleaning. All the homes were identical in layout, floor area and HVAC design. Only two homes were studied for each method. Due to time and budget constraints sufficient data could not have been collected for the results to be reported using statistical analysis. As such, the findings of this project are reported as the results of case studies.

2.3 Duct Cleaning Techniques

The three HVAC duct cleaning procedures employed for the purpose of this study are described in detail in Chapter 3 of this report. The procedures were applied according to the NAIMA (North American Insulation Manufacturers Association) guidelines for cleaning fiberglass-insulated ducts. The houses selected for this research project were identical, and all of them had fiberglass ductwork.

2.4 Organization of the Report

This report is subdivided into five major parts, as listed below:

SUMMARY AND CONCLUSIONS - This report begins with an executive summary of the research project and its results. Outcome of the study is outlined in detail in the section entitled "Findings, Conclusions and Recommendations."

INTRODUCTION AND OBJECTIVES (CHAPTERS 1 & 2) - In these chapters indoor air quality problems due to inadequate cleaning of HVAC ductwork are outlined. The background of the project is described and the justification for investigating the problem is given. In Chapter 2 scope and objectives of the study are explained.

RESEARCH METHODOLOGY (CHAPTER 3) - In this chapter, the approach used to conduct the research project, the study protocol, type of data collected and the collection procedures are described.

FIELD OBSERVATIONS AND DATA COLLECTION (CHAPTER 4) - In this chapter detailed results of observations and field data are reported. Figures and photographs are included to provide a summary of observations.

ANALYSIS OF RESULTS (CHAPTER 5) - The results of the analysis are presented using charts, graphs and tables. Both airborne particulate matter and viable bioaerosol concentrations recorded before, during and after cleaning are reported and discussed in this chapter.

The last part of the report contains appendices.

Chapter 3
RESEARCH METHODOLOGY

3.1 General

Eight homes were selected from a single neighborhood for the purpose of this research study. The age, floor plan, building design and materials, and HVAC design and materials of all eight homes were identical. *Figure 3.1* shows the floor plans and the HVAC layout. Two houses were selected for each cleaning procedure under investigation and two were used as study controls. The study protocol is described in detail below.

3.1.1 Selection of the residences for study

Letters were mailed out to 164 homeowners or residents in a certain neighborhood of South Florida requesting them to participate in this study. A sample of the letter is shown in *Appendix A.* Those who responded were contacted by the investigators to further explain the purpose of the project and to answer their questions. Eight homes were finally selected. The participating homeowners were promised that their ductwork will be cleaned at no cost to them. This offer was extended to the two control homes, selected for the purpose of this study, as well. In addition, they were also offered high-efficiency filters. In brief, from our experience with this selection process, it can be said

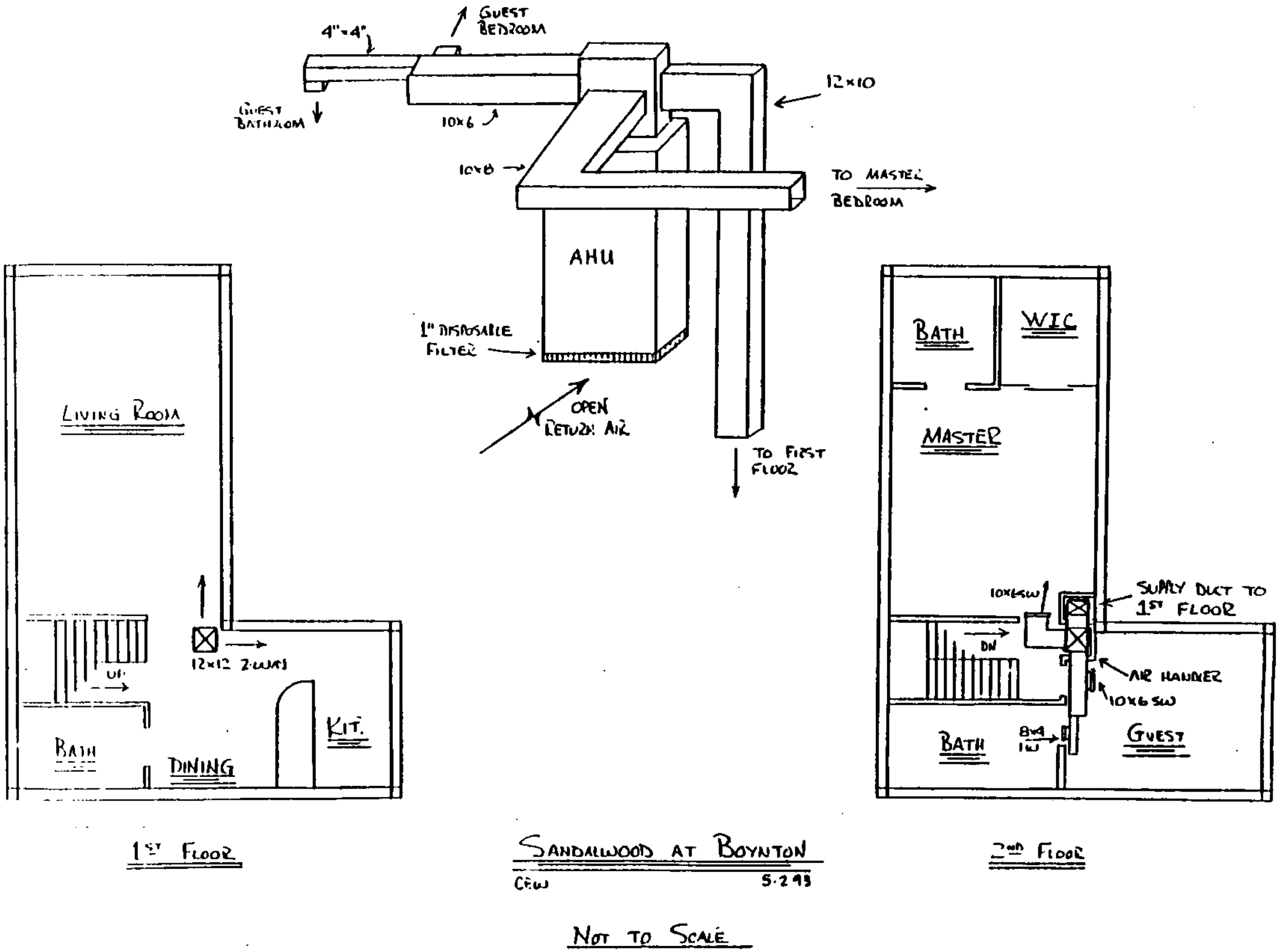

Figure 3.1. Floor Plan and HVAC Layout

that many homeowners are more than eager to participate in this kind of study. They, however, need to be assured that the procedure will not cause any harm or damage to their homes, that the study results will not be used for any commercial purposes, that the persons in charge of investigation are trustworthy, and that there are some incentives (such as the clean ductwork) for them.

3.2 Study Protocol

The study protocol was developed by Larry Robertson and Robert Garrison of Mycotech Biological Inc. of Texas.

I. Objective

To determine the effects of three commercial HVAC cleanng procedures on airborne particulate matter and viable bioaerosols in residential HVAC systems in southern Florida.

II. Scope

A. General Residential Test Sites

1. 8 Residential homes having the same geographical location, age, floor plan, building design and materials, and HVAC design and materials.

2. Specific Test Sites

a. 2 homes/HVAC units - Study Controls.
b. 2 homes/HVAC units - "Contact" Procedure.
c. 2 homes/HVAC units - "AirSweep" Procedure.
d. 2 homes/HVAC units - "MechBrush" Procedure.

The cleaning procedures are described in section 3.3 in detail.

B. General Analytical Description

1. Duct Board - Pre and Post cleaning

a. Surface texture - visual and photographic

b. Facing and closure - visual and photographic

2. Airborne Particulate Matter

a. Met One - 2 particle sizes 0.3 micron and 1.0 micron - Pre, During and Post cleaning

b. NIOSH 7400 fiber counting procedure - Pre, During and Post cleaning

c. NIOSH 0500 total nuisance dust - Pre, During and Post cleaning

3. Viable Bioaerosol

a. Andersen Sampling - Pre, During and Post cleaning

b. HVAC Sampling - Pre and Post cleaning

c. Burkard Sampler - Qualification and Quantification of Total Particulate - Pre, During and Post cleaning

III. Analytical Protocol

A. General Field Data

1. general hygiene of house; Normal Cleaning Practice (housekeeping habits) HVAC, air diffusers
2. history of home damage, repair, renovation, remodeling, water leaks, roof leaks
3. Percent carpet coverage, style, type, make, age
4. # of residents, age, sex, occupation
5. history of allergy and respiratory related medical problems
6. # of pets, type

7. general home contents, furniture type and composition, drapes, plants
8. general activity - ingress and egress
9. immediate outdoor surroundings, grass, rock, dirt, plants, industry
10. primary entrance orientation - magnetic north
11. proximity to expressway, airport, industry
12. hobbies of the residents
13. ductboard closure system
14. Any unusual content that might contribute to the contaminant level

B. Specific HVAC Data

1. design and layout; # diffusers; tonnage; diagrams
2. rated and actual CFM setting
3. air velocity at terminal supply distribution diffuser
4. diffuser style; orientation
5. HVAC controls - set to "manual on" during all pre and post indoor sampling
6. Filtration details
7. Description of any repairs done for leakage

C. Analysis of Airborne Particulate Matter

1. Pre cleaning Particulate Sampling
   a. Outdoor Data
      1. temperature
      2. relative humidity
      3. wind direction
      4. wind speed
      5. current weather conditions, rain, etc.

6. ambient pressure

b. Outdoor parameter

1. airborne particulate matter

a. Met-One Particle Analyzer

c. Indoor Data

1. temperature

2. relative humidity

3. ambient pressure

d. Indoor parameter

1. airborne particulate matter

a. Met-One Particle Analyzer

b. NIOSH 7400

c. NIOSH 0500

2. During-cleaning Particulate Sampling

a. Indoor parameter

1. airborne particulate matter

a. Met-One Particle Analyzer

b. NIOSH 7400

c. NIOSH 0500

3. 48-hour Post-cleaning Particulate Sampling

a. Outdoor Data

1. temperature

2. relative humidity

3. wind direction

4. wind speed

5. current weather conditions, rain, etc.

6. ambient pressure

b. Outdoor parameter

1. airborne particulate matter

a. Met-One Particle Analyzer

c. Indoor Data
    1. temperature
    2. relative humidity
    3. ambient pressure
d. Indoor parameter
    1. airborne particulate matter

D. Analysis of Airborne Viable Bioaerosol

1. Pre cleaning Viable Bioaerosol
    a. Outdoor Data
        1. temperature
        2. relative humidity
        3. wind direction
        4. wind speed
        5. current weather conditions, rain, etc.
        6. ambient pressure
    b. Outdoor parameter
        1. Viable Bioaerosol
            a. Andersen N-6 Sampler
            b. Burkard Sampler - Qualification and Quantification of Total Particulate
    c. Indoor Data
        1. temperature
        2. relative humidity
        3. ambient pressure
    d. Indoor parameter
        1. Viable Bioaerosol
            a. Andersen N-6 Sampler
            b. HVAC Sampling Method
            c. Burkard Sampler - Qualification and Quantification of Total Particulate

2. During-cleaning Viable Bioaerosol
    a. Indoor parameter
        1. Viable Bioaerosol
            a. Andersen N-6 Sampler
            b. Burkard Sampler - Qualification and Quantification of Total Particulate
3. 48-hour Post-cleaning Viable Bioaerosol
    a. Outdoor Data
        1. temperature
        2. relative humidity
        3. wind direction
        4. wind speed
        5. current weather conditions, rain, etc.
        6. ambient pressure
    b. Outdoor parameter
        1. Viable Bioaerosol
            a. Andersen N-6 Sampler
            b. Burkard Sampler - Qualification and Quantification of Total Particulate
    c. Indoor Data
        1. temperature
        2. relative humidity
        3. ambient pressure
    d. Indoor parameter
        1. Viable Bioaerosol
            a. Andersen N-6 Sampler
            b. HVAC Sampling Method
            c. Burkard Sampler - Qualification and Quantification of Total Particulate

3.3 Duct Cleaning Procedures

The three commercial HVAC duct cleaning procedures employed for the purpose of this study are described below. The descriptions are based on NAIMA (North American Insulation Manufacturers Association) guidelines for cleaning fiberglass-insulated ducts. The houses selected for this research study were identical in layout and size, all of them had fiberglass ductwork, and the NAIMA guidelines were followed in this research study.

Contact Vacuum Method (abbreviated as "Contact"):

Conventional vacuum cleaning of interior duct surfaces. Access is gained through exiting openings and outlets and hand vacuumed directly using commercial type equipment. The vacuum cleaner head is introduced into the duct at the opening furthest upstream and the machine turned on. Vacuuming proceeds downstream slowly enough to allow the vacuum to pick up all dirt and dust particles. Observation of the process is the best way to determine how long it takes before linings are considered sufficiently clean. When observation indicates the section of duct has been cleaned sufficiently, the vacuum device is withdrawn from the duct and inserted through the next opening, where the process is repeated. The procedure is shown in *Figure 3.2*. *Figure 3.3* shows the photograph of the same procedure as it was used in this research study. This method was applied only to the sections of ductwork that were accecssible to the crew.

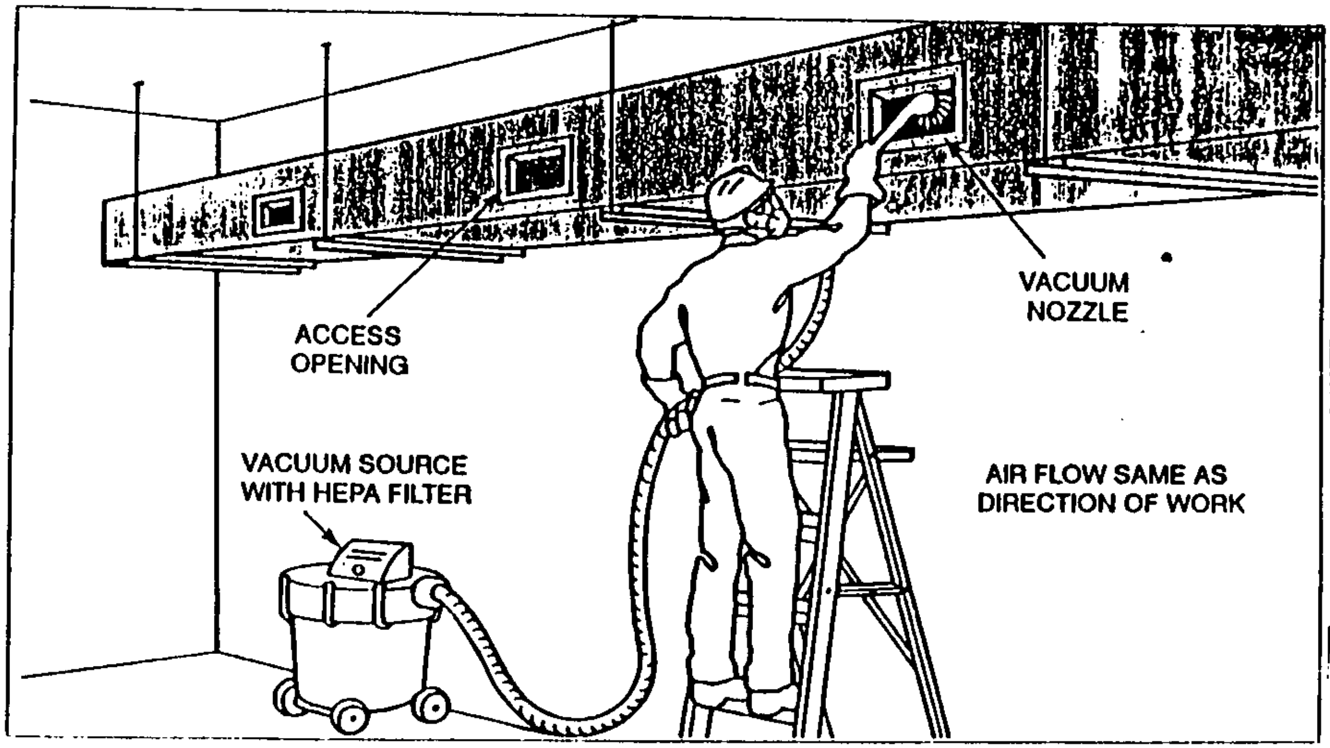

Figure 3.2. Contact Vacuum Procedure (Source: "Cleaning Fibrous Glass Insulated Ducts," North American Insulation Manufacterers Association, page 16)

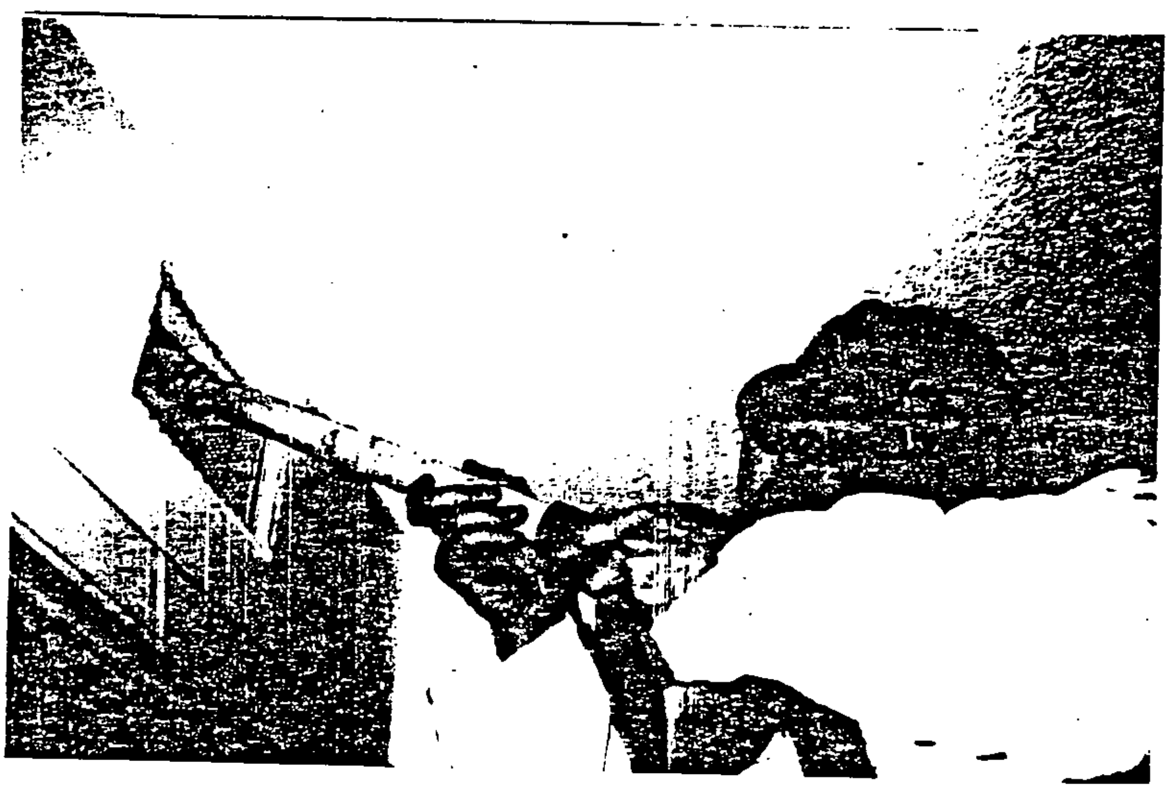

Figure 3.3. "Contact" Method

Air Washing or Air Sweep Method (abbreviated as "AirSweep"):

A vacuum collection device is connected to the downstream end of the section being cleaned through a predetermined opening, as shown in *Figure 3.4*. Compressed air is introduced into the duct through a hose terminating in a "skipper" nozzle. This nozzle is designed so that the compressed air propels it along inside the duct. This dislodges dirt and debris which, becoming airborne, are drawn downstream through the duct and out of the system by the vacuum collection equipment, as shown in *Figure 3.5*. The compressed air source should be able to produce between 160 and 200 psi air pressure, and have a 20-gallon receiver tank, for the air washing method to be effective.

All return and supply registers are removed for cleaning and to provide access into the ductwork. The duct system is then divided into sections using isolation bags and dividers. The negative air equipment is then attached to each section while a high pressure driven nozzle is inserted and used to dislodge the debris. The dislodged particles is pulled into the HEPA (High Efficiency Particle Arrestor) filtered negative air equipment. The mechanical air handling equipment is then cleaned.

The procedure is illustrated in *Figure 3.6* and the photograph taken during cleaning is shown in *Figure 3.7*.

Mechanical Brushing Method (abbreviated as "MechBrush"):

As with the air washing system, a vacuum collection device is connected to the downstream end of the section

Figure 3.4. Setting up hose for Vacuum Collection

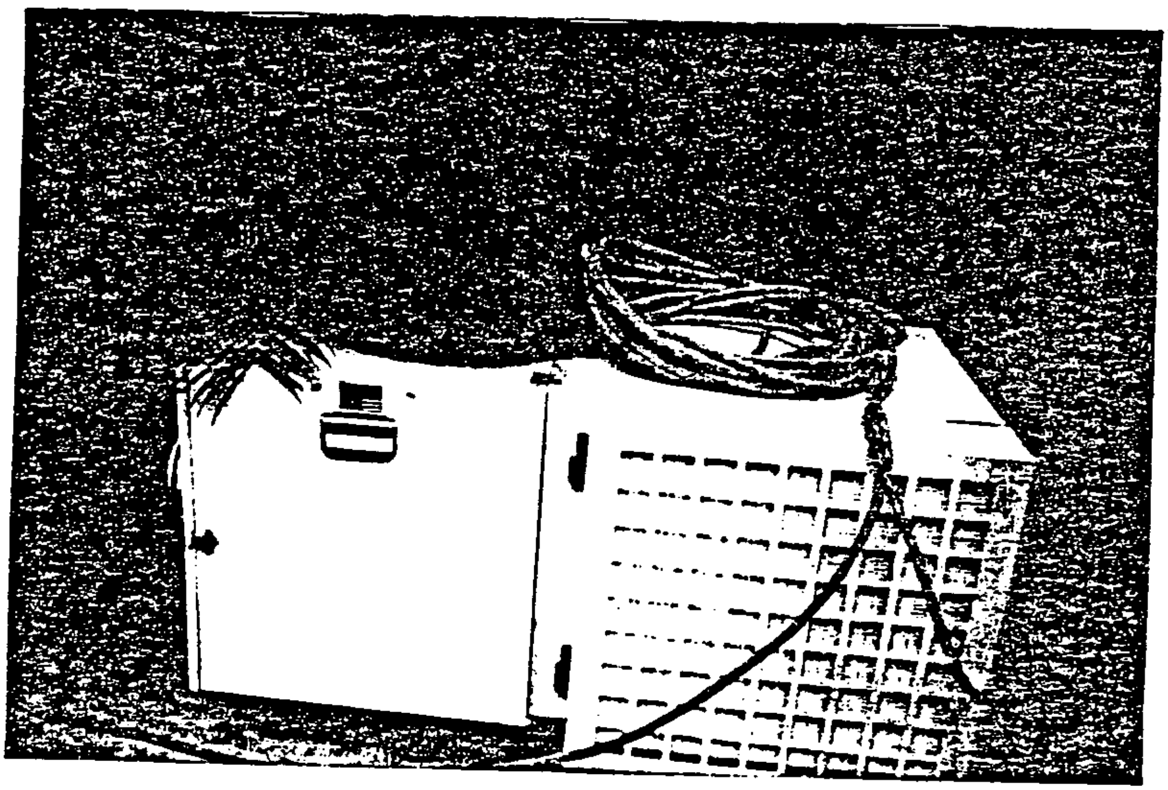

Figure 3.5. Vacuum Collection Equipment

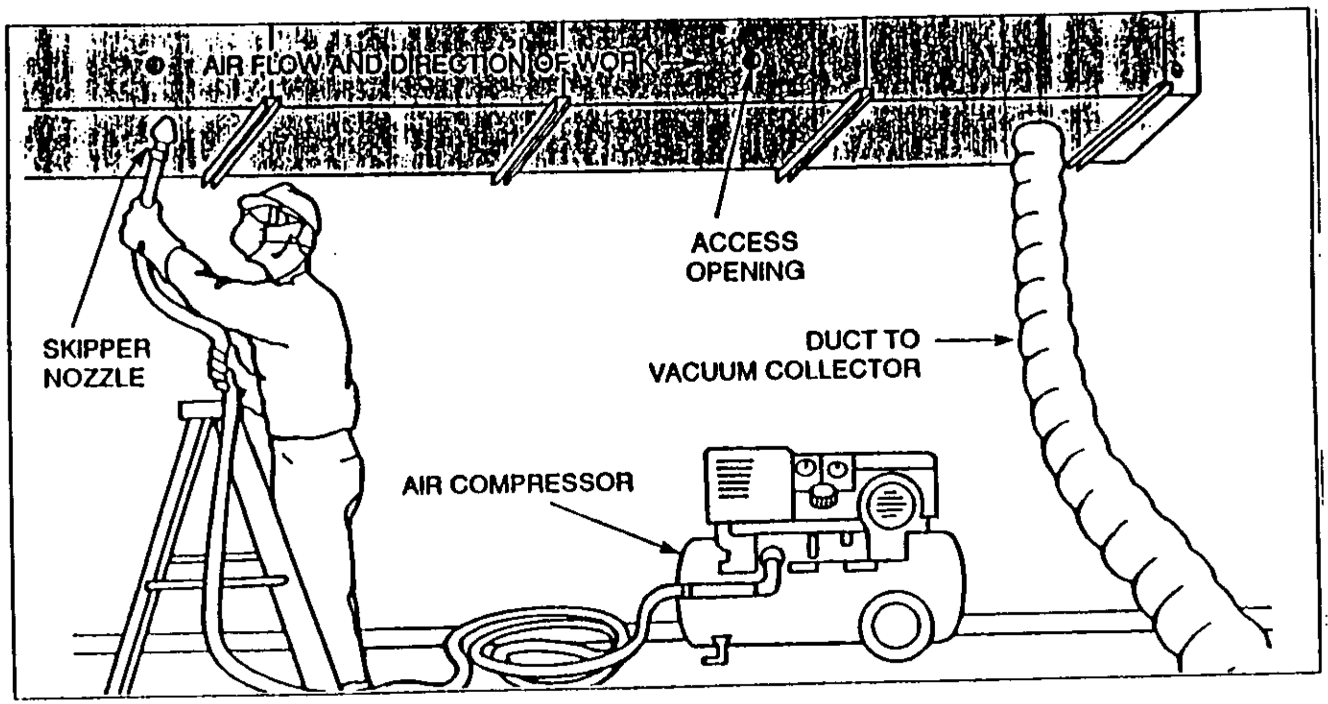

Figure 3.6. **Air Washing Procedure (Source: "Cleaning Fibrous Glass Insulated Ducts," North American Insulation Manufacterers Association, page 17)**

