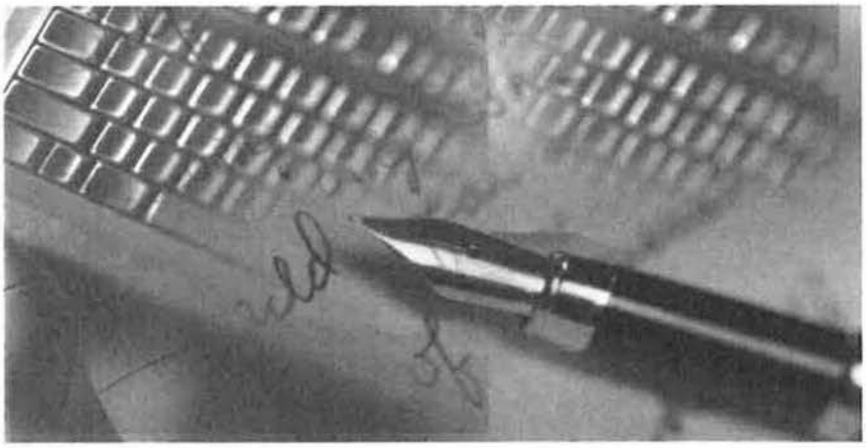
RESEARCH REPORT

EFFICIENCY OF RESIDENTIAL DUCT CLEANING



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EFFICIENCY OF RESIDENTIAL DUCT CLEANING

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DISPONIBLE AUSSI EN FRANÇAIS SOUS LE TITRE: L'EFFICACITÉ DU NETTOYAGE DES CONDUITS DE VENTILATION

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TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

LIST OF TABLES

LIST OF ILLUSTRATIONS

SUMMARY

This report presents the results of a study on the efficiency of residential duct cleaning. The study was performed in 33 houses and describes the results of measuring duct flows, fan amperage, dust, and micro-organisms before and after duct cleaning.

The study concludes that there were no significant improvements in duct flows, fan amperage, duct airborne dust, house airborne dust, or supply duct dust levels. Only dust concentrations in the return ducts and the concentrations in airborne micro-organisms have significantly improved after the duct cleaning. The reductions in airborne micro-organisms could not be attributed directly to the cleaning operations.

PREFACE

We would like to thank the people who participated in this study by providing us with access to their homes. In particular we would like to thank Mr. Guy Pinard the person responsible for the housing section in "La Presse" newspaper who allowed us to recruit the participants by providing a space in his column. We also wish to thank Canada Mortgage and Housing Corporation and, in particular, Don Fugler with the Research Division who made this study possible and who provided us with good support. We also want to thank the Environmental Laboratory at McMaster's University and the Laboratoire S.M. Inc. for their analyses.

NOTICE

This study was carried out by Auger, Donnini & Nguyen Inc. for Canada Mortgage and Housing Corporation pursuant to the National Housing Act. The analyses, interpretations and recommendations expressed herein are those of the consultants and do not necessarily reflect Canada Mortgage and Housing Corporation's views nor those of the divisions within the Corporation which have contributed to the study and to the publication of this report.

1. INTRODUCTION

Each year ventilation duct cleaning companies undertake extensive publicity campaigns to promote the beneficial aspects of cleaning ventilation ducts. Among the advantages listed are improvements in ventilation flow rates, reduction in airborne dust in houses, better comfort, and reductions in energy costs. There is no doubt that cleaning ducts is necessary in a number of cases but it is difficult to assess, on a quantitative level, the real results of duct cleaning. Subsequent to a number of requests from homeowners, CMHC decided to initiate a research project on duct cleaning in collaboration with our firm.

In a first stage, we proceeded with a review of the literature on ventilation duct cleaning. In the commercial field, the conclusion of a review of the literature published by Finnish research workers was that cleaning ducts did not affect ventilation flow rates due to the low concentration of dust which had accumulated in ducts (1). Similarly, for airborne micro-organisms, the researchers demonstrated that the effectiveness of biocides varied depending on the type of biocide used and that certain types could even cause skin irritation due to their chemical makeup.