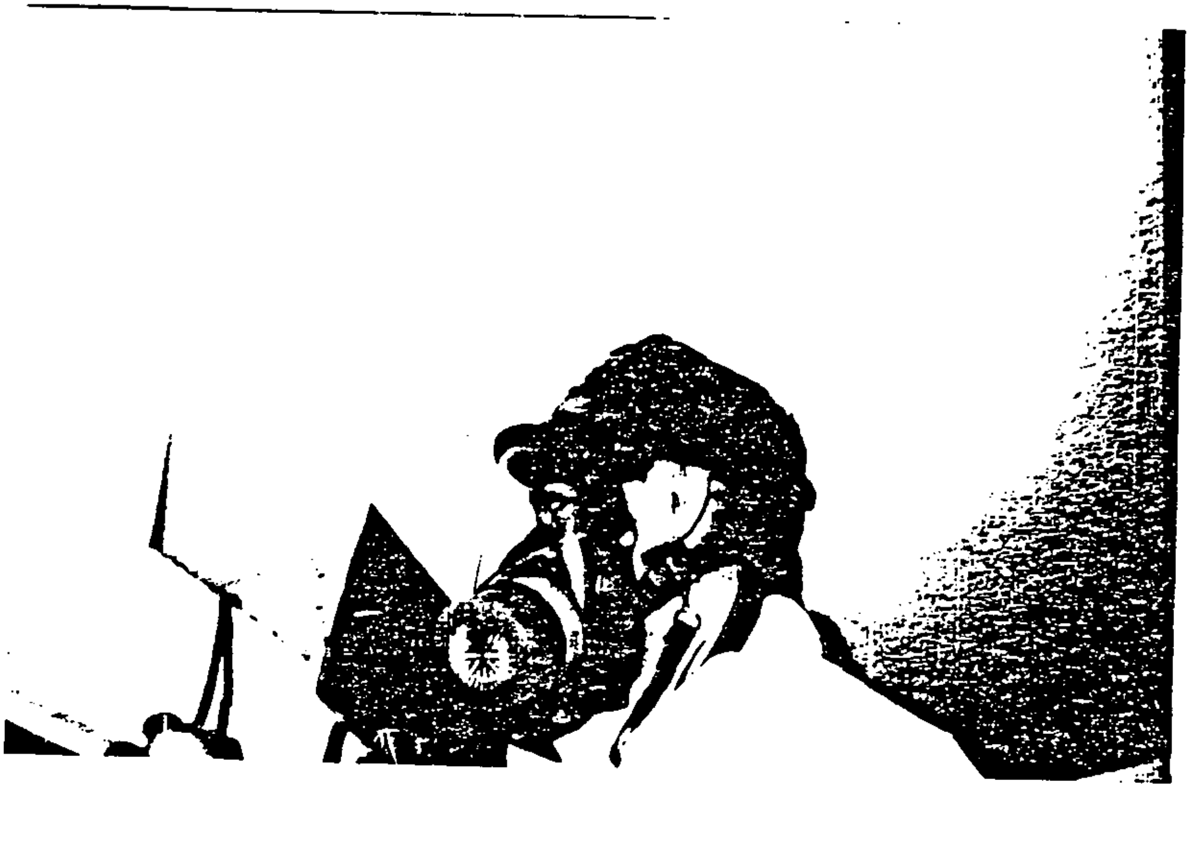

Figure 3.7. "AirSweep" Method

being cleaned through a predetermined opening. HEPA equipped negative air equipment is used on sections of the ductwork. Simultaneously, a rotary brush is inserted into the ductwork, as shown in *Figure 3.8*, and then either mechanically or manually agitated (rotated) to dislodge the debris. In the current research project the brush was agitated manually although the process was termed MechBrush.

Once the isolated section of the duct to be cleaned is under negative pressure, the rotary brushing device is introduced into the duct at the opening furthest upstream. The brushes are worked downstream slowly to dislodge dirt and dust particles. When observation suggests the section of duct has been cleaned sufficiently, the brush is withdrawn from the duct and inserted in the next downstream opening, where the process is repeated. *Figure 3.9* shows a photograph of the procedure.

3.4 Data Collection

According to the above protocol, data were collected and parameter readings were taken for each house (indoors and outdoors) before (*pre*), *during*, and after (*post*) the cleaning was carried out. The time gap allowed between *pre* and *post* was about 48 hours (two days). The study consisted of collection of data in three main groups as described below.

3.4.1 Collection of General Field Data

Temperature, relative humidity, and ambient pressure were recorded both indoors and outdoors every day during

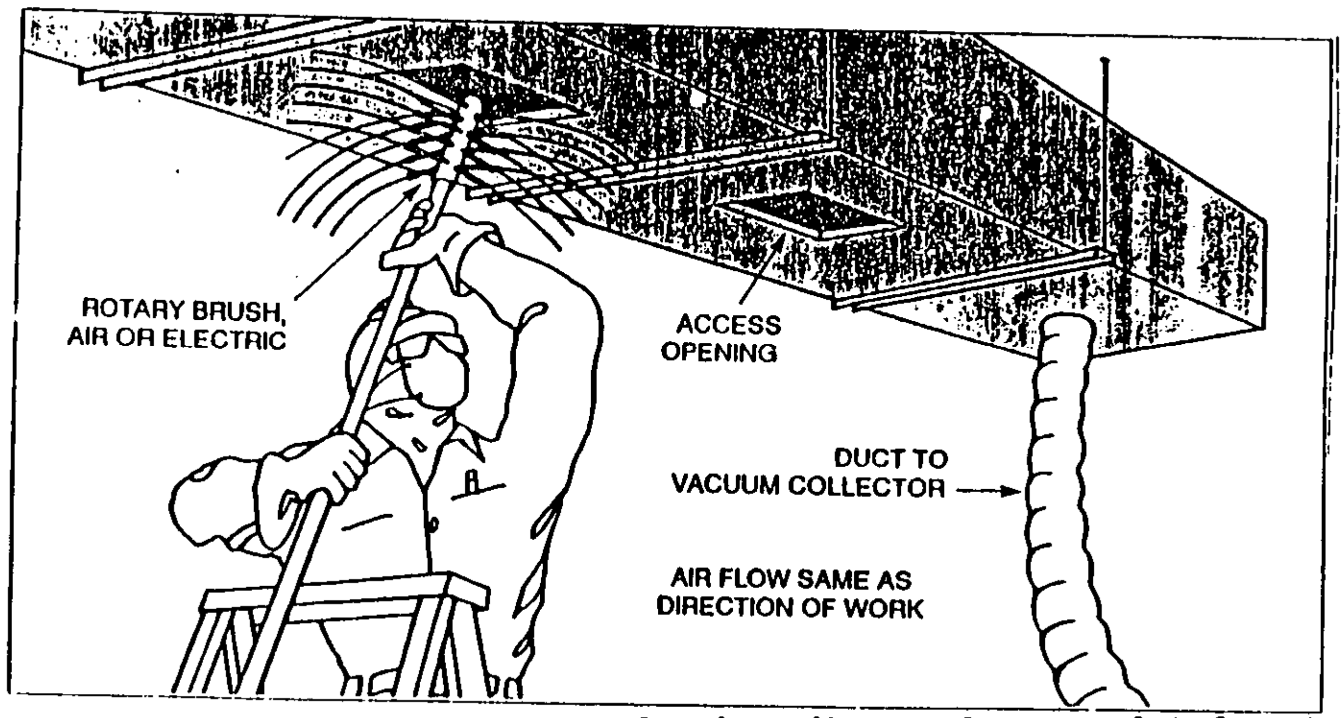

Figure 3.8. Rotary Brush Procedure (Source: "Cleaning Fibrous Glass Insulated Ducts," North American Insulation Manufacterers Association, page 18)

Figure 3.9. "MechBrush" Method

the study period. In addition, certain outdoor data such as wind direction, wind speed and general weather condition were recorded. General descriptions and hygiene of each house; normal cleaning practice; history of home remodeling and/or repair; number, age, sex, and occupation of residents; and number and type of pets were noted.

3.4.2 Airborne Particulate Matter

Met-One Particle Analyzer: Particle Count-readings were taken using Met-One Particle Analyzer, an automatic particle counter, both indoors and outdoors before (pre), during, and after (post) cleaning for every house under study except for the control study homes, for which readings were taken twice two days apart.

The Met-One particle analyzer used is basically an all-in-one sampler and analyzer. It prints out the analytical data at the end of its sampling cycle. The data are quantitative only and are expressed in terms of particles/ft^3. *Figure 3.10* shows a photograph of the Met-One particle analyzer set-up.

For both indoors and outdoors, 1 minute sampling time was used. Readings were taken at two levels: 0.3 microns and 1.0 microns. Met-One particle analyzer was used to collect readings before, during (indoors only) and after duct-cleaning.

NIOSH 7400 Fiber Counting Procedure: This is a sampling procedure that gives an index of airborne fibers. This method is used in conjunction with electron

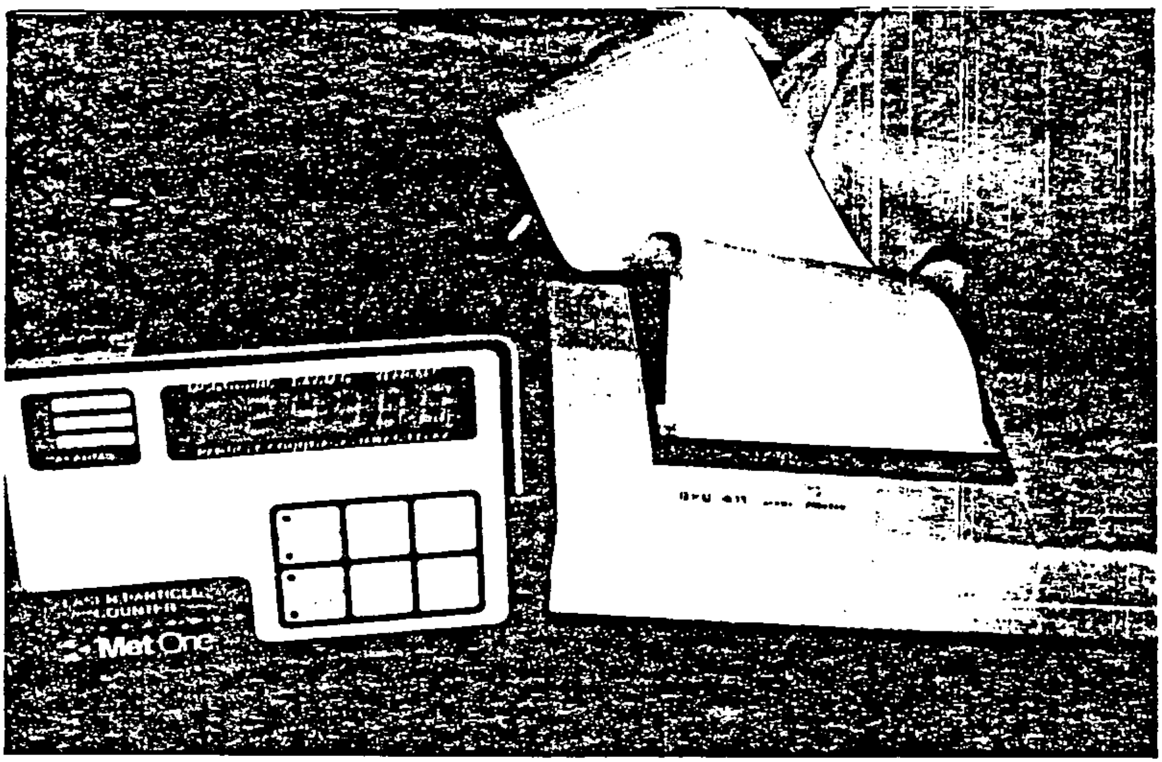

Figure 3.10. Set-up for Met-One Particle Analyzer

microscopy for assistance in identification of fibers. It is primarily used for estimating asbestos concentrations, although the subsequent analysis does not differentiate between asbestos and other fibers. Thus the results of this procedure represent total fiber count, not just the fibers from the fiberglass duct-work. The readings are expressed in terms of fibers/cubic centimeter (f/cc). It should be noted that the limit of detection (LOD) for the method is 0.01 f/cc. The equipment consists of a volummetric pump, connecting tubing and special cassettes for collecting samples. Sampling was used only indoor before, during and after duct-cleaning procedure was applied. *Figure 3.11* illustrates the sampling train of this procedure.

NIOSH 0500 Total Nuisance Dust: This is a nonspecific sampling method that determines the total dust concentration. This method is also used in conjunction with electron microscopy for analysis. The working range is 3 to 20 mg/m^3 for a 100-L air sample. This method is nonspecific and determines the total dust concentration. The sampling procedure is similar to NIOSH 7400. Different kind of cassettes, however, are used for collecting samples. Indoor samples were collected using this procedure before, during and after cleahing procedure was applied. The sampling technique is illustrated in *Figure 3.12*.

A photograph of the sample collection procedure for both the NIOSH procedures are shown in *Figure 3.13*.

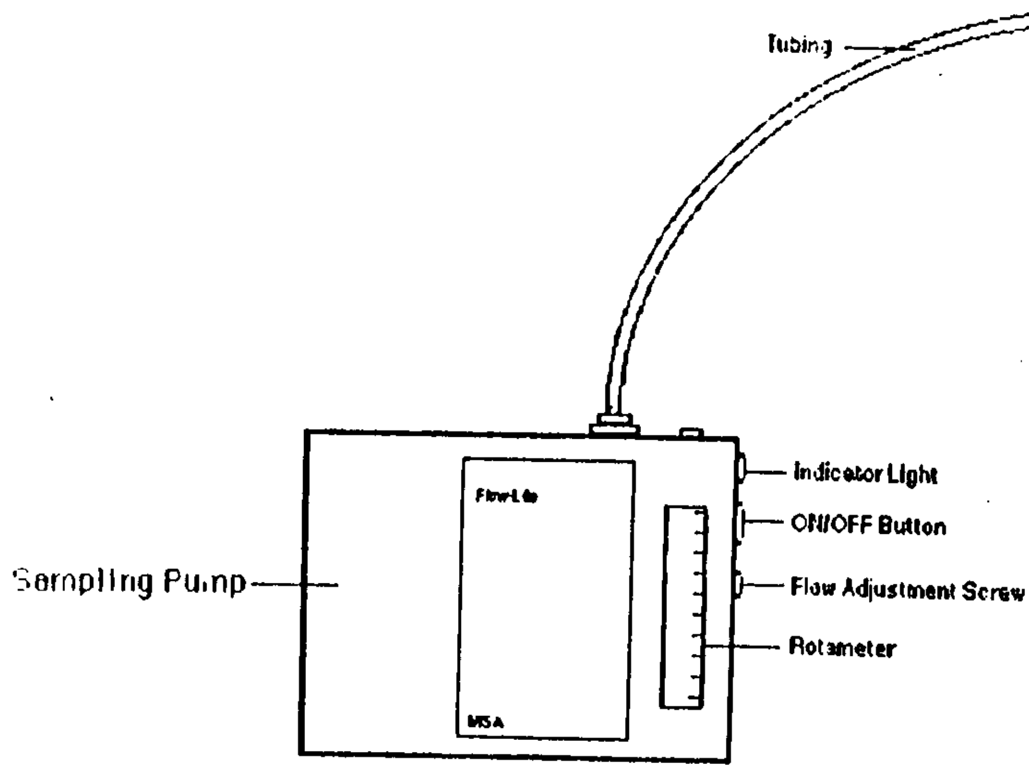

Figure 3.11. Sampling Procedure for NIOSH 7400 Fiber Counting Procedure

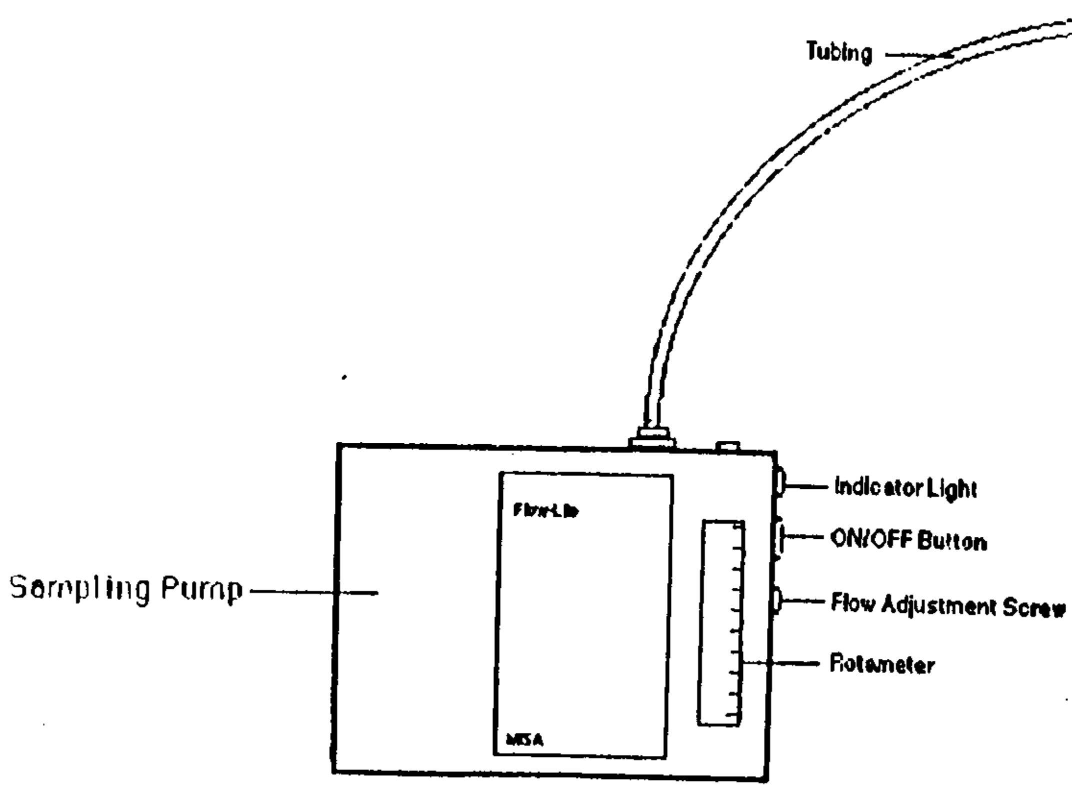

Figure 3.12. Sampling Procedure for NIOSH 0500 Total Nuisance Dust

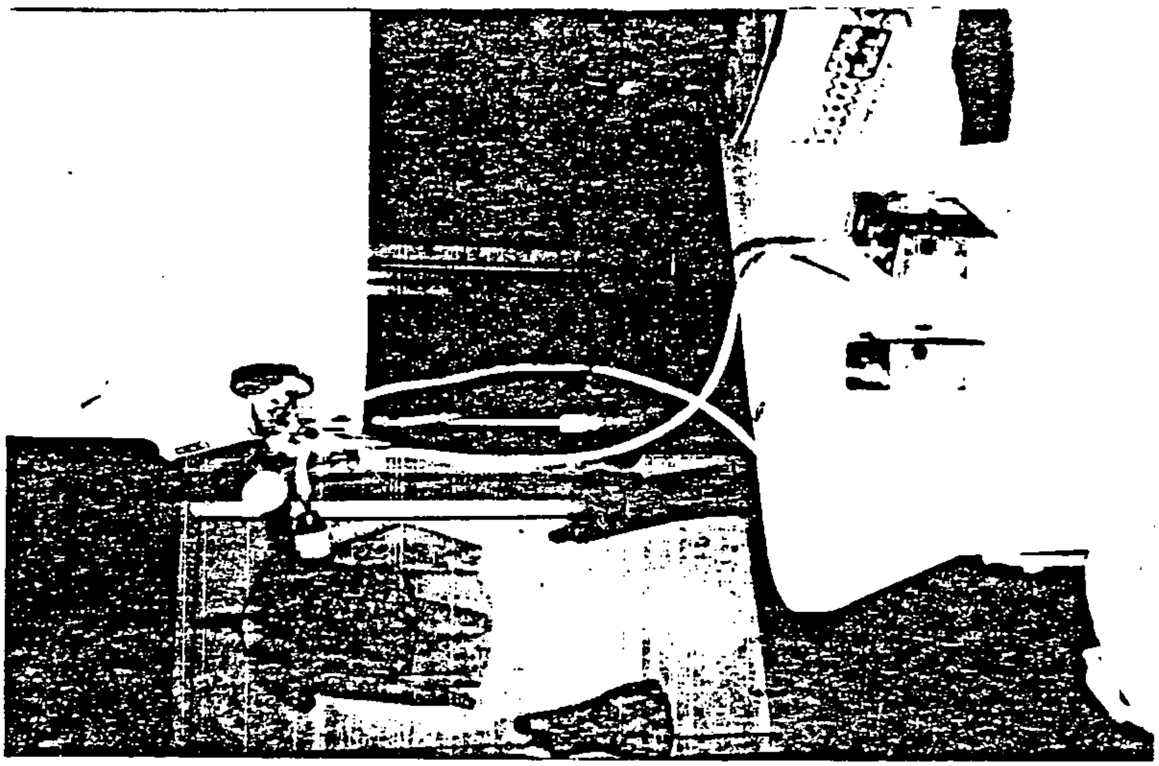

Figure 3.13. Sampling Set-up for NIOSH 7400 and NIOSH 0500 Procedures

3.4.3 Viable Bioaerosols

The following descriptions of the sampling procedures were written and provided by Larry Robertson, President of Mycotech Biological, Inc.