In the residential area, another more recent study reported variations in dust and micro-organisms during ventilation duct cleaning in eight houses (2). The researchers concluded that the rate of airborne dust in the houses increased during the cleaning but reduced less than two days after the cleaning. The results for micro-organisms indicated a reduction in airborne concentrations after the cleaning but these reductions could have been caused by the reduction of micro-organisms on the outside. These results do not correspond to the results of a study carried out a cleaning company which showed a reduction in airborne micro-organisms in houses after cleaning (3.4). Finally, the review of the literature made it possible to review the standard proposed by the American Association of Ventilation Duct Cleaners which provide details on a procedure to assess the efficiency of a ventilation duct cleaning (5). A number of other articles were reviewed but these deal with subjects related only indirectly to the objectives of our study.

After a review of the literature, a research plan was defined and executed as described in this report. Although the number of houses studied is relatively small (33), the results do provide an indication of the effect of ventilation duct cleaning.

2. METHODOLOGY

2.1 Selection of the Houses

In selecting the houses, an attempt was made to provide a representative sampling of houses to allow for a significant analysis of the variation in the parameters measured both before and after the cleaning. A total of 33 houses was chosen as being sufficient to provide a representative sample.

The first houses were found through contacts with colleagues with forced air systems in their houses. Subsequently, to obtain more participants, a publicity campaign was conducted in local newspapers with a sum of $100 being promised to participants. This campaign mentioned that the tests were to be confidential and that the cleaning companies were not to be aware of the test so as not to prejudice the results.

After this campaign, over fifty homeowners replied positively. The people chosen were to have a forced air heating system and the latter had to be due for a cleaning. A questionnaire and letter of agreement to keep all information confidential were sent to the participants. The questionnaire asked for general information on the dimensions of the house, the number of occupants and their lifestyles. The participants were to chose a cleaning company in one of four cleaning categories identified in the next section.

2.2 Cleaning Companies

The types of cleaning companies were established in a telephone survey with companies in the Montreal area. The telephone survey was conducted by a person pretending to want to have his townhouse duct system cleaned. Over 30 companies were contacted during this stage.

Subsequent to this survey, 33 companies were identified. Among the latter, 17 were eliminated as they offered only commercial or industrial cleaning services. Out of the 16 companies remaining, four types of duct cleaning techniques were identified. Twelve companies used a method involving industrial vacuums and cleaning brushes. One company also used this method with brushes but, in addition, used an air compressor to displace the dust. Two companies used a vacuum truck with compressed air jet in the return ducts. Finally, one company used a vacuum truck with a metal ball to bounce against the sides of the duct. These methods are described in greater detail in the following sections.

2.2.1 Cleaning With an Industrial Vacuum and Brushes

Cleaning with an industrial vacuum and brushes is the most common cleaning procedure. This method consists in going through all the ducts and cleaning them one by one with large brushes designed to fit snuggly against the inside of the ducts. Any debris and dust is pushed to the end of the ducts to cleanouts where they are removed with a vacuum system. The vacuums are used both to push the debris and to draw in the debris depending on the access to the duct. The type of vacuum used varies depending on the company but may be of a type similar to vacuum cleaners sold in hardware stores or a more sophisticated model. Certain vacuum cleaners have high efficiency particle accumulation (HEPA) filters and certain ones are models which are imported from Europe or the United States. As the competition is stiff, it is sometimes difficult to find out on the phone what type of vacuum the cleaning company actually uses and whether or not it uses high efficiency filters. In general, the company tries to have access to all parts of the ducts by making openings if necessary. In certain cases, a bactericide agent is sprayed over the system's components and in the ducts. Cleaning companies in this category may be made up of one or more employees and vary in size.

2.2.2 Cleaning with Industrial Vacuum and Air Spray

This type of cleaning is similar to the cleaning described in the preceding section but uses an air compressor to increase the pressure in the ducts. The air compressor is used to produce a jet of air in the ducts which pushes the dust toward the vacuum cleaner. This technique is used by one company which previously had used only a vacuum truck but abandoned this technique at one point to adopt the procedure using brushes but at the same time kept the compressor which it had formerly used.

2.2.3 Vacuum Truck

The vacuum truck method is employed mainly by the largest cleaning companies. The company's truck includes a high power vacuum cleaner and an air compressor. The vacuum cleaner is attached to the fan casing with 30cm diameter ducts extending from the fan casing to the outside going through either the main entrance way or the garage entrance way. The first stage in the cleaning process consists in connecting this vacuum duct by making a square hole in the return ducts. One member of the team goes around to all the return air vents, opens them and sprays the compressed air on the dust which is sucked into the vacuum outside. In some cases, the return air registers are not opened and the air is sprayed directly through the cracks in the return air register. During the second stage, the vacuum is connected to the air supply ducts and the compressor is hooked up to an extension which is inserted in all the ducts. The extension sprays compressed air and is inserted in the main supply ducts. During this time, a member of the team sprays bactericide on the system's components and in the supply duct registers. The bactericide is sucked towards the outside by the vacuum in the truck. Most companies also have cleaning brushes but do not use them in the cleaning operation.

2.2.4 Vacuum Truck and Metal Ball

This method is similar to the preceding one but uses a selection of metal balls attached to the end of the air compressor line. This technique makes it possible to use metal balls to stir up the air which is to be sucked in by the vacuum in the truck. Only one company actually used this system but the other companies said that they also use this method. The difference is that the other companies used only one metal ball attached to the compressor, rather than a number of these.

2.2.5 Cleaning of the Fan

Duct cleaning companies also offer a system tune-up which includes cleaning the circulating fan. The tune-up is offered by furnace service companies as an integral part of maintenance programs for furnaces which also includes a verification of the electrical and mechanical components of the heating and air conditioning systems. The fan is removed from the furnace and is sprayed with a detergent which is left to work while the other components are verified or changed. The homeowner can also request only the cleaning of the fan rather than a complete tune-up. The duct cleaning companies limit their service to compressed air cleaning of the blower.

2.3 Description of Measurement Methods

The measurement methods were defined after a bibliographical study of procedures which had already been used in this area, and were developed in a pilot study on two houses. The methods used are described in the following sections.

2.3.1 Parameters Describing the Houses

The parameters describing the houses were chosen using a questionnaire sent out to the participants. This questionnaire included the type of ventilation system, the number of residents during the day and at night, the number of smokers and the number of pets in the house. The volume of the houses was estimated according to the dimensions provided by the owners. All the participants replied to the questionnaire.

2.3.2 Measurement of Ventilation Parameters

Measurements of the ventilation parameters were effected with the circulation fans operating at their maximum speeds. These measurements are described in the following sections.

2.3.2.1 Current and Voltage

Fan current and voltage were measured using a voltage and current clamp attached to the fan's current terminals. The readings were taken after the voltage and current stabilized.

2.3.2.2 Pressure Differential

Pressure differential was measured with the Shortridge Airdata Multimeter. This apparatus was attached to each side of the supply air and return air ducts. Five readings were taken and the average was noted. The apparatus is accurate to within 2% of the reading over a reading range of 0.02 to 14900 Pa (0.0001 to 60.00 inches of water). The readings were taken at the same locations for all the tests.

2.3.2.3 Ventilation Flow Rates

Ventilation flow rates were measured using a Shortridge Flowhood Balometer which is accurate to 5% for readings within the 12 to 1180 L/s (25 to 2500 cfm) range. Variable sized Balometer skirts were used to cover the registers measured. Measurements were taken on two return air ducts and three supply air ducts. The Balometer's pressure measurement device, the Airdata Multimeter, takes five measurements and provides the average of these readings.

2.3.3 Dust Measurement

Dust was measured on the duct surface, in the air leaving the ducts, and in the house air.

2.3.3.1 Dust Measurement on Duct Surface

Dust on the duct surface was measured using the procedure described in the National Air Duct Cleaning Association (NADCA) standard (5). The method consists in taking measurements on a 100 sq. cm. surface determined by a plastic rectangular frame. The dust on this surface is sucked in with a flow of 10 L/s through a pre-weighed open-face filter which is then sent to the laboratory for analysis. The detection limit is 0.02 mg per sample. A sample is taken in the system's main return duct and in one supply duct.

2.3.3.2 Dust Measurement at Duct Exit

The dust coming out of the ducts is measured using a pre-weighed filter through which the air is sucked in at a flow rate of 15 L/s. The filter is placed directly on the supply air registers in the rooms. The samples are taken over a period of 60 to 120 minutes. The filters are sent to the laboratory for analysis purposes and the detection limit is 0.02 mg per sample. For the flow rates and measurement time, the test is accurate to 0.01 mg per cubic meters or more. Two samples per house were taken at the supply registers in the main rooms.

2.3.3.3 Measurement of House Airborne Dust

House airborne dust was measured using two methods. The first method consisted in using a pre-weighed filter as was the case for duct surface dust and the second method consisted in using a direct reading instrument.