Andersen Biological Sampler: The Andersen package contains the N-6 Single Stage Sampler, a volummetric pump, and connecting tubing. The Sampler must be calibrated to a flow rate of 28.3 l/min. Samples are collected on media plates that are subsequently analyzed for qualitative and quantitative data. Sampling was conducted in duplicate pre-cleaning outdoors and indoors, during cleaniing indoors, post-cleaning outdoors and indoors, and in the control homes. The sampling procedure is shown in *Figure 3.14*.

HVAC Bioaerosol Sampling: The HVAC sampling capitalizes on the fan system located in the HVAC unit itself and does not require any additional equipment. However, it does require that the airflow be recorded at the air duct register to be tested. A specific air register is selected (the same for every home) to conduct the test. The airflow rate at the specific test vent is determined while the unit was on. Two media plates, to allow duplicate readings, are taped to the air-conditioning vent such that the airflow impacted the media surfaces at a 90^0 angle. The air-conditioning unit is then turned on and the fan is allowed to run continuously for 10 minutes. This procedure of collecting samples was originated by the Mycotech Biological, Inc. of Texas. HVAC analytical sampling was conducted pre-cleaning, post-cleaning, and in the control homes. The sample collection procedure is illustrated in

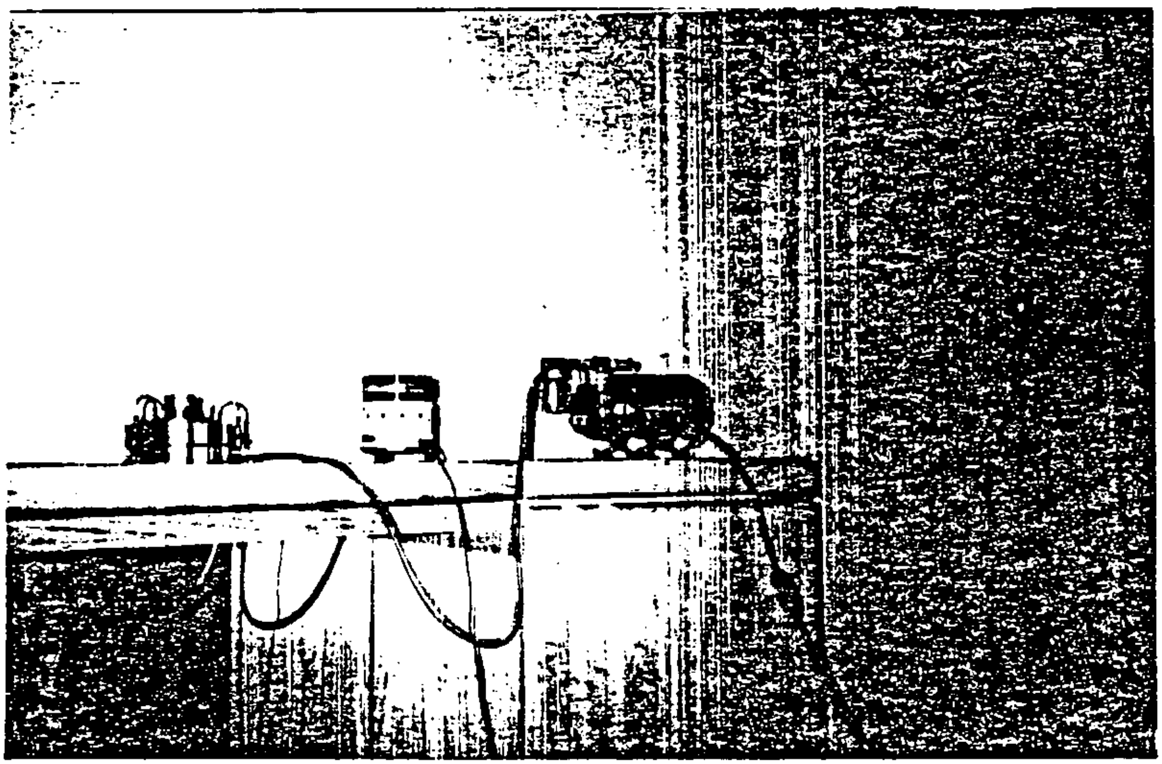

Figure 3.14. Sample Collection Set-up for Andersen (left) and Burkard (middle), pump for Andersen procedure is shown on the right.

Figure 3.15.

Burkard Sampling: The Burkard sampler draws a calibrated volume of air and deposits the airborne particulate on a microscope slid that has been prepared with a special hexane-silicon adhesive. The slides are then microscopically evaluated. Quantitative and qualitative data can be obtained from this procedure. Burkard sampling was conducted pre-cleaning indoors and outdoors, during cleaning, post-cleaning indoors and outdoors, and in the control homes. *Figure 3.14* illustrates the sample collection procedure.

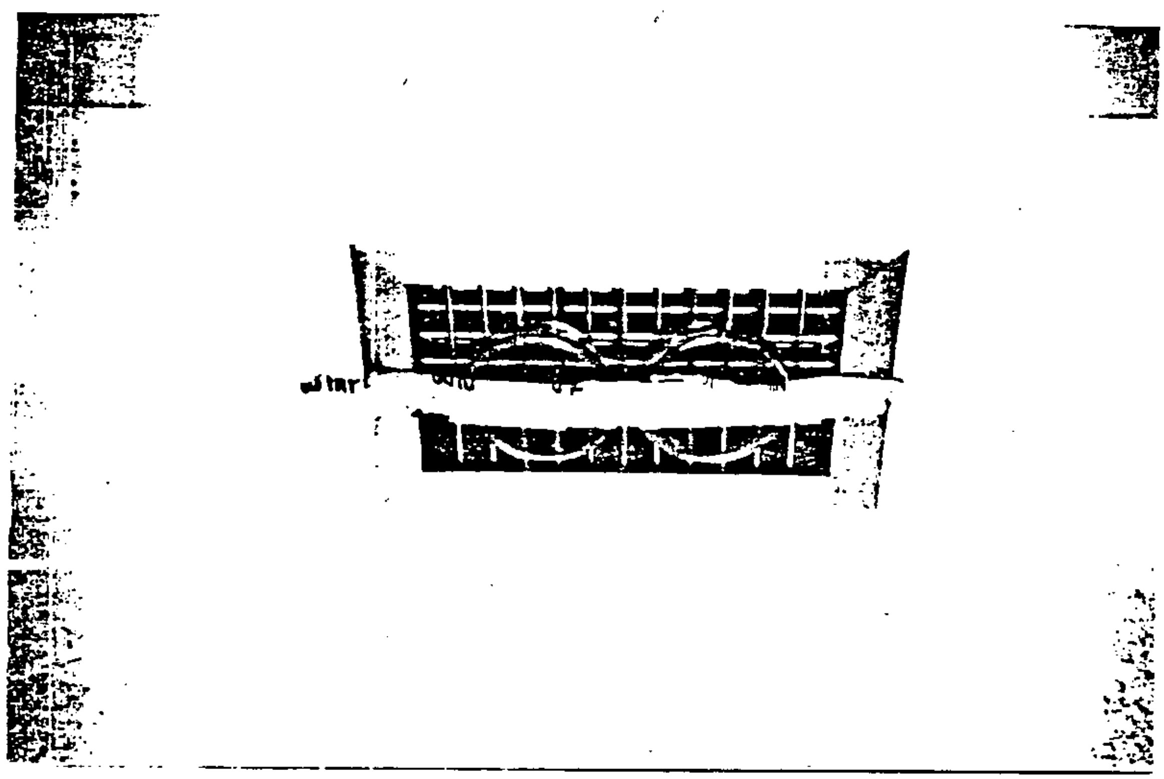

Figure 3.15. Sample Collection for HVAC procedure.

Chapter 4

FIELD OBSERVATIONS AND DATA COLLECTION

4.1 General

As mentioned earlier, the scope of this research study was rather limited and did not permit the investigators to collect enough data necessary for any statistical analysis. As such, the results reported herein, should be considered as case studies and we are aware of the danger of generalizing these results. Definite conclusions cannot be drawn from the limited information gathered in this project. The investigators strongly believe that the findings of this study, however limited, are very valuable and provide important and significant information on the topic of HVAC cleaning and indoor air quality of residential buildings. This study is one of the few that have been undertaken on this subject matter and the results would, hopefully, provide valuable directions for future studies.

Temperature, relative humidity, and ambient pressure were recorded both indoors and outdoors every day during the study period. In addition, certain outdoor data such as wind direction and speed were recorded. General descriptions and hygiene of each house; normal cleaning practice; history of home remodeling and/or repair; number, age and sex of residents; and number and type of pets were noted.

4.2 TEMPERATURE, RELATIVE HUMIDITY, AMBIENT PRESSURE, WIND SPEED-DIRECTION AND WEATHER CONDITIONS

Table 4.1 shows the summary of the indoor and outdoor temperature, relative humidity and ambient pressure for each home. Wind speed-direction and weather conditions were noted for outdoors only. These data were collected both before (pre) and after (post) cleaning. It should be noted that a time gap of about 48 hours was maintained between pre- and post-level readings.

The data do not indicate any significant differences from what is typical in southern Florida. Although, statistical correlation studies could not be performed due to insufficient data, the indoor readings do not seem to have detectable correlation with the duct-cleaning procedures.

An earlier study reported by Garrison et al[1] found no evidence of correlation between bioaerosol concentrations, before and after cleaning, and relative humidity.

4.3 GENERAL DESCRIPTION AND HYGIENE

Certain information that were thought to have an effect on the indoor air quality were collected for each house.

All the homes had a total of 1,285 sq.ft. of indoor floor space. All the rooms were carpeted except the

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[1] Garrison, R.A., Robertson, L.D., Koehn, R.D., and Wynn, S.R. "Effect of heating-ventilation-air conditioning system sanitation on airborne fungal populations in residential environments," *Annals of Allergy*, Vol. 71, No. 6, December 1993, p. 552.

Table 4.1. Temperature, Relative Humidity, Ambient Pressure, Wind Speed-Direction and Weather Conditions

Home	Temperature-Farenheit				Relative Humiidity-%				Ambient Pressure-in.Hg				Wind Speed-Direction		Weather condition	
	Pre		Post		Pre		Post		Pre		Post		Pre	Post	Pre	Post
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor	Outdoor	Outdoor	Outdoor	Outdoor
Control-1	79	79	82	75	68	71	52	71	30.15	30.13	30.07	30.09	14mph-S	14mph-SE	Partly Sunny	Cloudy
Control-2	77	79	79	75	80	71	60	71	30.15	30.13	30.08	30.09	14mph-S	14mph-SE	Partly Sunny	Cloudy
Contact-1	77	82	75	81	72	65	43	64	30.13	30.13	30.00	29.97	14mph-S	14mph-SE	Partly Sunny	Sunny
Contact-2	79	82	79	81	71	65	75	64	30.14	30.13	30.06	29.97	14mph-S	14mph-SE	Partly Sunny	Sunny
AirSweep-1	78	78	78	80	71	70	67	61	30.12	30.09	30.10	29.94	14mph-SE	17mph-S	Rain	Drizzle
AirSweep-2	80	78	77	80	75	70	67	61	30.14	30.09	30.02	29.94	14mph-SE	17mph-S	Rain	Drizzle
MechBrush-1	79	78	78	74	69	76	64	69	30.10	29.97	29.90	29.96	14mph-SE	14mph-N	Sunny	Partly Sunny
MechBrush-2	77	78	76	74	63	76	66	69	30.10	29.97	29.93	29.96	14mph-SE	14mph-N	Sunny	Partly Sunny

bathrooms and the kitchen, which were either tiled or covered with vinyl mat. The surroundings of the homes were mostly grass covered with white rocks in some spots. In the vicinity of the neighborhood, there was a fire station and the Motorola Cellular phone manufacturing plant was not too far away. The airport was about within 10 to 15 miles from the neighborhood and 5 to 6 miles from I-95.

The description of the interior, HVAC unit, occupants and other information are given in the following for each home.

4.3.1 Control 1

Cleaning practice: Regular, vacuum 1/week, dust 2/week.
Filter type: spun fiberglass disposable
Any damage/repair: None.
Residents/allergy problems:
1 male 40 yrs no allergy problem;
1 female 37 yrs allergic from dust, pollen;
1 female 3 yrs no allergy problem.
Pet: 1 dog
Furniture: fabric
Indoor plant: none
Cooking frequency: everyday
House Facing: Northwest
Condition of the HVAC unit: Accumulated dirt in the airhandling unit, the drain pan and the blower cage.

4.3.2 Control 2

Cleaning practice: Regular, vacuum 1/week, dust 2/week.
Filter type: spun fiberglass disposable

Any damage/repair: None.

Residents/allergy problems:

1 male 33 yrs, no allergy problem;

1 female 28 yrs, no allergy problem;

1 female 1 yr, has allergy problem, runny nose.

A grandmother, who occasionally visits, smokes inside the house.

Pet: None

Furniture: fabric

Indoor plant: in the balcony

Cooking frequency: about 3 days/week

House Facing: West

Condition of the HVAC unit: Accumulated clumps of dirt in the side wall, corroded coil, wet drain pan.

4.3.3 Contact 1

Cleaning practice: Regular, vacuum 1/week, dust 1/week.

Filter type: spun fiberglass disposable

Any damage/repair: None. Professional pest control every month using powder and other spray chemicals.

Residents/allergy problems:

1 male 34 yrs, no allergy problem;

1 female 34 yrs, no allergy problem;

1 female 8 yrs, no allergy problem;

1 female 5 yrs, no allergy problem.

Pet: 1 dog

Furniture: fabric

Indoor plant: none

Cooking frequency: about 3 days/week

House Facing: North

Condition of the HVAC unit: Gray mold, heavy accumulation of dirt in the air handler and on the side walls.

4.3.4 Contact 2

Cleaning practice: Regular, vacuum 1/week, dust 1/week, change filters every six weeks.
Filter type: spun fiber glass disposable
Any damage/repair: None.
Residents/allergy problems:
1 male 72 yrs, no allergy problem;
1 female 69 yrs, runny nose, since moved in this house;
Pet: None
Furniture: velvet (plush)
Indoor plant: one
Cooking frequency: every day
House Facing: East
Condition of the HVAC unit: Gray mold, heavy accumulation of dirt in the air handler, white wet accumulation on the side walls, water in the drain pan.

4.3.5 AirSweep 1

Cleaning practice: Regular.
Filter type: spun fiberglass disposable
Any damage/repair: None.
Residents/allergy problems:
1 female 44 yrs, gets allergy from dust, cats; under medication.
Pet: 1 dog
Furniture: fabric
Indoor plant: none
Cooking frequency: does not cook much
House Facing: North

Condition of the HVAC unit: Very dirty, Stained coil, smells bad.

4.3.6 AirSweep 2

Cleaning practice: Regular.

Filter type: spun fiberglass disposable

Any damage/repair: None.

Residents/allergy problems:

1 female 23 yrs, no allergy problem; manicurist- does at home 2/3 times a week using polish, acrylic liquid and powder, acetone.

1 male 27 yrs, no allergy problem.

Both occupants smoke inside the house.

Pet: none

Furniture: Vinyl

Indoor plant: 4 small indoor plants

Cooking frequency: does not cook much

House Facing: East

Condition of the HVAC unit: Severe dirt in air filter, mold on the surface of air handler, rust in the pan, dirty side wall.

4.3.7 MechBrush 1

Cleaning practice: Regular, vacuum 1/wk, wash 1/wk, dust every other week.

Filter type: fiberglass media with impregnated charcoal, using for a year as advised by the physician.

Any damage/repair: had a sewer leak, downstairs kitchen carpet was wet for several days before testing.

Residents/allergy problems:

1 female 46 yrs, smokes twice a day, has allergy from

dust, has breathing problem and asthma.
Pet: none
Furniture: fabric/Vinyl
Indoor plant: none
Cooking frequency: not a lot
House Facing: South
Condition of the HVAC unit: Relatively clean inside AC unit.

4.3.8 MechBrush 2

Cleaning practice: Regular, vacuum 1/wk.
Filter type: spun fiberglass disposable.
Any damage/repair: none
Residents/allergy problems:
1 male 45 yrs, sinus problem since moved in Florida,
1 male 35, no allergy problem.
Pet: 1 dog
Furniture: fabric
Indoor plant: none
Cooking frequency: couple of times a week
House Facing: North
Condition of the HVAC unit: Accumulated water in the drain pan, very dirty interior of the AC unit.

Pictures taken during the process of observation are reproduced in *Figures 4.1 to 4.8*. These photographs illustrate the conditions of the air conditioning unit, (air handler, blower cage, and drain pan), interior of the ductwork, filters and cleaned air handling units.

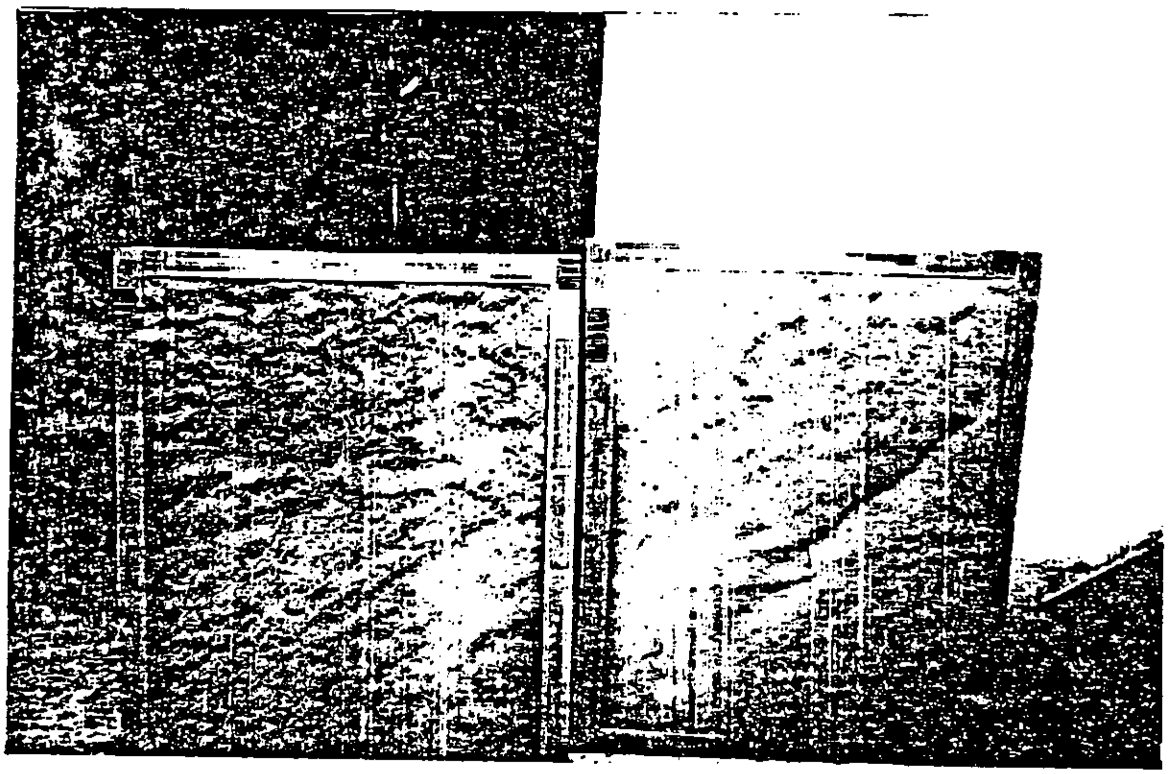


Figure 4.1. Clogged Spun Fiberglass Disposable Filters

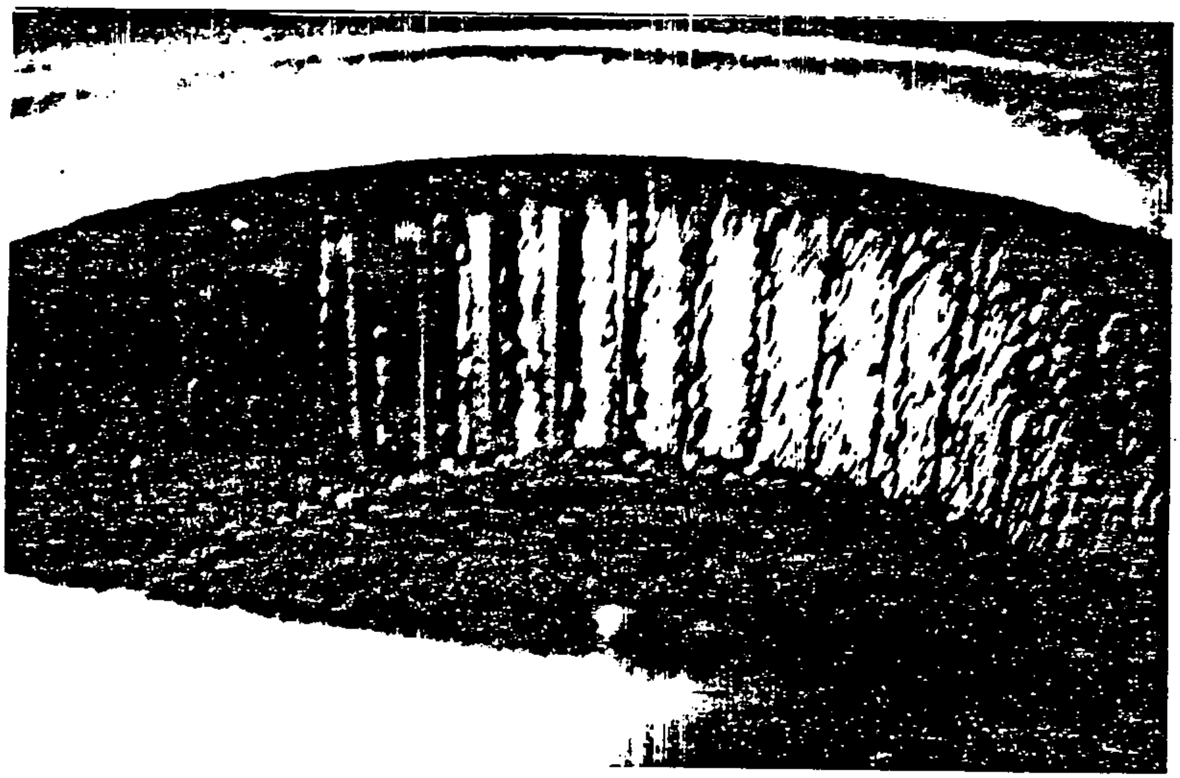


Figure 4.2. Accumulated Dirt on the Surface of the Blower Coil

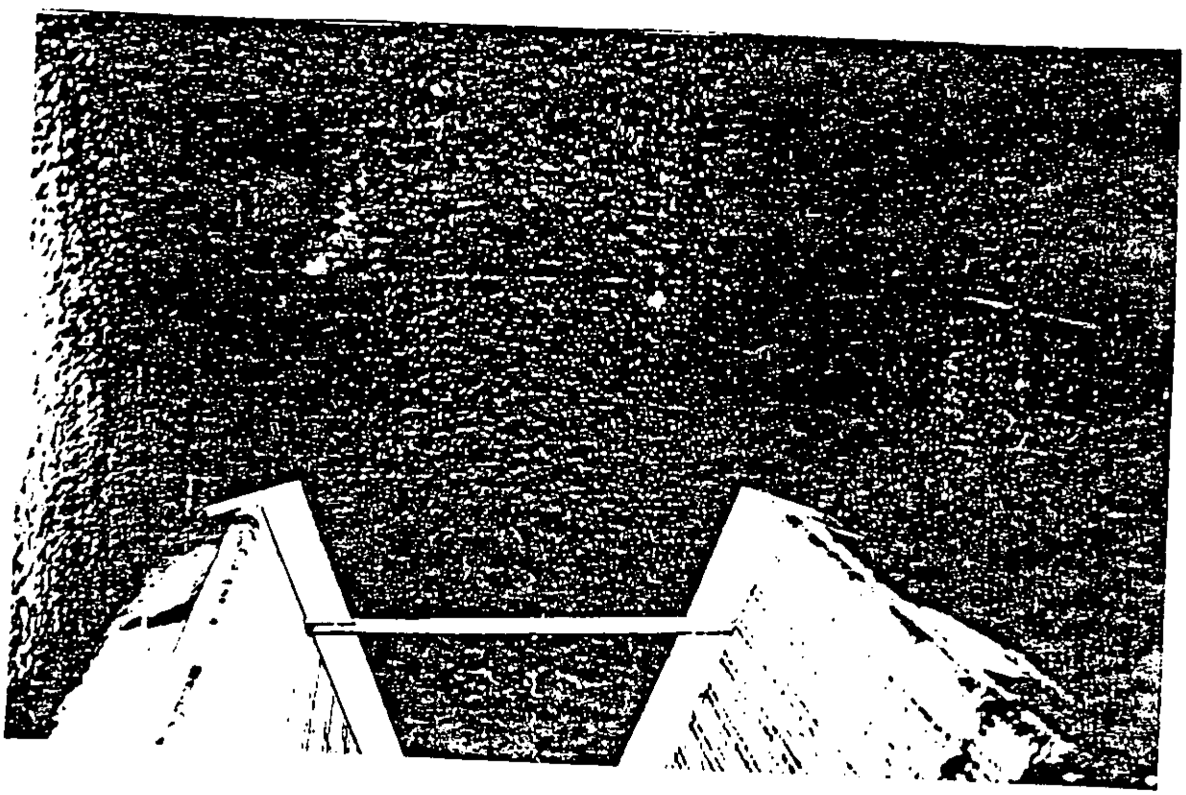


Figure 4.3. White Mold on the Inside Wall of the AC Unit

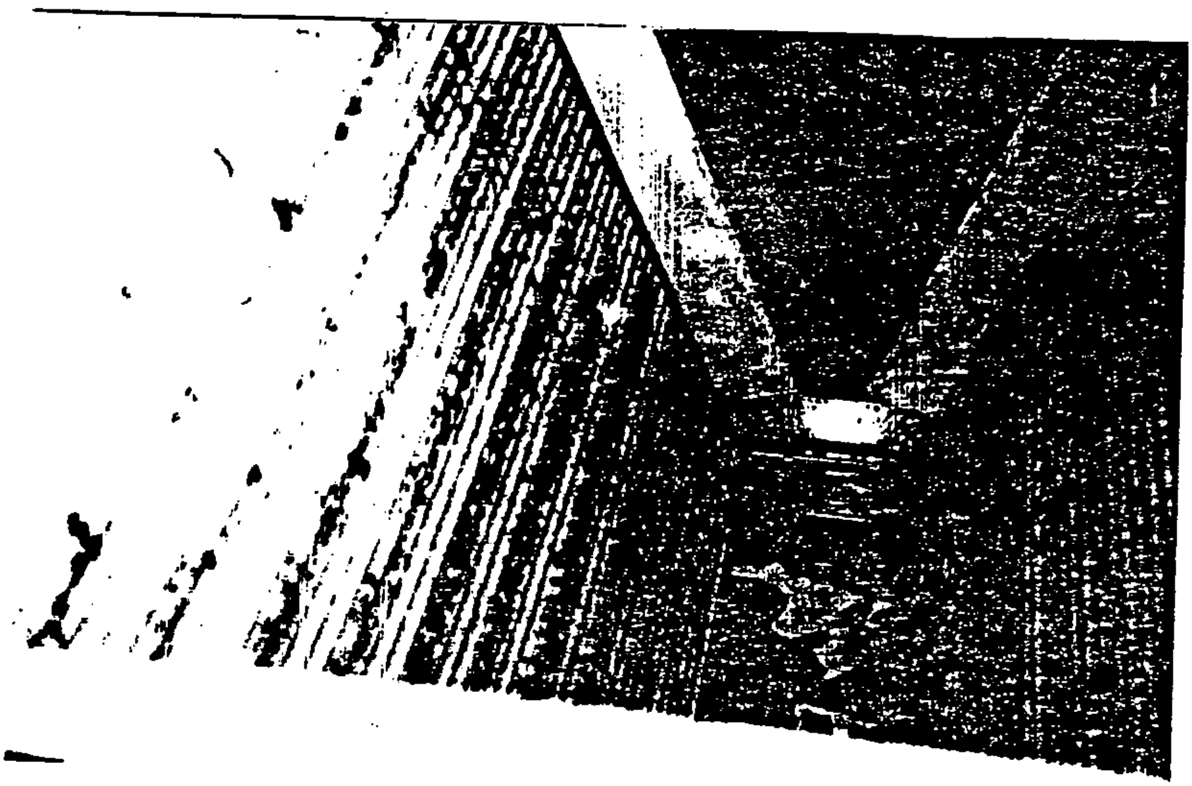


Figure 4.4. Caked Dirt in the Wet Drain Pan

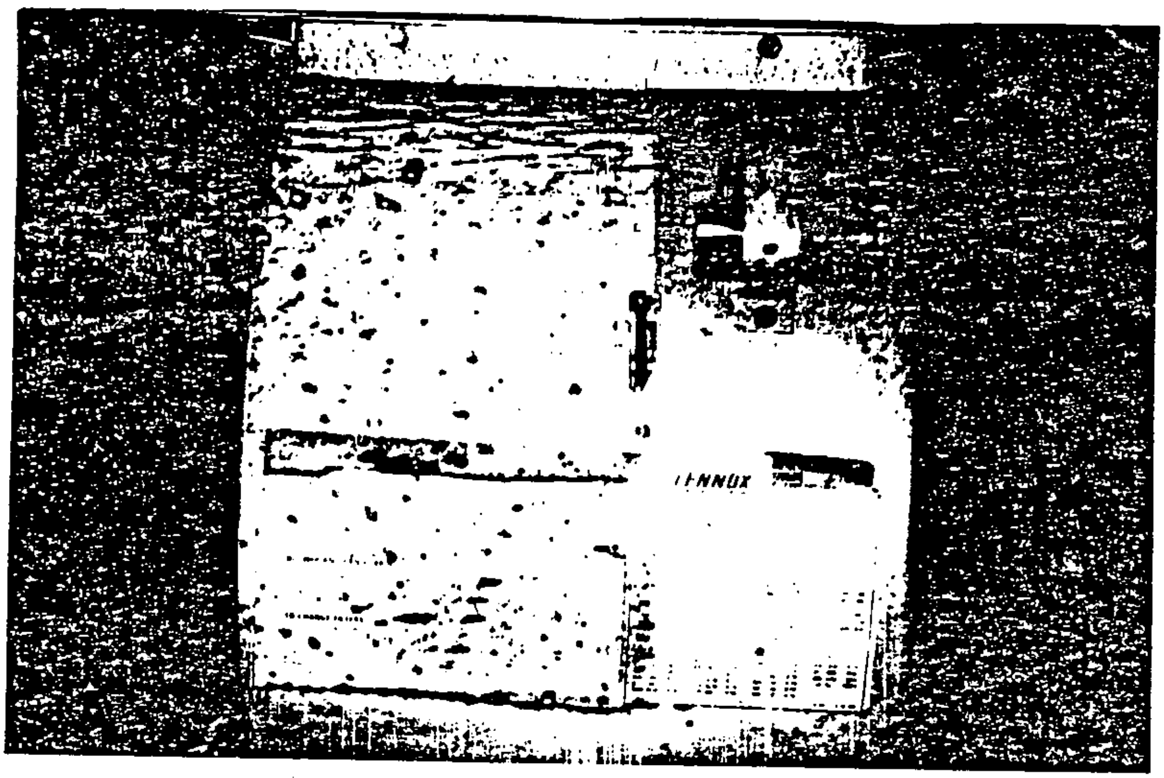


Figure 4.5. Rust on the Label of the Blower Cage

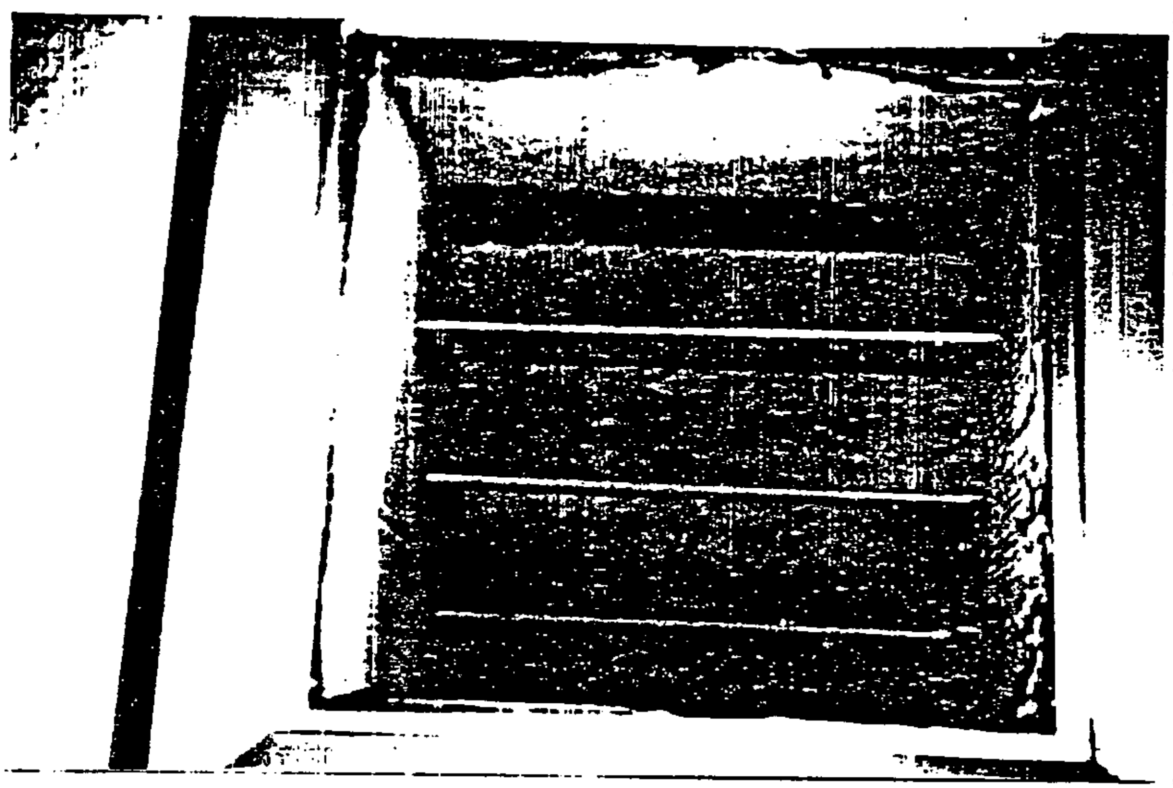


Figure 4.6. Inside the Ductwork

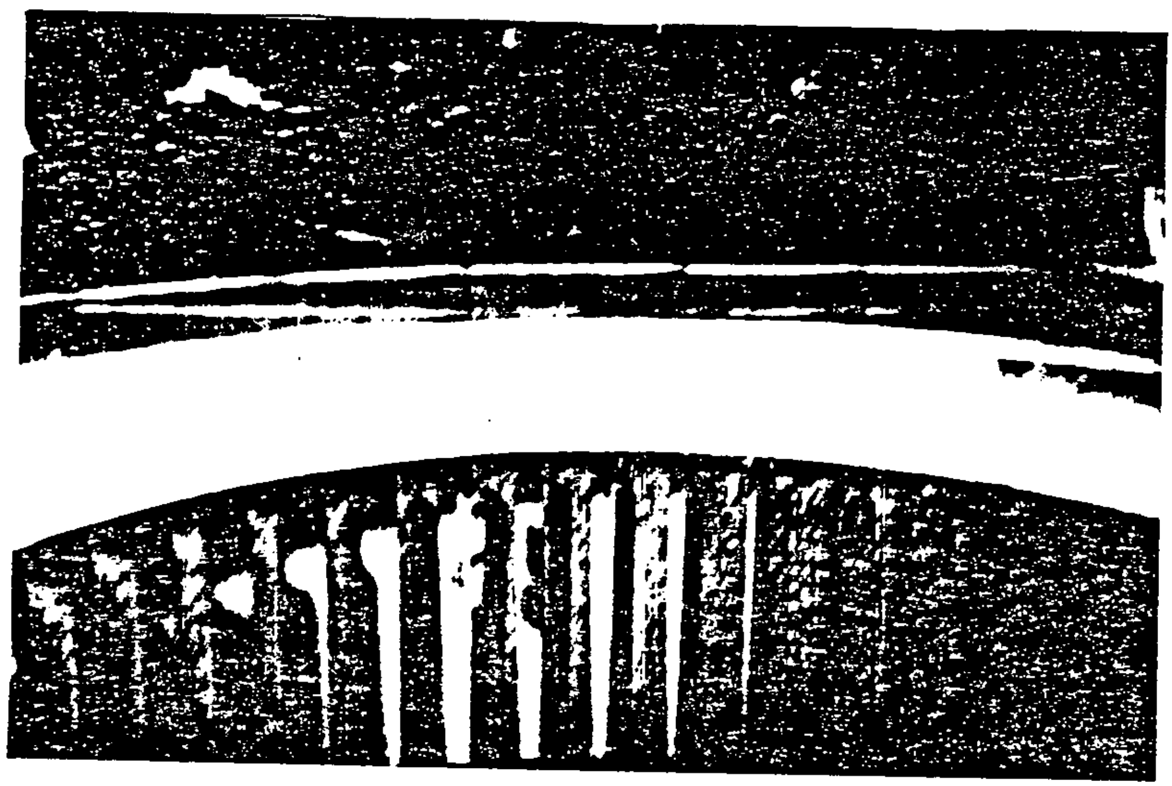


Figure 4.7. Clean Blower Coil

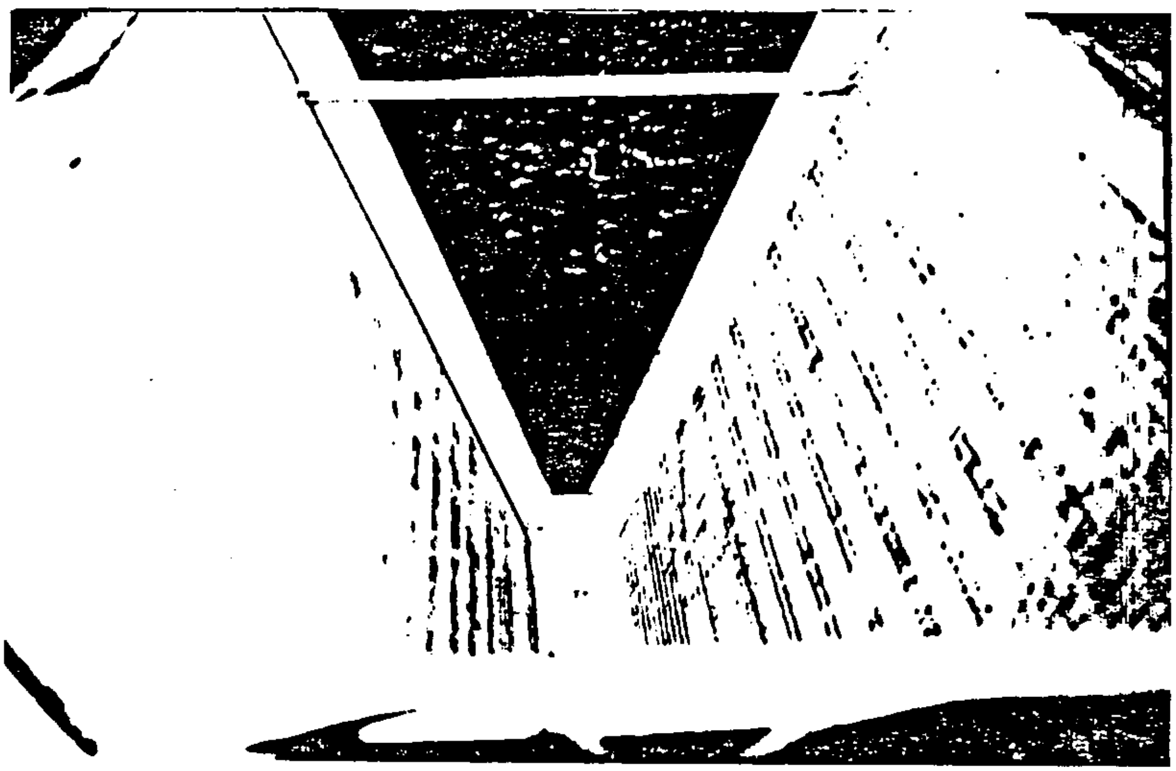


Figure 4.8. Clean Drain Pan

4.4 RATED VS. ACTUAL CFM (cu ft./min)

Air volume rate readings were taken with the help of a Ballometer with the HVAC unit on. The ballometer was placed at the air duct register so that air can flow through the meter that indicates the reading. These readings were taken for each home before and after duct-cleaning. The readings are shown in *Table 4.2*.

It should be noted that the rated CFM for these homes was 1000. The total actual CFM, as indicated in *Table 4.2* were found to be greater than the rated CFM in all homes (Pre and Post) except for AirSweep 2 (Pre). The HVAC air velocity readings, reported in the next chapter, for AirSweep 2 (Pre) was also found to be unusually low for some reasons not clear to the investigators. In AirSweep 1, an increase of about 10% (from 1105 CFM to 1220 CFM) from pre- to post-level was noticed. A decrease of about 3.7% and an increase of 7% were recorded for Contact 1 and Contact 2 respectively. Both MechBrush 1 and 2 showed a reduction in actual CFM from pre- to post- level; 5.7% for MechBrush 1 and 4.7% for MechBrush 2. In one of the control homes 10% increase and in the other 2.5% reduction were observed. If control home fluctuations are considered normal, the fluctuations observed in the study homes cannot be said to have been affected by the duct-cleaning procedures.

4.5 STATIC PRESSURE - MANOMETER READINGS (inch. water)

Static pressures observed for the HVAC units before and after duct-cleaning are reported in *Table 4.3*. All the study homes showed some drop in static pressure. Significant drops were indicated in MechBrush homes (about 50% on average) and in Contact 2 (62.5%).

Table 4.2. Actual Air Volume rate (CFM - cu. ft/min) - Pre/Post Comparison

Home	Pre					Post				
	Living	M. Bed	C. Bed	Bath	Total	Living	M. Bed	C. Bed	Bath	Total
Control 1	400	360	260	50	1070	410	390	280	100	1180
Control 2	460	410	200	100	1170	430	410	190	110	1140
Contact 1	405	390	340	50	1185	420	340	320	60	1140
Contact 2	380	390	330	50	1150	390	390	350	100	1230
AirSweep 1	395	350	300	60	1105	400	380	320	120	1220
AirSweep 2	220	200	150	50	620	430	340	370	120	1260
MechBrush 1	435	360	350	160	1305	380	440	320	90	1230
MechBrush 2	490	380	370	40	1280	425	365	340	90	1220

Table 4.3. Static Pressure - Manometer Reading (in. water) - Pre/Post Comparison

Home	Pre	Post
Control 1		0.09
Control 2		0.10
Contact 1	0.09	0.08
Contact 2	0.08	0.03
AirSweep 1	0.09	0.07
AirSweep 2	0.08	0.07
MechBrush 1	0.10	0.04
MechBrush 2	0.10	0.06

Chapter 5
ANALYSIS OF RESULTS

5.1 General

In this chapter, analysis of study parameters are reported. The major parameters studied are airborne particulate matter and viable bioaerosols. Results of quantitative, and where possible, qualitative analysis were obtained for each home under study.

5.2 Airborne Particulate Matter

Three procedures were employed to collect readings on the airborne particulate concentration. These are Met One particle counter, NIOSH 7400 fiber count, and NIOSH 0500 total nuisance dust count.

5.2.1 Met-One Particle counter

The particle counter was set to give particle counts per cubic feet at two levels - 0.3 micron and larger and 1.0 micron and larger. The readings were collected for all the homes under investigation before, during and after duct-cleaning. The average of 15-minutes readings are shown in *Table 5.1* and *Table 5.2* for 0.3 microns and 1.0 microns respectively. *Table 5.1* indicates high particle counts for Control 2 (pre), AirSweep 2 (post) and MechBrush 2 (post). It became known to the investigators that cigarette-smoking had taken place shortly before collection of these data in all three cases. Corresponding readings at 1.0 micron level as shown in *Table 5.2* do not show the effects of cigarette

Table 5.1 **METONE (particle count)**

SIZE 0.3 MICRONS AND LARGER

	INDOOR					OUTDOOR			
HOMES	PRE	DURING	% CHANGE PRE TO DURING	POST	% CHANGE PRE TO POST	PRE	POST	% CHANGE PRE-IND PRE-OUTD	% CHANGE POST-IND POST-OUTD
CONTROL 1	16490			33016	100.22%	21912	40627	32.88%	23.05%
CONTROL 2	563378			10934	-98.06%	21912	40627	-96.11%	271.57%
CONTACT 1	44399	53776	21.12%	27235	-38.66%	19449	44789	-56.19%	64.45%
CONTACT 2	14461	180126	1145.60%	37369	158.41%	19449	44789	34.49%	19.86%
AIRSWEEP 1	28180	208753	640.78%	64917	130.37%	40627	33404	44.17%	-48.54%
AIRSWEEP 2	52028	107044	105.74%	198909	282.31%	40627	33404	-21.91%	-83.21%
MECHBRUSH 1	175612	332913	89.57%	180024	2.51%	49789	207188	-71.65%	15.09%
MECHBRUSH 2	40401	104448	158.53%	231787	473.72%	49789	207188	23.24%	-10.61%

Notes:

Post readings were taken 2 days after pre.

Readings are average of 15 minutes readings

Table 5.2 **METONE (particle count)**

SIZE 1.0 MICRONS AND LARGER

	INDOOR					OUTDOOR			
HOMES	PRE	DURING	% CHANGE PRE TO DURING	POST	% CHANGE PRE TO POST	PRE	POST	% CHANGE PRE-IND PRE-OUTD	% CHANGE POST-IND POST-OUTD
CONTROL 1	3095			4641	49.95%	3396	1714	9.73%	-63.07%
CONTROL 2	1114			1865	67.41%	3396	1714	204.85%	-8.10%
CONTACT 1	9369	15796	68.60%	3691	-60.60%	2368	3160	-74.73%	-14.39%
CONTACT 2	3417	19850	480.92%	5076	48.55%	2368	3160	-30.70%	-37.75%
AIRSWEEP 1	5321	15561	192.45%	4715	-11.39%	1714	1904	-67.79%	-59.62%
AIRSWEEP 2	4686	5288	12.85%	2588	-44.77%	1714	1904	-63.42%	-26.43%
MECHBRUSH 1	7290	33373	357.79%	3505	-51.92%	3160	1031	-56.65%	-70.58%
MECHBRUSH 2	6877	8450	22.87%	6296	-8.45%	3160	1031	-54.05%	-83.62%

Notes:

Post readings were taken 2 days after pre.

Readings are average of 15 minutes readings smoking.

It was observed, in general, that particle counts typically were much higher when the duct cleaning was being performed (during cleaning). This effect were evident at both 0.3 microns and 1.0 micron levels. This is probably due to disturbances caused by the cleaning procedures employed. The readings obtained for particles 1.0 micron or larger follow similar patterns, although as expected, they were always less than the corresponding readings for particles 0.3 microns and larger.

Post readings at the 0.3 microns level were not found to have been reduced significantly. Even if we ignore AirSweep 2 and MechBrush 2, we notice that only in Contact 1, particle count shows a reduction of about 39%. Others show an increase. In MechBrush 1, very little change (about +2.5%) was observed. One control home showed an increase (100%) and the other indicated a reduction (98%) in particle count at this level.

At 1.0 micron-level, however, the effects are not similar. Both AirSweep and MechBrush homes indicated a reduction in particle counts two days after cleaning. One of the Contact homes showed reduction while the other experienced an increase. The two control homes were found to have an increase of about 59% on the average at 1.0 micron-level. It was not possible for the investigators to collect further readings on the concentration of particulate matter. Thus the long-term effect of the cleaning procedures on the airborne particle concentration could not be known at this point.

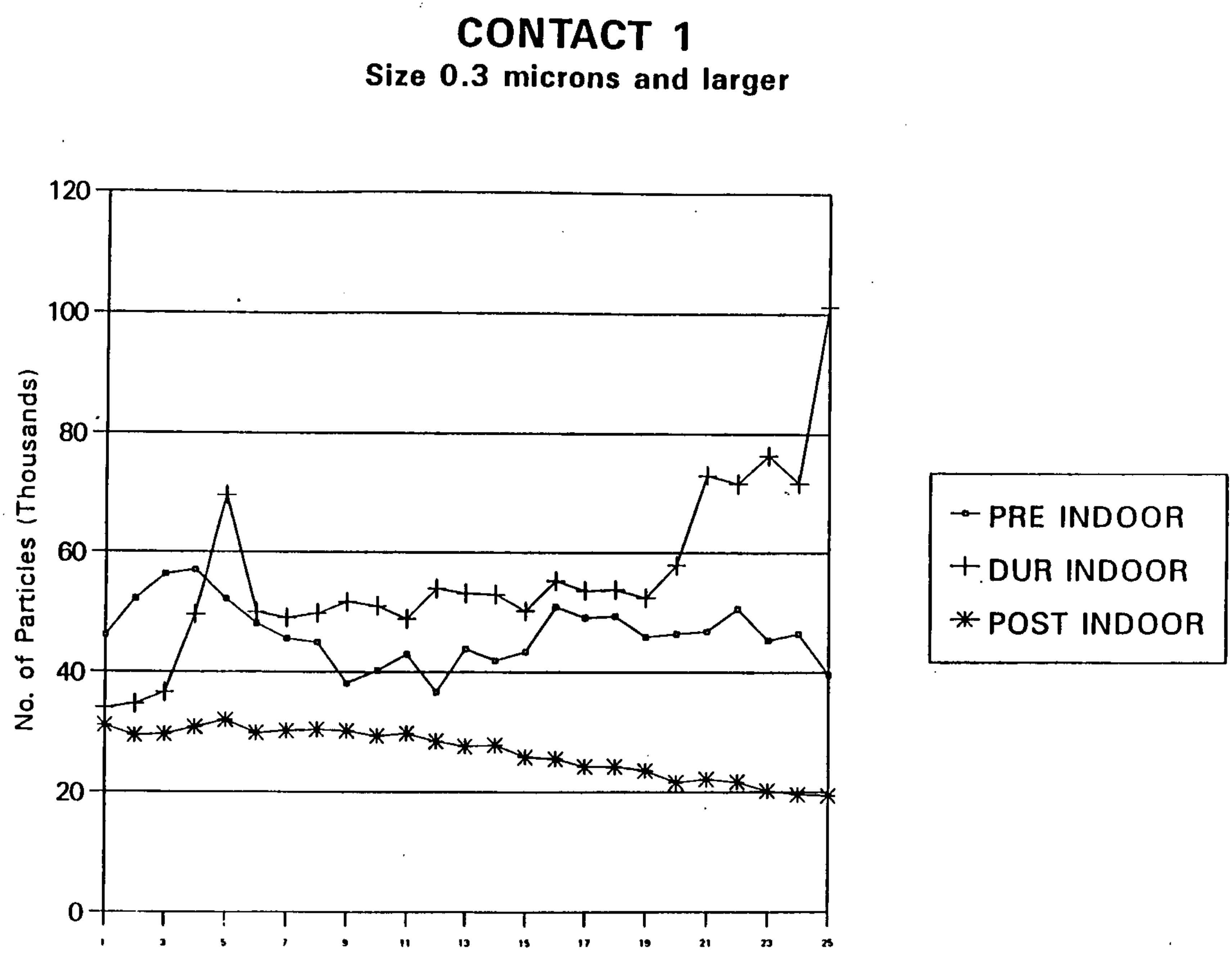
Tables 5.1 and 5.2 also show the outdoor readings of

Met-One particle counts. A comparison of indoor and outdoor, at both levels 0.3 and 1.0 microns, before (pre) and after (post) cleaning were made and reported. Only in a few cases, were indoor readings found to be higher than corresponding outdoor readings at 0.3 micron level. The opposite was found to be true at the 1.0 micron level, indoor readings were, in most cases, lower than the corresponding outdoor readings.

Met-One readings are also shown graphically in *Figures 5.1* to *5.12*. These graphical illustrations provide a pictorial representation of comparison between pre-, during-, and post-level concentrations of airborne particulate matter for the homes under study. As pointed out earlier, these figures indicate a consistent pattern. They show that the readings during cleaning, in most cases, are higher than the pre or post level readings (except for AirSweep 2 and MechBrush 2 at the 0.3 microns level; apparently these readings were affected by cigarette smoking). The post readings, in most cases, dropped to at or near the pre-level readings. Whether these readings would drop further or go up, could not be known, since readings were taken only once, after about 48 hours.

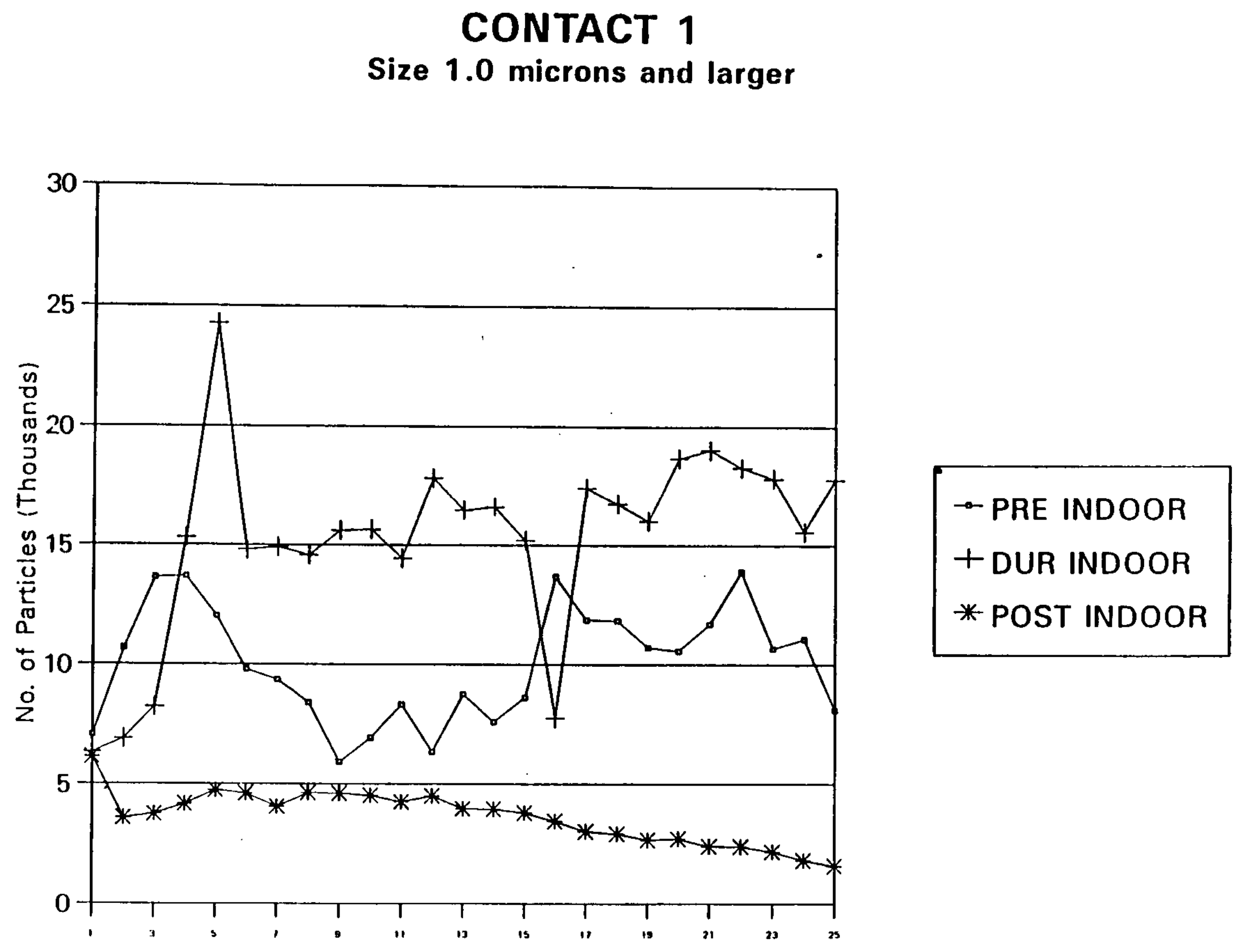
5.2.2 NIOSH 7400 Fiber Count

Results obtained from this procedure and subsequent microscopic analysis are reported in *Figure 5.13*. The control homes do not show any difference in the fiber-counts taken two days apart. Both Contact 1 and Contact 2 homes show slight increase in post and during fiber-counts from pre-level counts. Although, in Contact 1,



CONTACT 1
Size 0.3 microns and larger
No. of Particles (Thousands)
120
100
80
60
40
20
0
1
3
5
7
9
11
13
15
17
19
21
23
25
MINUTES
PRE INDOOR
DUR INDOOR
POST INDOOR

Figure 5.1


CONTACT 1
Size 1.0 microns and larger
No. of Particles (Thousands)
30
25
20
15
10
5
0
1
3
5
7
9
11
13
15
17
19
21
23
25
MINUTES
PRE INDOOR
DUR INDOOR
POST INDOOR
Figure 5.2

CONTACT 2

Size 1.0 microns and larger

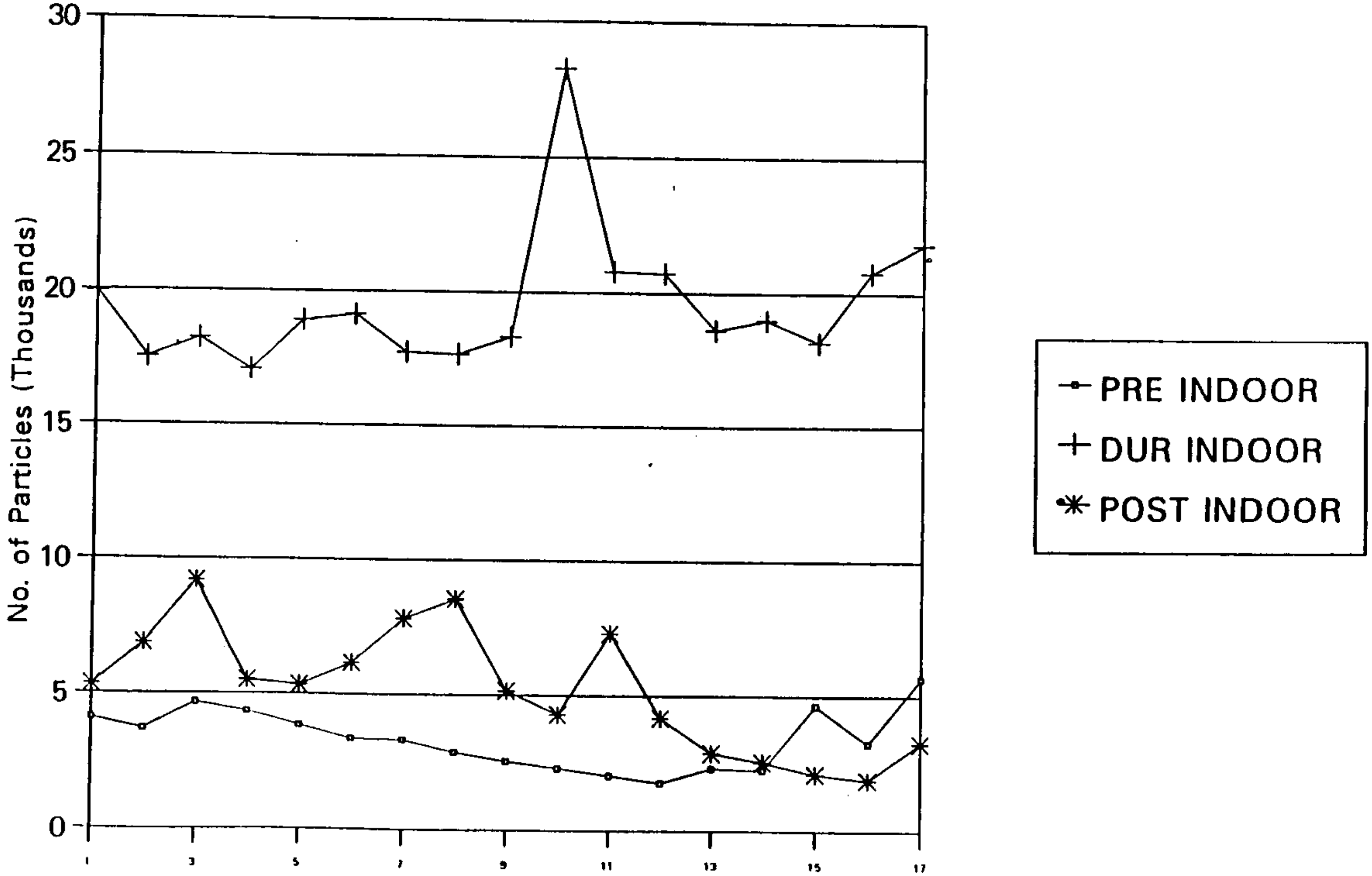


Figure 5.3

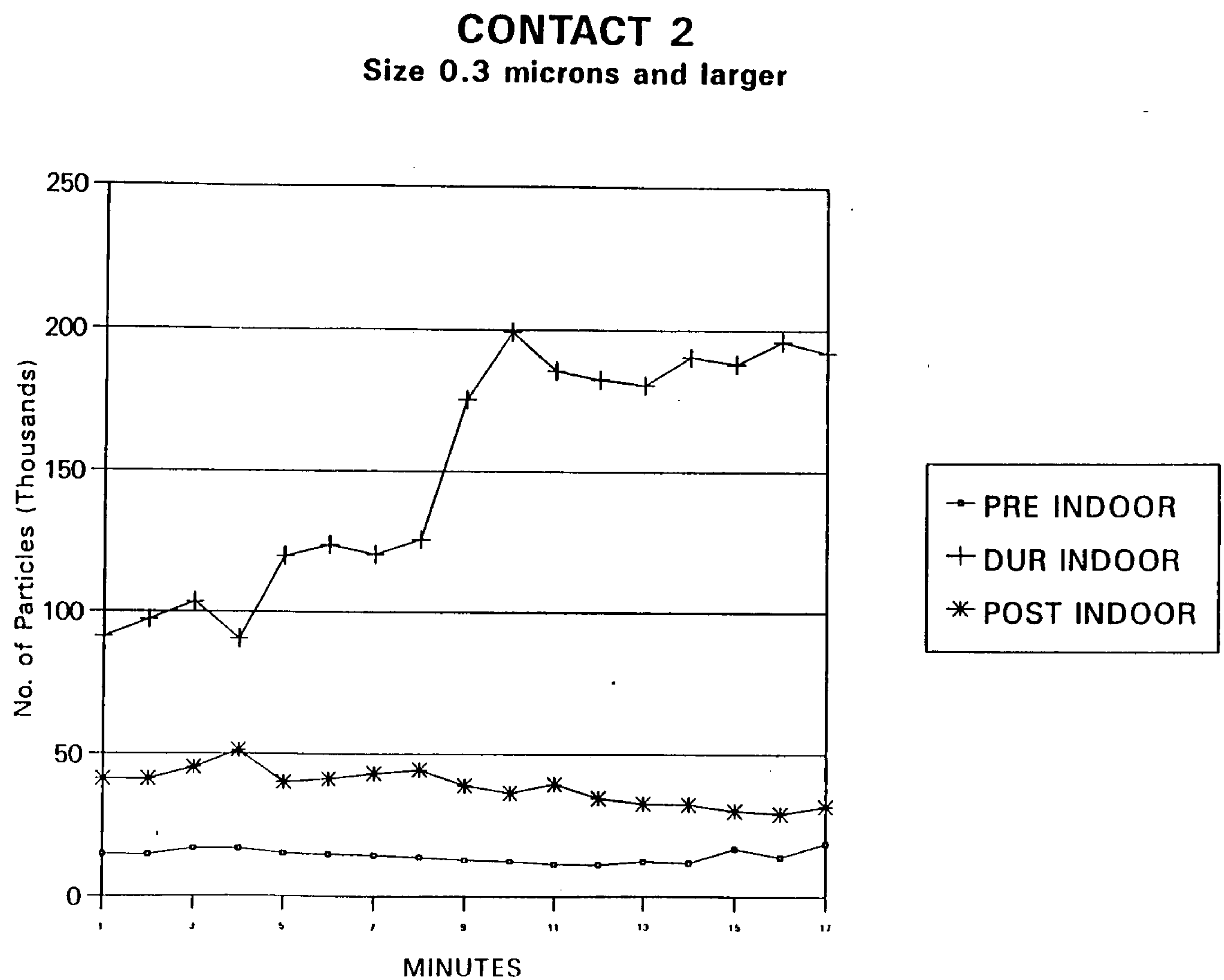

CONTACT 2
Size 0.3 microns and larger
250
200
150
100
50
0
No. of Particles (Thousands)
1
3
5
7
9
11
13
15
17
MINUTES
PRE INDOOR
DUR INDOOR
POST INDOOR

Figure 5.4

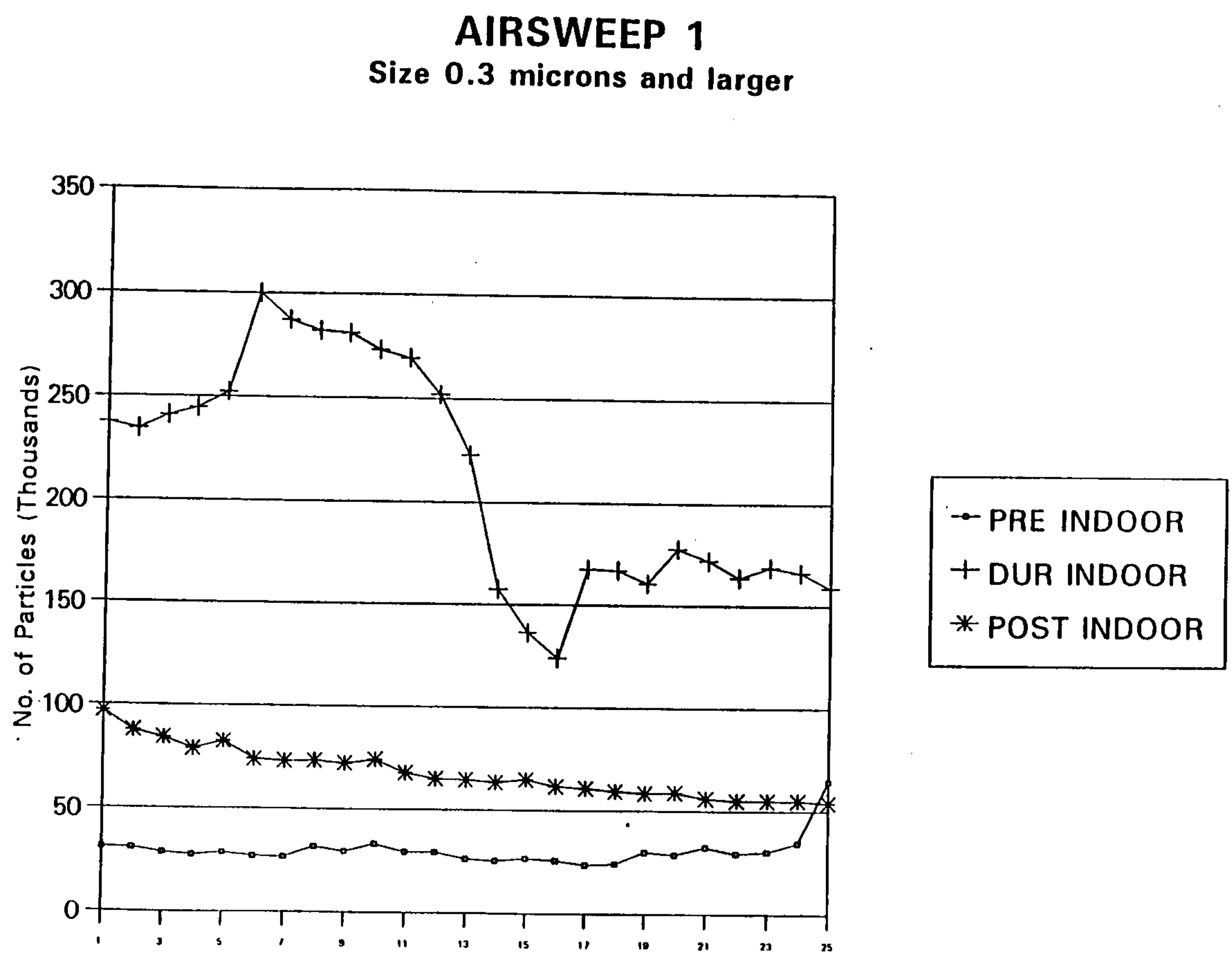

AIRSWEEP 1
Size 0.3 microns and larger
No. of Particles (Thousands)
350
300
250
200
150
100
50
0
1
3
5
7
9
11
13
15
17
19
21
23
25
MINUTES
PRE INDOOR
DUR INDOOR
POST INDOOR

Figure 5.5

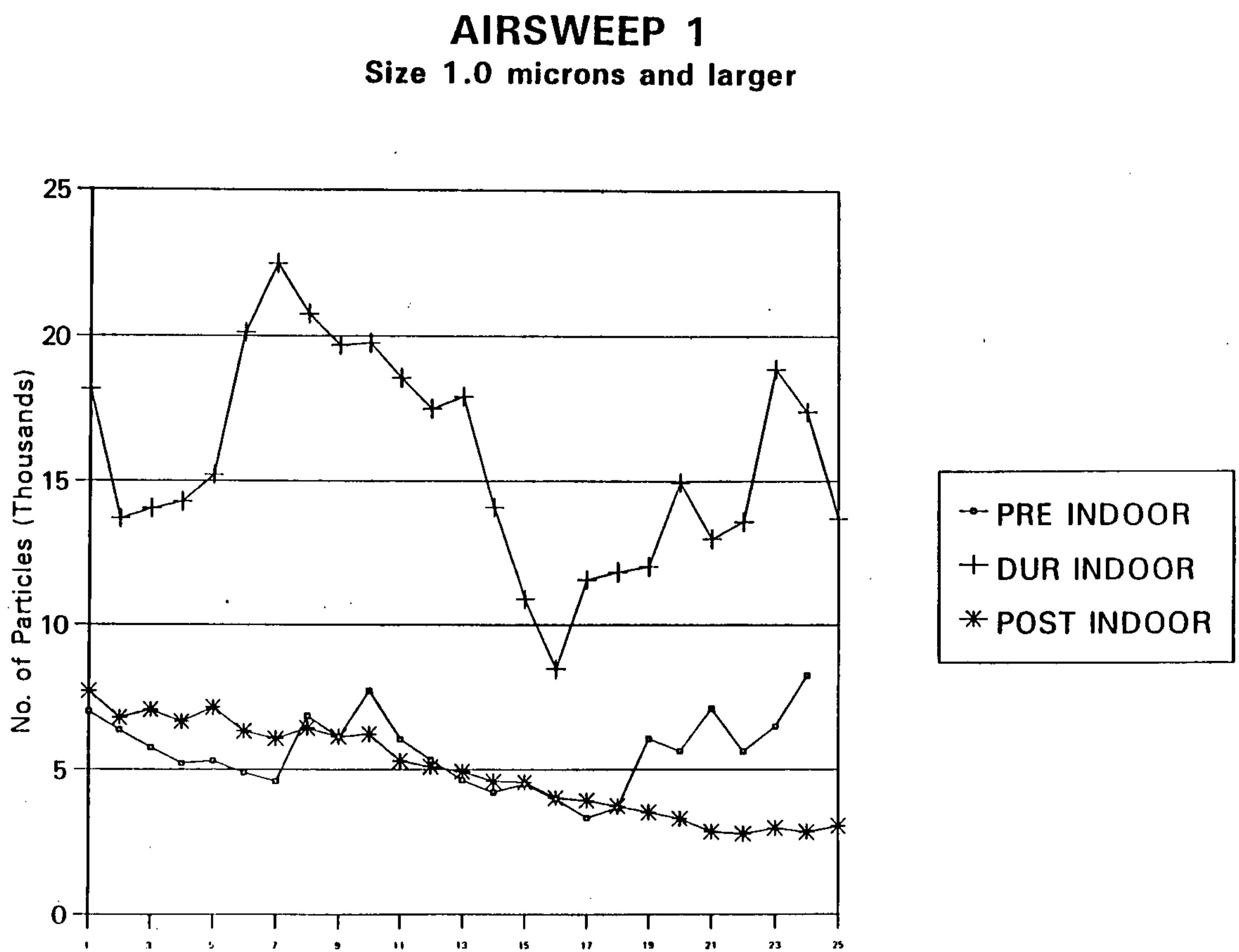

AIRSWEEP 1
Size 1.0 microns and larger
25
20
15
10
5
0
No. of Particles (Thousands)
1
3
5
7
9
11
13
15
17
19
21
23
25
MINUTES
PRE INDOOR
DUR INDOOR
POST INDOOR

Figure 5.6

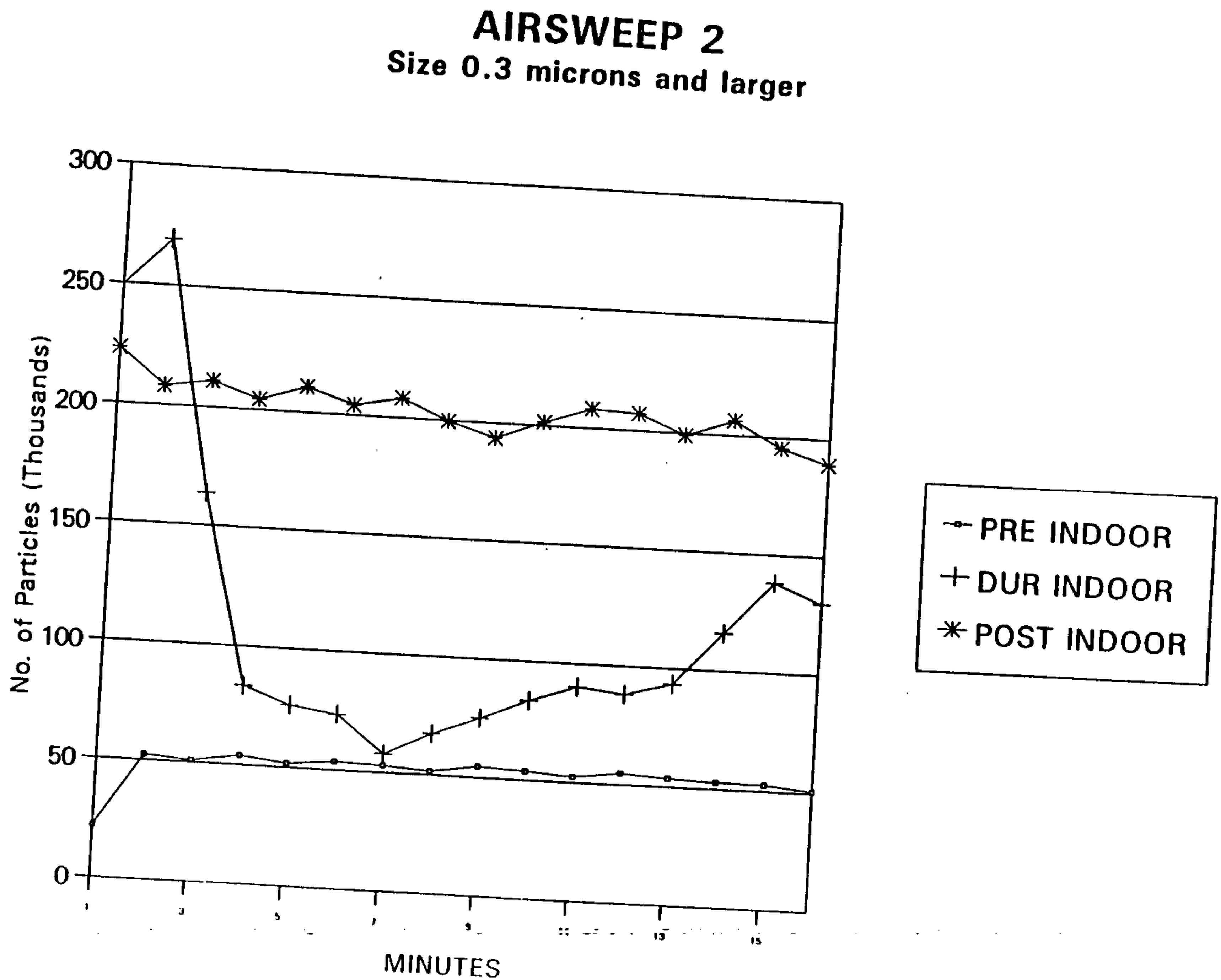

AIRSWEEP 2
Size 0.3 microns and larger
No. of Particles (Thousands)
300
250
200
150
100
50
0
MINUTES
PRE INDOOR
DUR INDOOR
POST INDOOR

Figure 5.7

AIRSWEEP 2

Size 1.0 microns and larger

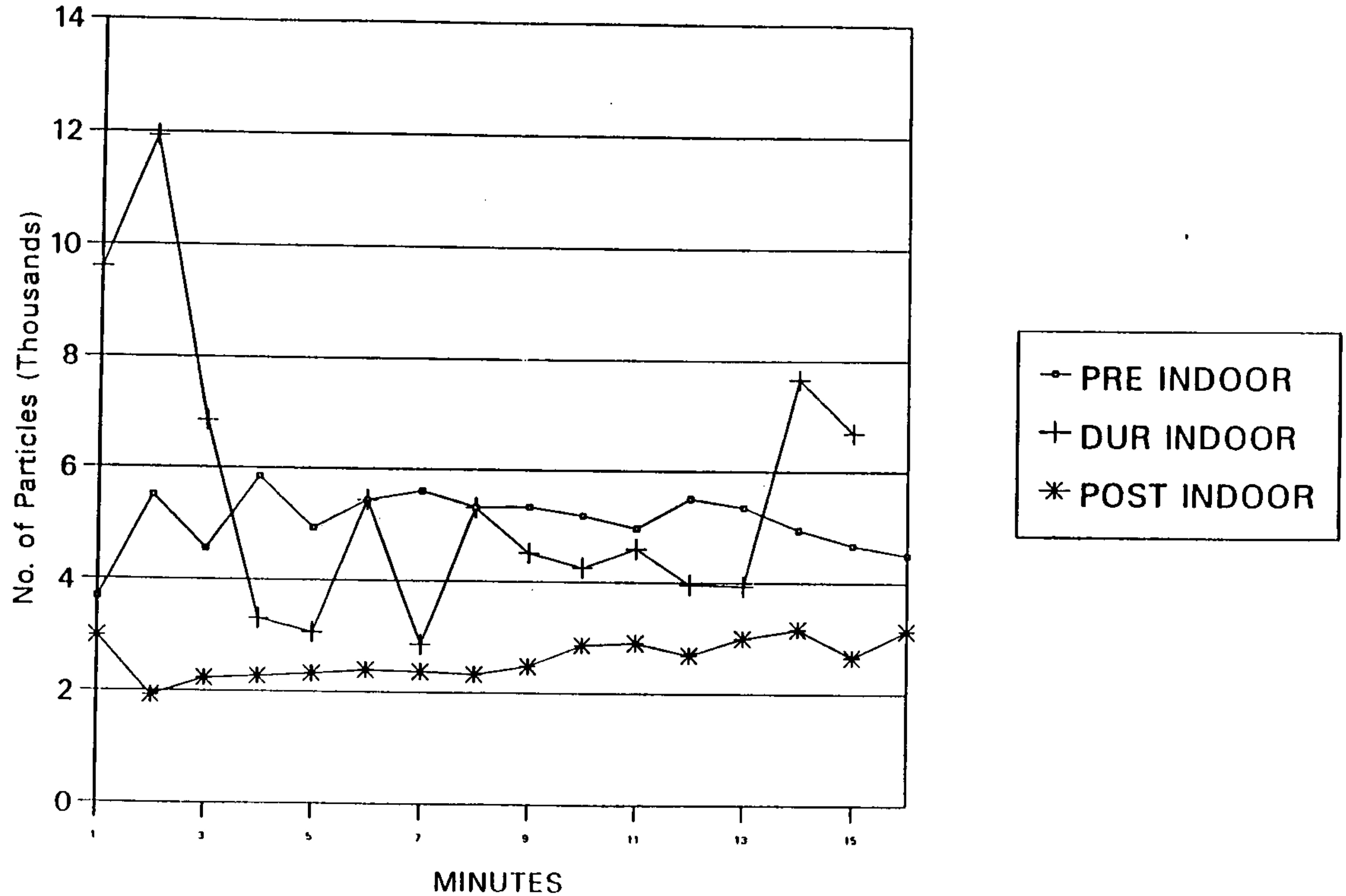


Figure 5.8

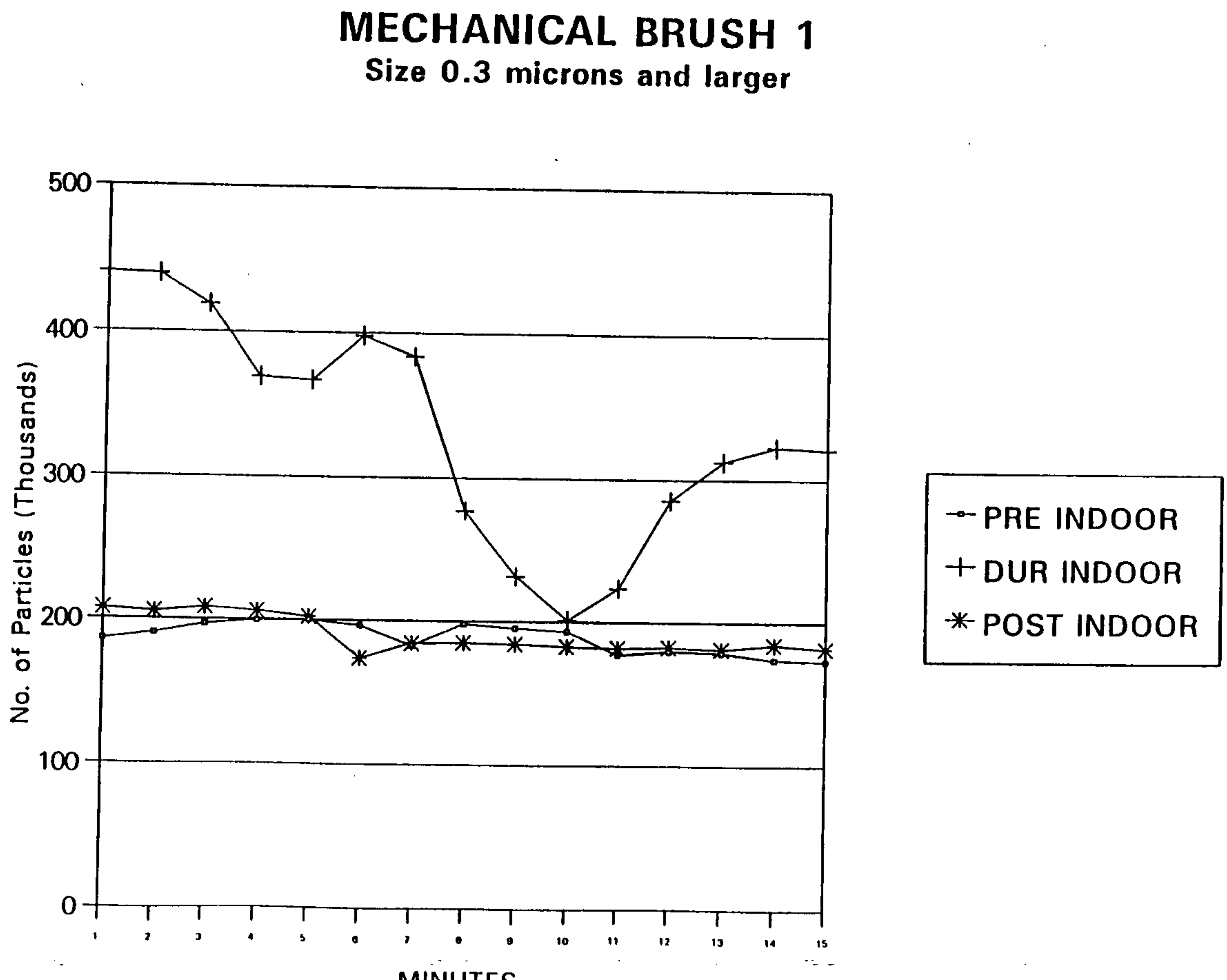

MECHANICAL BRUSH 1
Size 0.3 microns and larger
No. of Particles (Thousands)
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
MINUTES
PRE INDOOR
DUR INDOOR
POST INDOOR

Figure 5.9

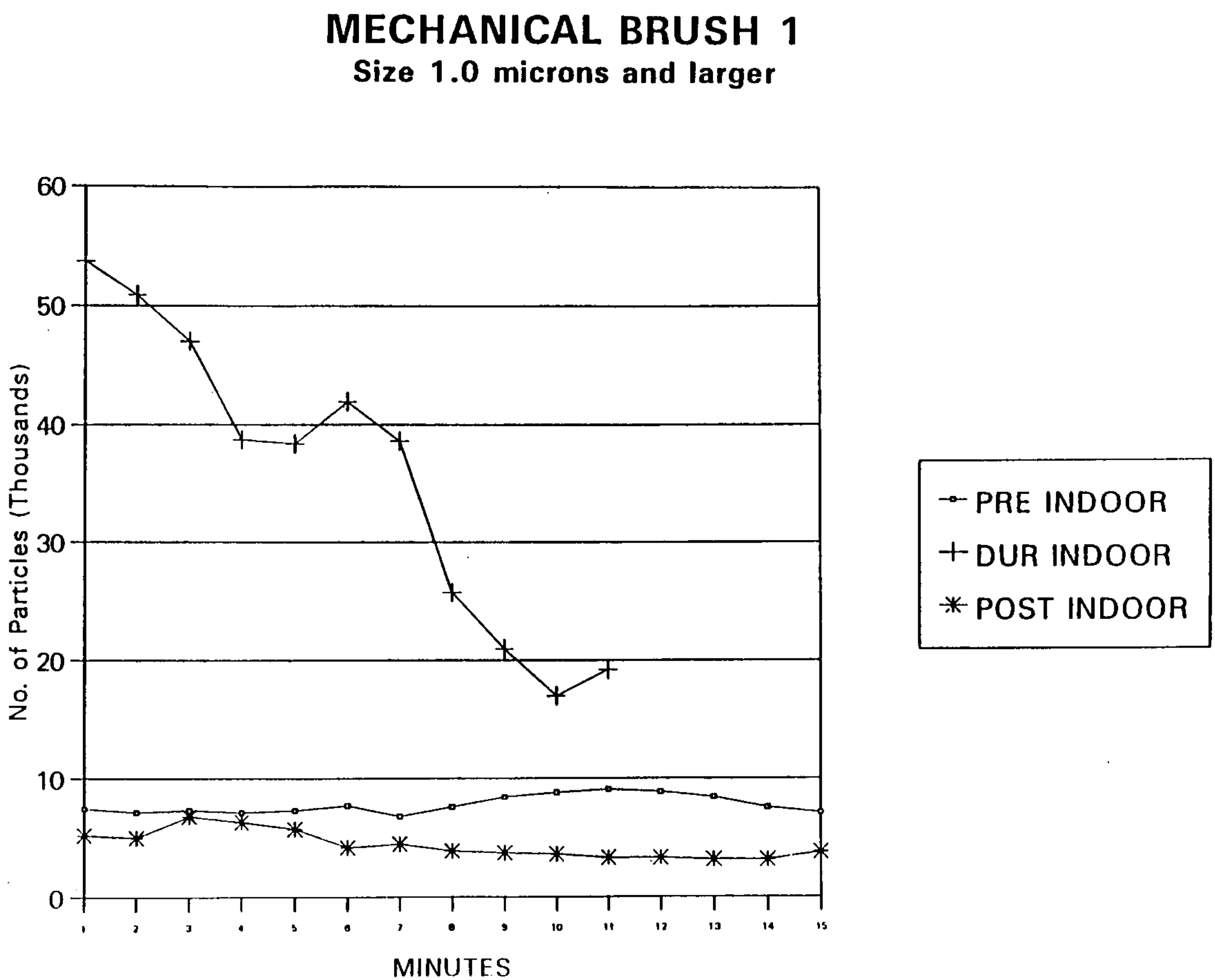

MECHANICAL BRUSH 1
Size 1.0 microns and larger
No. of Particles (Thousands)
60
50
40
30
20
10
0
MINUTES
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
PRE INDOOR
DUR INDOOR
POST INDOOR

Figure 5.10

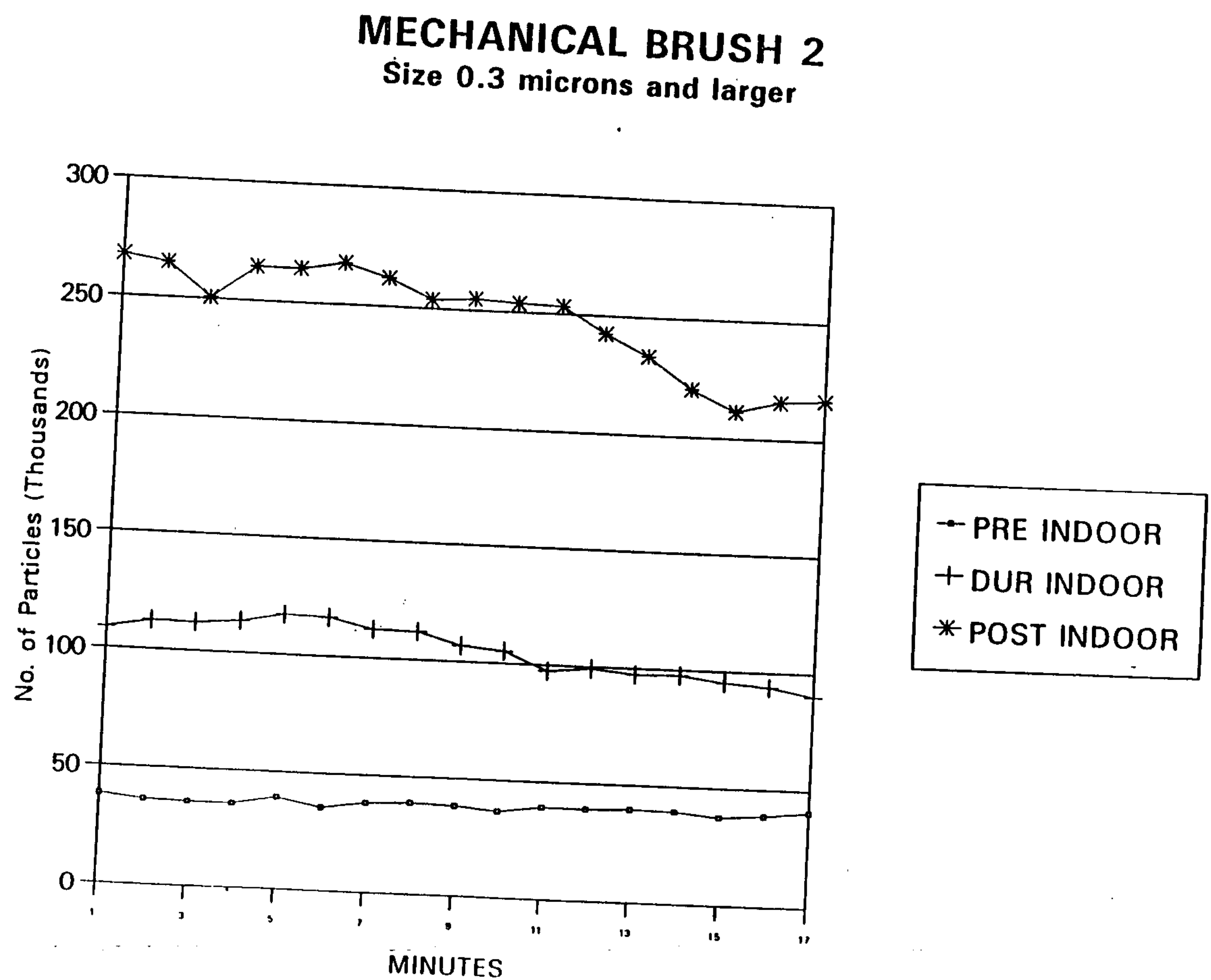

MECHANICAL BRUSH 2
Size 0.3 microns and larger
No. of Particles (Thousands)
300
250
200
150
100
50
0
MINUTES
PRE INDOOR
DUR INDOOR
POST INDOOR

Figure 5.11

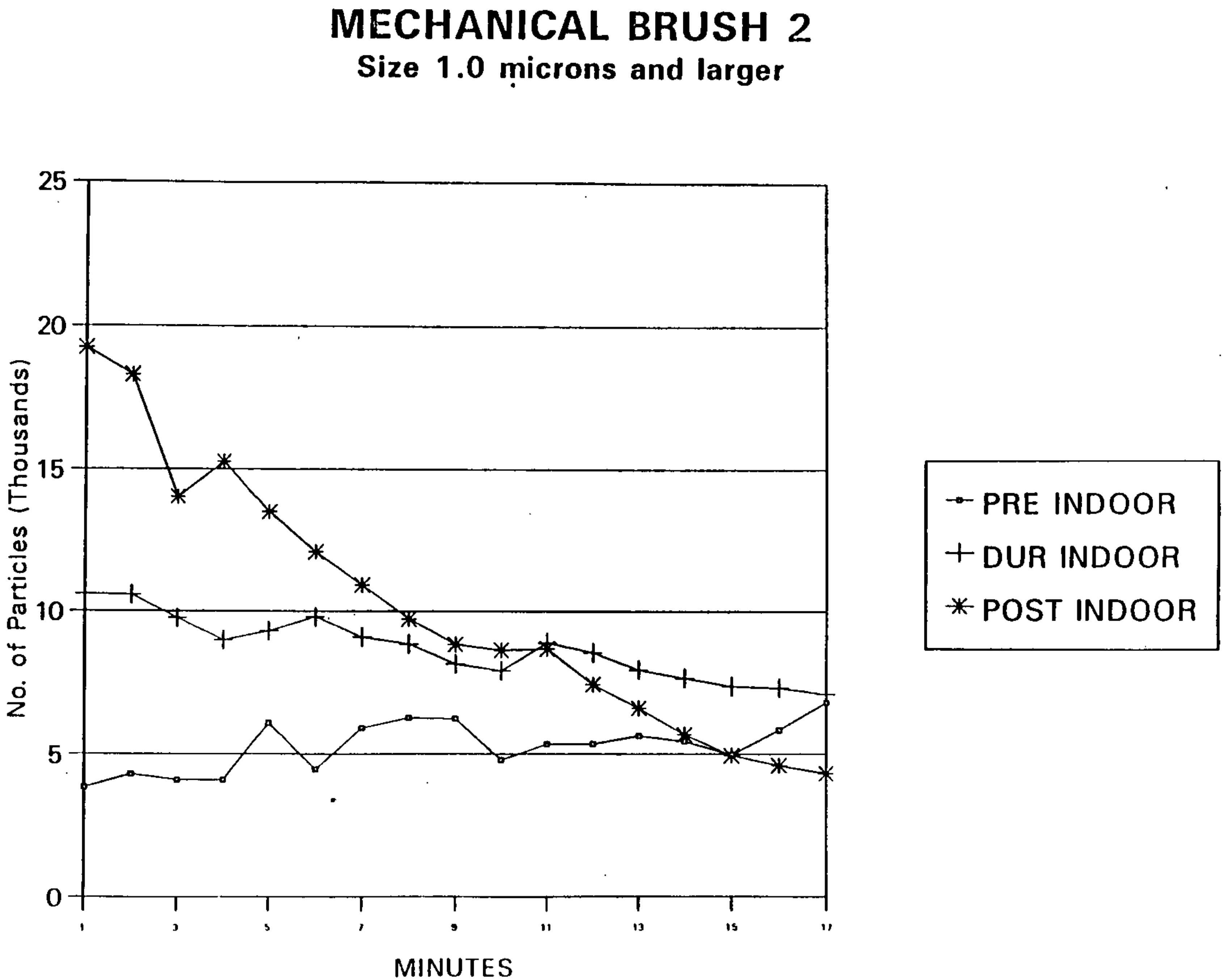

MECHANICAL BRUSH 2
Size 1.0 microns and larger
No. of Particles (Thousands)
25
20
15
10
5
0
1
3
5
7
9
11
13
15
17
MINUTES
PRE INDOOR
DUR INDOOR
POST INDOOR

Figure 5.12

NIOSH 7400 (fiber/cc)
Total
(Post readings were taken 48 hrs after pre and during)

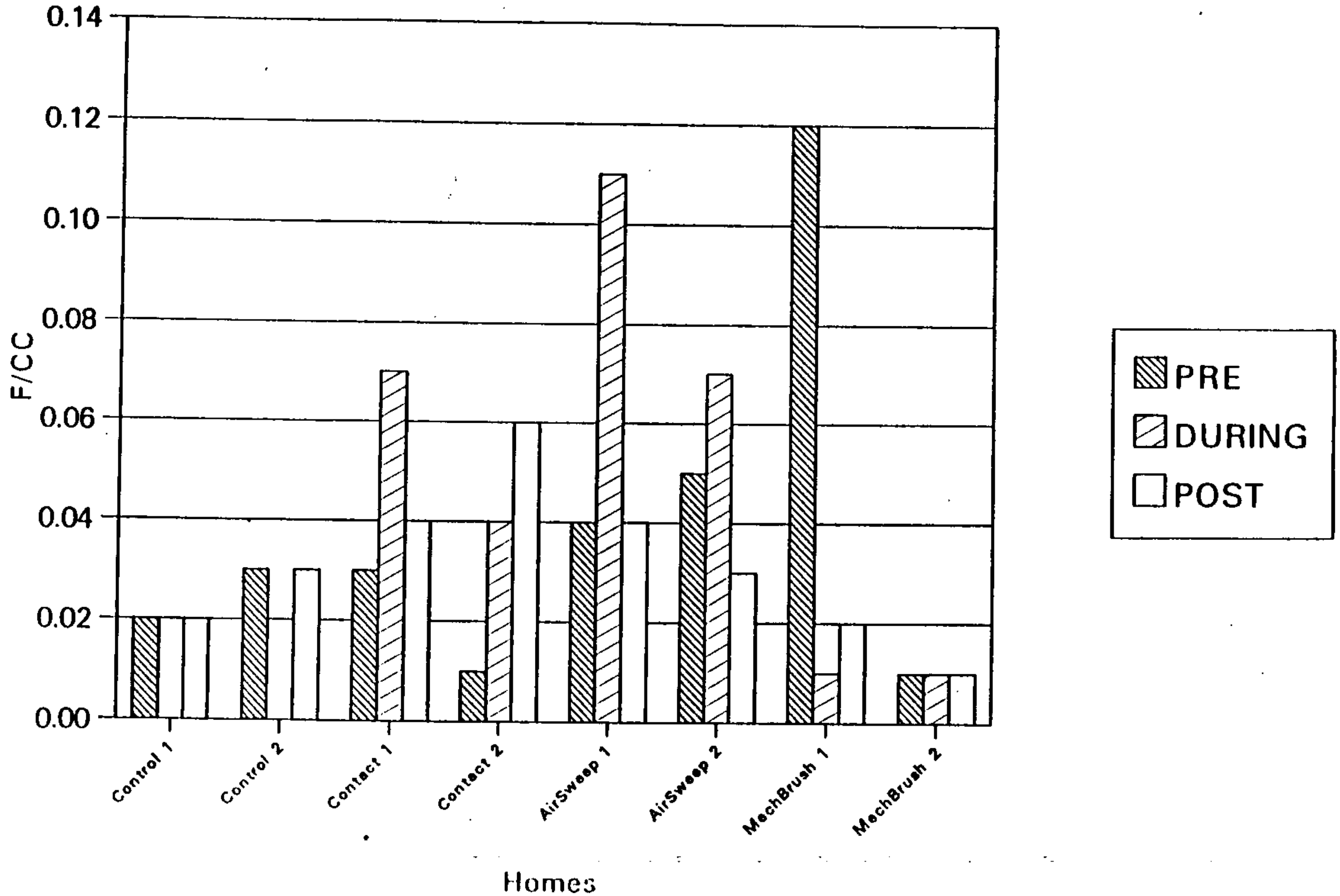


Figure 5. 13

post-level count was found to be dropping from the during-level fiber count. In both AirSweep 1 and 2, during-level fiber counts were found to be higher than the pre-level counts. The post-level counts were found to be dropping, in AirSweep 1 at the same level as pre and in AirSweep 2, even lower than the pre-level. In MechBrush 1, a high fiber count was observed before cleaning, for reasons unknown to the investigators. The during and post readings were found to be very low. In MechBrush 2 all pre, during and post readings were at or below the level of detection.

The findings of this analysis suggest that cleaning procedures do not increase the amount of fiber inside the house. The investigators are aware about the concerns of many individuals that cleaning of fiberglass duct work may increase the amount of fiber in the house. The results of this study do not support those concerns. Although, during cleaning, fiber count was found to be at a higher level than the pre-level. This observation is in agreement with the Met-One particle analyzer readings. Disturbances caused in the indoor air during cleaning might have increased the fiber count.

5.2.3 NIOSH 0500 Total Nuisance Dust

Only two detectable readings were obtained. Most of the results were below the limit of detection for this method, except for the post-level readings of Contact 1 and AirSweep 2. In Contact 1, the result obtained was 0.65 mg/m^3, and in AirSweep 2, it was 0.31 mg/m^3.

5.2.4 Total Biological Particulate-Burkard Sampling

Single samples were collected for every home before (pre), during and after (post) duct-cleaning. Pre and post samples were also collected for the two control homes. Samples were collected both indoor and outdoor. The complete results of the analysis are shown in *Appendix D* in terms of spore/m^3.

(Note: Unidentified-M is unidentified moniliaceous or hyaline spores that could not be positively based on spore morphology, and unidentified-D is unidentified dematiaceous or dark spores that could not be positively identified based on spore morphology.)

Unusually high concentrations of unidentified-M was obtained in sample numbered 18. As shown in *Table 5.3* and *Figure 5.14*, this apparent anomaly resulted in indicating a reduction of 95.45% from pre to post in spore/m^3 for MechBrush 1. Percent change in MechBrush 2 could not be known, since sample #30 was missing. All other homes showed a reduction in spore/m^3 from pre to post. The range was varying from 22% to 91%. During readings were found to be lower than pre-readings except for Contact 2. Outdoor sample analysis and percent change from indoor to outdoor are also included in *Table 5.3*.

5.3 VIABLE BIOAEROSOL

Three procedures were employed to collect the readings of bioaerosol concentrations. The three methods are Andersen, HVAC and Burkard.

Table 5.3 **BURKARD (spore/m3)**

TOTAL

	INDOOR					OUTDOOR			
HOMES	PRE	DURING	% CHANGE PRE TO DURING	POST	% CHANGE PRE TO POST	PRE	POST	% CHANGE PRE-IND PRE-OUTD	% CHANGE POST-IND POST-OUTD
CONTROL 1	2030			1848	-8.97%	455	364	-77.59%	-80.30%
CONTROL 2	5030			2090	-58.45%	455	364	-90.95%	-82.58%
CONTACT 1	4003	0	-100.00%	364	-90.91%	1061	3152	-73.49%	765.93%
CONTACT 2	2606	4394	68.61%	2030	-22.10%	1061	3152	-59.29%	55.27%
AIRSWEEP 1	5242	3697	-29.47%	818	-84.40%	364	1848	-93.06%	125.92%
AIRSWEEP 2	12181	9243	-24.12%	1758	-85.57%	364	1848	-97.01%	5.12%
MECHBRUSH 1	25333	0	-100.00%	1152	-95.45%	3152	3606	-87.56%	213.02%
MECHBRUSH 2	0	3424	---	---	---	3152	3606	---	---

Note:

Post readings were taken 2 days after pre

BURKARD (spore/m3)
Total
(Post readings were taken 48 hrs after pre and during)

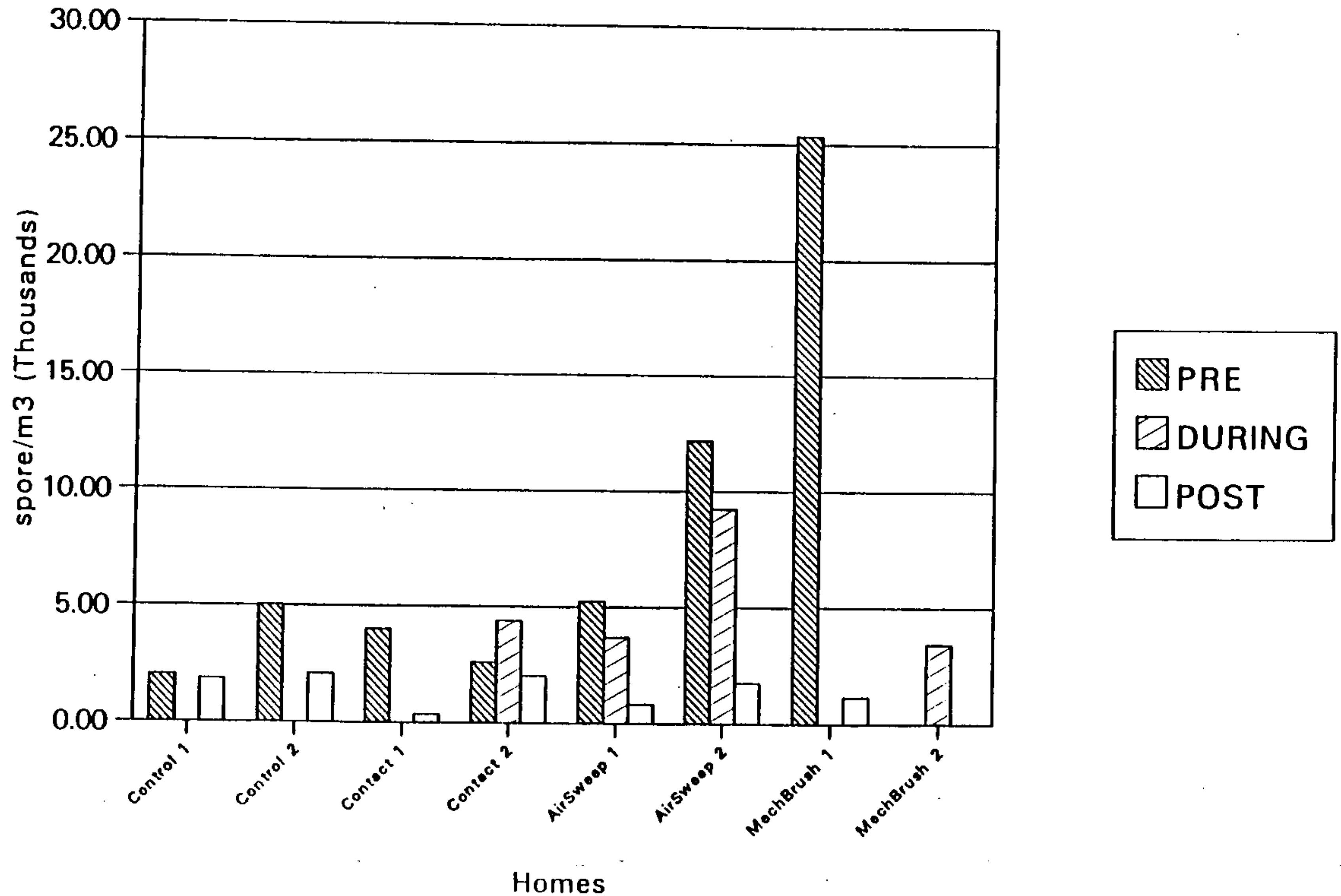


Figure 5.14

5.3.1 Andersen Biological Sampler

The samples were collected in duplicate both indoor and outdoor for every home before (pre), during, and after (post) duct cleaning. The detailed results of analysis (both qualitative and quantitative) in terms of Colony Forming Units/m^3 (cfu's/m^3) are shown in *Appendix B*. Mycotech Biological Inc. reported that they have noted that the agar base had become dislodged during shipping and had fallen into the lid of some of the petri dishes received by them for analysis. These samples were numbered 12, 22, and 23. Unusually high bacteria and yeast CFU count were obtained for these samples. Accordingly, the investigators ignored the result obtained from sample #12 and the duplicate sample #11 was used for the analysis instead. For samples #22 and #23, bacteria and yeast CFU/m^3 were considered to be 1 and the corresponding numbers shown in the *Appendix B* were ignored. It is evident from Appendix B that the major types of microbial contaminants are Cladosporium, Penicillium, Sterile hyphae, Yeast, and Bacteria.

Table 5.4 shows the total CFU's/m^3 for all the homes under study with percent changes from pre to during, pre to post, pre-indoor to pre-outdoor, and post-indoor to post-outdoor. The pre, during, and post concentrations are also shown graphically in *Figure 5.15*. These results indicate that CFU's/m^3 are higher during cleaning than the pre-level. Post-level readings are lower than the pre-level readings in almost all homes except Contact 2 and MechBrush 2. The other two methods of bioaerosol sampling, HVAC and Burkard, do not agree with these results, as we shall see later. These observations

Table 5.4 **ANDERSEN (cfu's/m3)**

TOTAL

	INDOOR					OUTDOOR			
HOMES	PRE	DURING	% CHANGE PRE TO DURING	POST	% CHANGE PRE POST	PRE	POST	% CHANGE PRE-IND PRE-OUTD	% CHANGE POST-IND POST-OUTD
CONTROL 1	601.00			790.00	31.45%	314.75	158.50	-47.63%	-79.94%
CONTROL 2	266.00			325.50	22.37%	314.75	158.50	18.33%	-51.31%
CONTACT 1	423.50	437.50	3.31%	196.00	-53.72%	273.70	673.00	-35.37%	243.37%
CONTACT 2	287.00	360.00	25.44%	611.50	113.07%	273.70	673.00	-4.63%	10.06%
AIRSWEEP 1	563.50	657.00	16.59%	154.00	-72.67%	158.50	507.00	-71.87%	229.22%
AIRSWEEP 2	821.50	874.00	6.39%	269.50	-67.19%	158.50	507.00	-80.71%	88.13%
MECHBRUSH 1	283.50	723.50	155.20%	157.50	-44.44%	673.00	376.00	137.39%	138.73%
MECHBRUSH 2	294.00	793.50	169.90%	294.00	0.00%	673.00	376.00	128.91%	27.89%

Note:

Post readings were taken 2 days after pre

ANDERSEN (cfu's/m3)
Total
(Post readings were taken 48 hrs after pre and during)

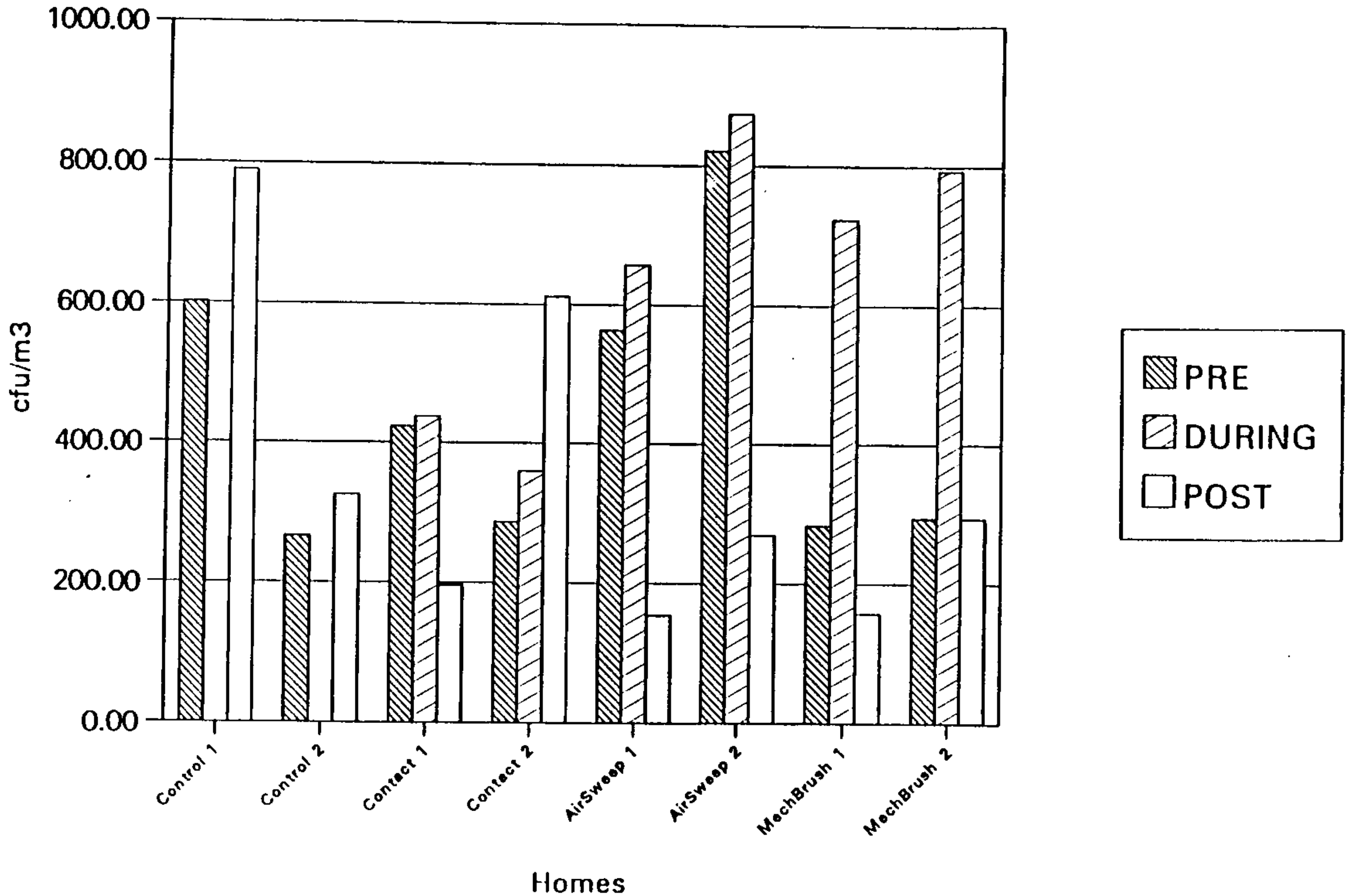


Figure 5.15

suggest that cleaning procedures are effective to some extent in reducing the level of bioaerosol contaminants. All the homes, with the two exceptions as noted above, had shown a reduction ranging from 45% to 73%, although the two control homes experienced an increase in total CFU's/m^3.

5.3.2 HVAC Biological Sampler

As stated earlier, the HVAC method is a simpler version of biological sampling that can be used in lieu of sophisticated and expensive methods (such as Andersen) for limited purposes. It can be used as a screening method to decide if further investigation is necessary. The samples were collected in duplicate for every home before (pre) and after (post). Samples were collected only indoor for obvious reasons. During readings were not collected since the AC unit could not be turned on during cleaning. The results of the complete analysis, expressed in terms of CFU's/sample are shown in *Appendix C*. Again, as in the Andersen procedure, the major contaminants were found to be Cladosporium, Penicillium, Sterile Hyphae, Yeast, and Bacteria. According to Mycotech Biological, Inc. the company that performed the laboratory analysis, samples numbered 11, 12, 13 and 29 were found to be in a disturbed state. Their bacterial counts were unusually high. In addition, sample #27 also showed an unusually high concentration of Penicillium. Accordingly, bacterial counts of samples 11, 12, and 13 were considered to be 1 for subsequent analysis, results of which are shown in *Table 5.5* and *Figure 5.16*. Sample numbers 27 and 29 were ignored altogether and their

Table 5.5 **HVAC (cfu's/sample)**

	INDOOR		
HOMES	PRE	POST	% CHANGE PRE TO POST
CONTROL 1	31.50	31.00	-1.59%
CONTROL 2	17.00	21.00	23.53%
CONTACT 1	18.50	2.50	-86.49%
CONTACT 2	61.50	12.50	-79.67%
AIRSWEEP 1	108.50	16.00	-85.25%
AIRSWEEP 2	24.00	34.00	41.67%
MECHBRUSH 1	79.00	17.00	-78.48%
MECHBRUSH 2	130.50	10.00	-92.34%

Note:

Post readings were taken 2 days after pre

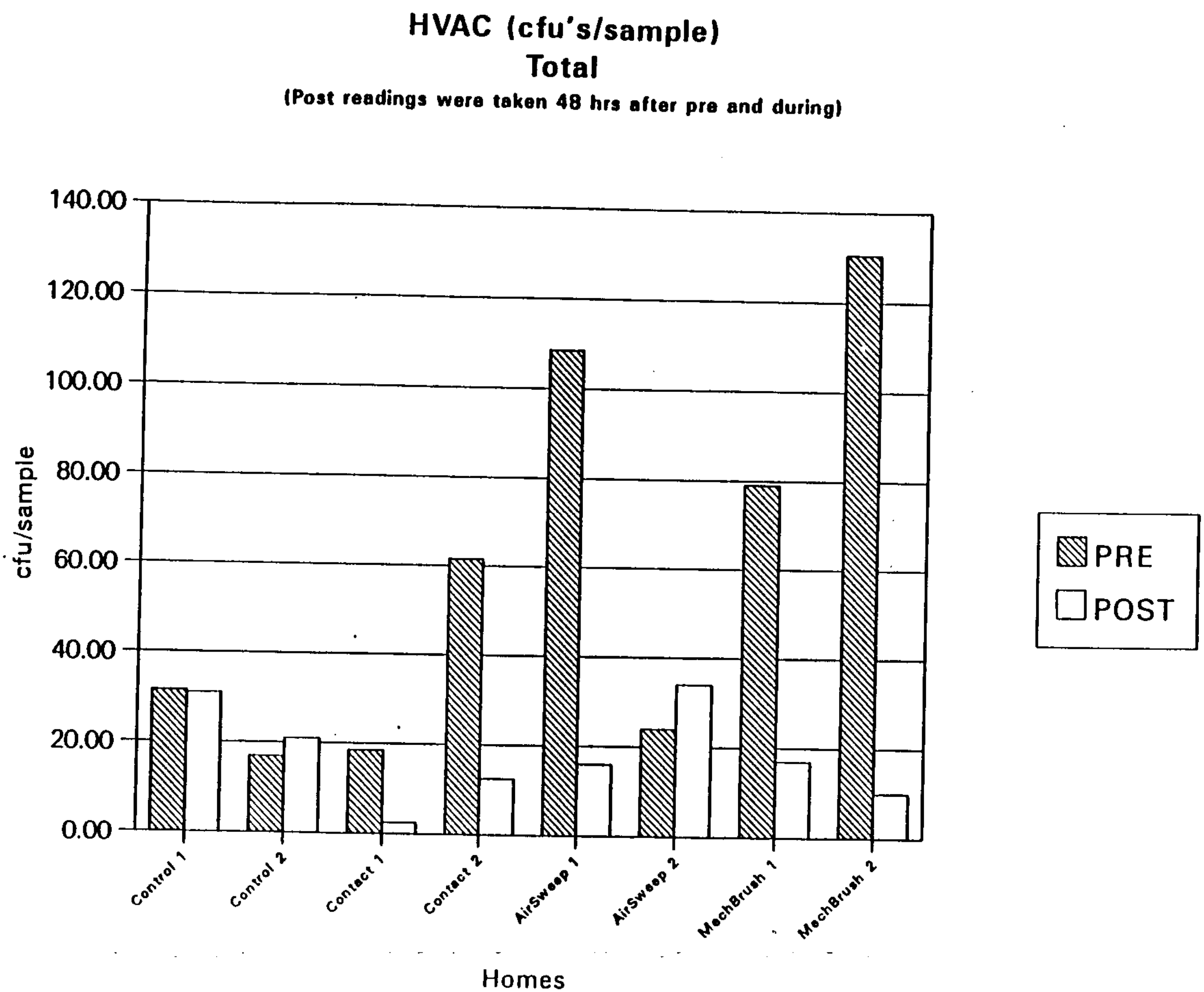

HVAC (cfu's/sample)
Total
(Post readings were taken 48 hrs after pre and during)
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
cfu/sample
Control 1
Control 2
Contact 1
Contact 2
AirSweep 1
AirSweep 2
MechBrush 1
MechBrush 2
Homes
PRE
POST

Figure 5.16

duplicate samples, 28 and 30 respectively, were considered for analysis.

These results indicate substantial reduction in bioaerosol concentrations from pre- to post-level ranging from 79% to 92%. The same pattern was evident for Contact 2 and MechBrush 2, the homes that indicated an increase in the Andersen procedure. AirSweep 2, however, showed an increase in total bioaerosol concentration according to HVAC sampling procedure.

Air velocities, in terms of ft/min, taken at the master bedroom air register while the AC unit was kept on, are shown in *Table 5.6*. AirSweep 2 pre velocities were found to be unusually low. Corresponding ballometer readings were also unusually low for this house. The reasons for this anomaly were not clear to the investigators. MechBrush 2 pre readings were missed by mistake. Control homes and the Contact homes indicate a reduction, in the order of 5% to 9.5%, in air velocities. AirSweep 1 and MechBrush 1 showed an increase.

Table 5.6. HVAC Velocities in ft/min. - Pre/Post Comparison

Home	Pre				Post				% Change Pre to Post
	Test 1	Test 2	Test 3	Average	Test 1	Test 2	Test 3	Average	
Control 1	996	1076	1085	1052	926	972	982	960	-8.74
Control 2	1078	1091	1020	1063	999	978	1010	996	-6.30
Contact 1	835	822	838	832	756	754	750	753	-9.49
Contact 2	1009	1012	990	1004	994	907	958	953	-5.08
AirSweep 1	829	842	831	834	884	938	895	906	8.63
AirSweep 2	459	465	464	463	879	835	841	852	84.0
MechBrush 1	909	874	859	881	927	916	907	917	4.08
MechBrush 2	—	—	—	Missed	879	925	887	897	—

APPENDIX A

Sample Letter

Florida International University

Donald J Leone
or Current Resident
760 Buttonwood Lane
Boynton Beach, FL 33436

November 20, 1992

Dear Homeowner:

The Department of Education of the state of Florida through the Building Construction Industry Advisory Committee (BCIAC) has awarded the Department of Construction Management of Florida International University a grant to investigate the effectiveness of HVAC sanitation processes on indoor air quality in residential homes.

We need to select a few homes to conduct our investigation. The purpose of this letter is to make a request to you. Would you be willing to let us use your residence for this investigation? It involves sanitation of your duct-work and collection of data before and after sanitation. Data collection includes use of instrumentation to take readings, sampling, and photographs. By participating in this study you will be getting your duct work cleaned at no cost, but more importantly, you will be contributing to a valuable research study, results of which will benefit all of us.

If you shall have any questions regarding this research project please contact the Principal Investigator Dr. Irtishad Ahmad at (305) 348-3172 or the BCIAC Coordinator for this project Mr. Deane Ellis at (407) 278-7125 ext. 420.

In order to start the investigation by the scheduled time frame, we need to know your decision to participate as soon as possible. Please call at one of the above numbers or send us a note:

Attn: Dr. Irtishad Ahmad
Dept. of Construction Management (VH 230)
Florida International University
Miami, Fl 33199
Fax: (305) 348-2766

Thank you in advance.

Sincerely,

SAMPLE

Irtishad Ahmad, PhD, PE.
Assistant Professor

Department of Construction Management • College of Engineering and Design
VH 230, University Park, Miami, Florida 33199 • 305 348-3172 • FAX 305 348-2766

APPENDIX B

Andersen Sampling

ANDERSEN SAMPLING (CFU's/m3)

SAMPLE	SANITATION METHOD	TIME-LOCATION	TOTAL	Alternaria	Aspergillus	Botrytis	Candida	Cephalosporium	Cladosporiu	Curvularia	Geotrichum
A1	Control-1	Pre-Outdoor	297	0	0	0	0	0	0	0	0
A2	Control-1	Pre-Outdoor	490	0	0	0	52	0	122	0	0
A3	Control-1	Pre-Indoor	566	0	0	0	28	0	203	0	0
A4	Control-1	Pre-Indoor	636	0	7	0	0	0	287	0	0
A5	Control-2	Pre-Outdoor	210	0	0	0	17	0	52	0	0
A6	Control-2	Pre-Outdoor	262	0	52	0	0	0	35	0	0
A7	Control-2	Pre-Indoor	364	0	0	0	0	0	84	0	0
A8	Control-2	Pre-Indoor	168	0	0	0	0	0	42	0	0
A9	Contact-1	Pre-Indoor	434	0	0	0	0	0	273	0	0
A10	Contact-1	Pre-Indoor	413	0	0	0	0	0	105	28	0
A11	Contact-1	Pre-Outdoor	402	0	0	0	0	0	140	0	17
A12	Contact-1	Pre-Outdoor	3671	17	0	0	0	0	122	52	17
A13	Contact-1	During-Indoor	399	0	14	0	0	0	308	0	0
A14	Contact-1	During-Indoor	476	0	0	0	0	0	315	0	0
A15	Contact-2	Pre-Indoor	273	0	0	0	0	0	84	0	21
A16	Contact-2	Pre-Indoor	301	0	0	0	0	0	98	0	7
A17	Contact-2	Pre-Outdoor	157	0	0	0	0	0	35	0	0
A18	Contact-2	Pre-Outdoor	262	0	0	0	0	0	87	0	35
A19	Contact-2	During-Indoor	552	0	0	0	0	0	98	49	0
A20	Contact-2	During-Indoor	168	0	0	0	0	0	14	56	0
A21	AirSweep-1	Pre-Indoor	1007	0	0	0	0	0	622	0	0
A22	AirSweep-1	Pre-Indoor	2580	0	0	0	0	0	0	0	42
A23	AirSweep-1	Pre-Outdoor	2955	0	0	0	0	0	52	0	0
A24	AirSweep-1	Pre-Outdoor	192	0	17	0	35	0	35	0	0
A25	AirSweep-1	During-Indoor	720	0	0	0	0	0	77	0	0
A26	AirSweep-1	During-Indoor	594	0	7	0	0	0	35	0	0
A27	Number not	used									
A28	AirSweep-2	Pre-Indoor	902	0	7	0	0	0	448	0	0
A29	AirSweep-2	Pre-Indoor	741	0	0	0	0	0	378	0	0
A30	AirSweep-2	During-Indoor	846	0	0	0	14	0	636	0	0
A31	AirSweep-2	During-Indoor	902	0	7	0	0	0	559	0	0

ANDERSEN SAMPLING (CFU's/m3) *(Continued)*

SAMPLE	SANITATION METHOD	TIME-LOCATION	TOTAL	Alternaria	Aspergillus	Botrytis	Candida	Cephalosporium	Cladosporiu	Curvularia	Geotrichum
A32	Control-1	Post-Indoor	804	14	0	56	0	0	664	0	0
A33	Control-1	Post-Indoor	776	21	0	0	0	0	685	0	0
A34	Control-2	Post-Indoor	329	0	0	0	0	0	42	0	0
A35	Control-2	Post-Indoor	322	0	0	0	0	0	28	14	0
A36	MechBrush-1	Pre-Indoor	266	0	0	7	0	0	161	0	0
A37	MechBrush-1	Pre-Indoor	301	0	0	0	0	0	168	21	0
A38	MechBrush-1	During-Indoor	622	0	7	0	0	0	434	0	0
A39	MechBrush-1	During-indoor	825	0	7	0	0	0	643	0	21
A40	Contact-1	Post-Indoor	266	0	0	0	0	0	175	0	0
A41	Contact-1	Post-Indoor	126	0	0	0	0	0	70	0	0
A42	MechBrush-2	Pre-Indoor	245	0	0	0	0	0	112	0	0
A43	MechBrush-2	Pre-Indoor	343	0	7	0	0	0	98	0	0
A44	Number not	used									
A45	MechBrus1&2	Pre-Outdoor	524	0	17	0	0	0	385	0	0
A46	MechBrus1&2	Pre-Outdoor	822	0	0	0	0	0	420	0	52
A47	MechBrush-2	During-Indoor	643	0	0	0	0	21	531	14	14
A48	MechBrush-2	During-Indoor	944	0	0	0	0	0	629	14	0
A49	Contact-2	Post-Indoor	517	0	0	0	0	0	189	35	0
A50	Contact-2	Post-indoor	706	0	0	0	0	0	245	14	0
A51	AirSweep-1	Post-Outdoor	542	0	17	0	0	0	280	0	0
A52	AirSweep-1	Post-Outdoor	472	0	0	0	0	0	262	0	35
A53	AirSweep-2	Post-Indoor	140	0	0	28	0	0	35	7	0
A54	AirSweep-2	Post-Indoor	168	0	7	0	0	0	56	0	0
A55	AirSweep-1	Post-Indoor	329	0	0	0	0	0	105	21	7
A56	AirSweep-1	Post-Indoor	210	0	0	0	0	0	21	49	0
A57	MechBrush-1	Post-Indoor	231	0	0	0	0	0	21	0	0
A58	MechBrush-1	Post-Indoor	84	0	0	0	0	0	7	0	0
A59	MechBrus1&2	Post-Outdoor	385	0	0	0	0	0	210	35	0
A60	MechBrus1&2	Post-Outdoor	367	0	0	0	0	0	192	52	0
A61	MechBrush-2	Post-Indoor	280	0	0	0	0	0	133	63	0
A62	MechBrush-2	Post-Indoor	308	0	0	0	0	0	203	14	0

ANDERSEN SAMPLING (CFU's/m3) *(Continued)*

SAMPLE	SANITATION METHOD	TIME-LOCATION	Penicillium	Pestalotipsi	Phoma	Rhizopus	Trichoderm	Sterile hyphae	Yeast	Bacteria
A1	Control-1	Pre-Outdoor	0	0	0	0	0	245	17	35
A2	Control-1	Pre-Outdoor	35	0	0	0	0	122	35	122
A3	Control-1	Pre-Indoor	217	0	0	0	0	70	21	28
A4	Control-1	Pre-Indoor	273	0	0	0	0	28	28	14
A5	Control-2	Pre-Outdoor	17	0	0	0	0	0	70	52
A6	Control-2	Pre-Outdoor	0	0	0	0	0	70	70	35
A7	Control-2	Pre-Indoor	28	0	0	0	0	140	49	56
A8	Control-2	Pre-Indoor	56	0	0	7	0	0	35	28
A9	Contact-1	Pre-Indoor	49	0	0	7	0	77	28	0
A10	Contact-1	Pre-Indoor	49	0	0	7	0	224	7	0
A11	Contact-1	Pre-Outdoor	17	0	0	0	0	87	52	87
A12	Contact-1	Pre-Outdoor	0	0	0	0	0	87	52	3322
A13	Contact-1	During-Indoor	21	0	0	0	0	28	21	7
A14	Contact-1	During-Indoor	49	0	0	7	0	63	35	7
A15	Contact-2	Pre-Indoor	49	0	0	0	0	70	35	14
A16	Contact-2	Pre-Indoor	91	0	0	0	0	91	14	0
A17	Contact-2	Pre-Outdoor	0	0	0	0	0	122	0	0
A18	Contact-2	Pre-Outdoor	0	0	0	0	0	105	0	35
A19	Contact-2	During-Indoor	287	0	0	0	0	77	42	0
A20	Contact-2	During-Indoor	56	0	0	0	0	42	0	0
A21	AirSweep-1	Pre-Indoor	280	0	0	0	0	105	0	0
A22	AirSweep-1	Pre-Indoor	14	0	0	0	0	63	1399	1063
A23	AirSweep-1	Pre-Outdoor	0	0	0	0	0	70	2098	734
A24	AirSweep-1	Pre-Outdoor	0	0	0	0	0	105	0	0
A25	AirSweep-1	During-Indoor	503	0	0	0	0	98	0	42
A26	AirSweep-1	During-Indoor	266	0	0	7	0	105	0	175
A27	Number not	used								
A28	AirSweep-2	Pre-Indoor	301	0	0	0	0	56	91	0
A29	AirSweep-2	Pre-Indoor	217	0	0	0	0	77	56	14
A30	AirSweep-2	During-Indoor	84	0	0	0	0	66	0	56
A31	AirSweep-2	During-Indoor	231	0	0	0	0	28	77	0

ANDERSEN SAMPLING (CFU's/m3) *(Continued)*

SAMPLE	SANITATION METHOD	TIME-LOCATION	Penicillium	Pestalotipsi	Phoma	Rhizopus	Trichoderm	Sterile hyphae	Yeast	Bacteria
A32	Control-1	Post-Indoor	21	14	0	0	0	28	21	0
A33	Control-1	Post-Indoor	21	21	0	0	0	28	21	0
A34	Control-2	Post-Indoor	182	0	0	0	0	77	28	0
A35	Control-2	Post-Indoor	98	0	0	0	0	91	56	35
A36	MechBrush-1	Pre-Indoor	49	0	0	7	0	0	0	42
A37	MechBrush-1	Pre-Indoor	84	0	0	7	0	0	21	0
A38	MechBrush-1	During-Indoor	63	0	0	7	0	105	7	0
A39	MechBrush-1	During-indoor	84	0	0	0	0	56	7	7
A40	Contact-1	Post-Indoor	0	0	0	77	0	0	14	0
A41	Contact-1	Post-Indoor	0	0	0	28	0	21	7	0
A42	MechBrush-2	Pre-Indoor	14	0	0	0	0	105	14	0
A43	MechBrush-2	Pre-Indoor	112	0	7	0	0	119	0	0
A44	Number not	used								
A45	MechBrus1&2	Pre-Outdoor	105	0	17	0	0	0	0	0
A46	MechBrus1&2	Pre-Outdoor	17	0	0	0	0	297	35	0
A47	MechBrush-2	During-Indoor	49	0	7	0	0	0	7	0
A48	MechBrush-2	During-Indoor	77	0	7	0	0	91	35	91
A49	Contact-2	Post-Indoor	203	0	14	0	0	77	0	0
A50	Contact-2	Post-indoor	336	0	7	0	0	91	14	0
A51	AirSweep-1	Post-Outdoor	17	0	87	0	0	70	70	0
A52	AirSweep-1	Post-Outdoor	52	0	0	0	0	70	17	35
A53	AirSweep-2	Post-Indoor	0	7	0	0	0	63	0	0
A54	AirSweep-2	Post-Indoor	28	7	0	0	0	42	28	0
A55	AirSweep-1	Post-Indoor	35	0	0	0	0	140	21	0
A56	AirSweep-1	Post-Indoor	0	0	0	0	0	140	0	0
A57	MechBrush-1	Post-Indoor	154	0	0	0	0	14	35	7
A58	MechBrush-1	Post-Indoor	14	0	0	0	0	28	28	7
A59	MechBrus1&2	Post-Outdoor	0	0	0	0	0	87	52	0
A60	MechBrus1&2	Post-Outdoor	17	0	0	0	0	70	35	0
A61	MechBrush-2	Post-Indoor	7	0	0	0	7	56	14	0
A62	MechBrush-2	Post-Indoor	0	0	21	0	7	28	35	0

APPENDIX C

HVAC Sampling

HVAC SAMPLING (CFU's/Sample)

SAMPLE	SANITATION METHOD	TIME	TOTAL	Alternaria	Aspergillus	Cldosporium	Curvularia	Geotrichum	Penicillium	Stachybotrys	Sterile hyphu	Yeast	Bacteria
H1	Control-1	Pre	28	0	0	24	0	0	2	0	0	2	0
H2	Control-1	Pre	35	0	0	27	0	0	5	0	0	0	3
H3	Control-2	Pre	14	0	0	4	2	0	5	0	2	0	1
H4	Control-2	Pre	20	0	0	7	0	0	13	0	0	0	0
H5	Contact-1	Pre	24	0	0	11	0	0	10	0	1	2	0
H6	Contact-1	Pre	13	0	0	0	0	0	9	0	2	2	0
H7	Contact-2	Pre	79	0	0	21	0	0	54	0	4	0	0
H8	Contact-2	Pre	44	0	2	11	0	0	28	0	1	2	0
H9	AirSweep-1	Pre	138	0	0	34	0	0	101	0	3	0	0
H10	AirSweep-1	Pre	79	0	0	16	0	0	60	0	3	0	0
H11	AirSweep-2	Pre	95	0	0	1	0	0	34	0	0	0	60
H12	AirSweep-2	Pre	131	0	0	3	0	0	3	0	0	0	120
H13	Control-1	Post	295	0	5	130	0	1	2	0	0	2	160
H14	Control-1	Post	31	0	0	30	0	0	0	0	0	0	1
H15	Control-2	Post	472	0	0	220	0	0	252	0	0	0	0
H16	Control-2	Post	21	0	2	9	0	0	6	0	0	4	0
H17	MechBrush-1	Pre	77	0	2	0	0	0	50	0	0	25	0
H18	MechBrush-1	Pre	81	0	0	4	0	0	40	0	0	37	0
H19	Contact-1	Post	3	0	0	0	0	0	1	1	1	0	0
H20	Contact-1	Post	2	0	0	0	0	0	1	0	1	0	0
H21	MechBrush-2	Pre	143	0	0	28	2	0	43	0	0	68	2
H22	MechBrush-2	Pre	118	0	0	40	0	0	75	0	0	3	0
H23	Contact-2	Post	14	0	0	6	0	0	5	0	0	2	1
H24	Contact-2	Post	11	0	0	3	0	0	5	0	3	0	0
H25	AirSweep-1	Post	10	0	0	3	0	0	0	0	1	2	4
H26	AirSweep-1	Post	22	0	0	0	2	0	16	0	2	0	2
H27	AirSweep-2	Post	301	0	0	1	0	0	300	0	0	0	0
H28	AirSweep-2	Post	34	0	0	1	0	0	15	0	3	15	0
H29	MechBrush-1	Post	507	0	0	3	0	0	0	0	0	4	500
H30	MechBrush-1	Post	17	0	0	2	0	0	0	0	0	1	14
H31	MechBrush-2	Post	7	0	0	0	4	1	0	0	2	0	0
H32	MechBrush-2	Post	13	2	0	5	0	1	0	0	1	4	0

APPENDIX D

Burkard Sampling

BURKARD SAMPLING (SPORE/m3)

SAMPLE	SANITATION METHOD	TIME-LOCATION	TOTAL	Unidentified M	Cladosporiu	Alternaria	Drechslera	Pollen	Hyphae	Pestalatopsis	Unidentified-P	Ascospores
B1	Control-1	Pre-Outdoor	1182	121	424	61	0	364	30	0	0	182
B2	Control-1	Pre-Indoor	2030	667	879	30	0	91	152	0	0	152
B3	Control-2	Pre-Outdoor	455	182	91	0	0	30	61	0	0	61
B4	Control-2	Pre-Indoor	5030	1848	1152	242	182	30	424	0	939	152
B5	Contact-1	Pre-Indoor	4000	1364	667	121	61	61	667	0	667	61
B6	Contact-1	Pre-Outdoor	1061	121	242	0	0	182	30	0	0	212
B7	Contact-1	During-Indoo	0	0	0	0	0	0	0	0	0	0
B8	Contact-2	Pre-Indoor	2606	515	636	182	30	30	182	0	697	121
B9	Contact-2	Pre-Outdoor	242	0	0	30	30	0	0	0	30	91
B10	Contact-2	During-Indoo	4394	909	1364	182	152	0	667	61	788	212
B11	AirSweep-1	Pre-Indoor	5242	1273	1424	91	30	212	697	333	364	333
B12	AirSweep-1	During-indoo	3697	909	1121	0	0	0	606	273	242	303
B13	AirSweep-2	Pre-Indoor	12182	8030	1909	30	30	0	1273	30	212	364
B14	AirSweep-2	During-Indoo	9242	2788	4303	0	0	0	970	0	121	182
B15	Control-1	Post-Indoor	1848	424	485	30	0	91	303	91	182	61
B16	Control-2	Post-Indoor	2091	424	515	30	0	61	515	30	212	91
B17	Control-1&2	Post-Outdoor	364	0	61	0	0	0	91	0	0	30
B18	MechBrush-1	Pre-Indoor	25333	24667	242	0	61	61	121	0	0	0
B19	MechBrush-1	During-Indoo	0	0	0	0	0	0	0	0	0	0
B20	Contact-1	Post-Indoor	364	61	91	0	0	0	0	0	0	121
B21	MechBrush-2	Pre-Indoor	0	0	0	0	0	0	0	0	0	0
B22	MechBrush-2	Pre-Outdoor	3152	121	636	0	0	485	303	0	1303	242
B23	MechBrush-2	During-Indoo	3424	242	1909	0	0	152	273	30	394	303
B24	Contact-2	Post-Indoor	2030	697	394	0	121	152	30	61	152	333
B25	AirSweep-1&	Post-Outdoor	1848	91	424	61	0	0	0	0	0	758
B26	AirSweep-1	Post-Indoor	818	91	61	0	0	30	121	91	0	152
B27	AirSweep-2	Post-Indoor	1758	182	121	30	0	182	152	91	91	333
B28	MechBrush-1	Post-Indoor	1152	394	91	30	0	182	30	0	242	30
B29	MechBrush-1	Post-Outdoor	3606	61	939	61	30	485	0	0	515	939
B30	MechBrush-2	Post-Indoor	Sample	results	missing							

BURKARD SAMPLING (SPORE/m3) *(Continued)*

SAMPLE	SANITATION METHOD	TIME-LOCATION	Nigrospora	Peronospora	Curvularia	Insect	Periconia	Epicoccum	Botrytis	Sporodesmiu	Stemphyliu	Basidiospore	Stachybotry
B1	Control-1	Pre-Outdoor	0	0	0	0	0	0	0	0	0	0	0
B2	Control-1	Pre-Indoor	0	0	30	0	0	0	0	0	30	30	0
B3	Control-2	Pre-Outdoor	0	0	30	0	0	0	0	0	0	0	0
B4	Control-2	Pre-Indoor	0	0	0	0	0	0	0	0	30	0	30
B5	Contact-1	Pre-Indoor	61	0	61	121	0	91	0	0	0	0	0
B6	Contact-1	Pre-Outdoor	0	0	0	0	0	0	0	0	0	30	0
B7	Contact-1	During-Indoo	0	0	0	0	0	0	0	0	0	0	0
B8	Contact-2	Pre-Indoor	0	0	61	30	0	30	0	61	30	0	0
B9	Contact-2	Pre-Outdoor	30	0	0	0	0	0	0	30	0	0	0
B10	Contact-2	During-Indoo	30	0	0	0	0	30	0	0	0	0	0
B11	AirSweep-1	Pre-Indoor	121	0	91	30	0	61	182	0	0	0	0
B12	AirSweep-1	During-indoo	0	152	91	0	0	0	0	0	0	0	0
B13	AirSweep-2	Pre-Indoor	30	61	30	61	91	30	0	0	0	0	0
B14	AirSweep-2	During-Indoo	121	667	30	61	0	0	0	0	0	0	0
B15	Control-1	Post-Indoor	30	30	91	30	0	0	0	0	0	o	0
B16	Control-2	Post-Indoor	30	61	0	121	0	0	0	0	0	0	0
B17	Control-1&2	Post-Outdoor	0	61	0	0	0	0	0	0	0	0	61
B18	MechBrush-1	Pre-Indoor	61	61	61	0	0	0	0	0	0	0	0
B19	MechBrush-1	During-Indoo	0	0	0	0	0	0	0	0	0	0	0
B20	Contact-1	Post-Indoor	0	0	30	61	0	0	0	0	0	0	0
B21	MechBrush-2	Pre-Indoor	0	0	0	0	0	0	0	0	0	0	0
B22	MechBrush-2	Pre-Outdoor	0	30	0	30	0	0	0	0	0	0	0
B23	MechBrush-2	During-Indoo	61	0	30	0	30	0	0	0	0	0	0
B24	Contact-2	Post-Indoor	30	61	0	0	0	0	0	0	0	0	0
B25	AirSweep-1&	Post-Outdoor	0	121	0	0	0	0	0	0	0	182	0
B26	AirSweep-1	Post-Indoor	0	212	61	0	0	0	0	0	0	0	0
B27	AirSweep-2	Post-Indoor	61	30	242	152	0	0	0	0	0	91	0
B28	MechBrush-1	Post-Indoor	0	61	30	61	0	0	0	0	0	0	0
B29	MechBrush-1	Post-Outdoor	0	30	30	30	0	0	0	0	0	455	0
B30	MechBrush-2	Post-Indoor	Sample	results	missing								