For the gravimetric method, one sample per house was taken in the main room of the house. This room was always the living room located on the ground floor. The samples were taken over a period of 60 to 120 minutes. The filters were sent to the laboratory for analysis purposes and the detection limit is 0.02 mg per sample. For the flow rates and measurement times, the test is accurate to 0.01 mg per cubic meter or more.

The direct reading instrument was used to measure dust in six areas in the house. This device called the Miniram MIE model PDM-an uses a light dispersion technique to measure dust particles and the detection limit is 0.01 mg per cubic meter. It is calibrated to identify particles from 0.1 to 10 um in correlation with a gravimetric measurement. The instrument was left on a table in the room for a period of 5 minutes. In two cases, the device was left in the room for 3 days to have a continuous measurement of dust while the ducts were being cleaned. The voltage register was hooked up to the device and took measurements every 15 seconds.

2.3.4 Micro-Organism Measurement

The micro-organisms measured included yeast, mold and bacteria. These micro-organisms were measured on duct surfaces and in the air.

2.3.4.1 Micro-Organisms on Duct Surface

Micro-organisms on duct surfaces were measured using culture medium contained on RODAC contact plates. The 25 cm^2 contact plates were applied against the duct surface in areas where there were an accumulation of dust. A culture medium was used for the bacteria and another for yeast and mould. The samples were sent to the analysis laboratory for incubation and analysis. The plates are analyzed and the results are expressed in colony forming units per 25 cm^2. The surface samples are taken at two locations in the supply and return air ducts and at the same locations before and after duct cleaning.

2.3.4.2 Duct Airborne Micro-Organisms

House airborne micro-organisms were collected using the Biotest RCS Sampler device. The latter draws in a quantity of 40 litres of air using a centrifugal fan which exposes culture medium slides for bacteria and for yeast and mould. These slides are kept cool before being sent to the laboratory for incubation and analysis. The results are expressed in colony forming units per cubic meter (CFU/m^3). Airborne micro-organism measurements were taken in the basement and on the ground floor of the house.

3. RESULTS

This section presents the results obtained from measurements taken in the 33 houses. The measurements were taken during the period from July to October 1993. The results presented include the characteristics of the houses, ventilation measurements, dust and micro-organisms meausrements.

The results are analyzed to determine the effect of cleaning on improvements in the parameters measured. The analysis deals with the differences between the before and after measurements and compares the average differences for all the data, presenting confidence intervals for calculating any differences in measurement. In spite of the efforts invested to analyze the efficiency of the various techniques, the results did not indicate large significant differences between the techniques. That is why the results are not discussed for the sub-groups. The results presented in detail in tables are for all types of cleaning, and one can thus observe to some degree the differences or the similarities between the effectiveness of the various techniques.

This section contains the results for the data obtained through measurements and the following section presents a combined analysis of the results to establish the global influence of the parameters. This section thus does not combine the various parameters but merely presents the results obtained.

3.1 Types of Houses and Cleaning Techniques Studied

A total of 33 houses were studied in eight different cleaning categories. Table 3.1 summarizes the sampling of the houses obtained at the end of the on-site measurements stage. Originally, there was to be an equal number of houses in each of the categories. A certain number of factors, however, changed the distribution as the study went on. Two owners who had been classed in the N3 and V2 category decided to change cleaning companies without providing us with any notice. In one case, in category V4, the company responsible for fan cleaning caused damage to the fan and was not able to proceed with the cleaning.

Table 3.1: Sampling of Houses and Techniques

Reference	Cleaning Category	Number of Houses
N1	Industrial vacuum with brushes	8
N2	Vacuum Truck	7
N3	Vacuum Truck with Metal Ball	4
N4	Industrial Vacuum and Air Spray	7
V1	Like N1 with cleaning of fan	3
V2	Like N2 with cleaning of fan	1
V3	Like N3 with cleaning of fan	2
V4	Like N4 with cleaning of fan	1
	TOTAL	33

The data shown in the tables in the report are classified by category as described in Table 3.1 and by a house code going from M1 to M33. This classification is used for all the tables presented in the report. Missing values are identified by shaded areas on the tables. Missing values include those values not reported due to experimental errors, lost or destroyed samples or values the results of which were deemed to be doubtful.

As shown in Table 3.1 (following page), the average age of the houses studied was 26 years, going from the youngest house which was built in 1993 to the oldest house built in 1948. The average number of people residing in the house was two during the day and three at night and approximately one-third of the occupants smoked. Each house, on an average, had one pet, most of which were either dogs or cats.

Table 3.3 (following pages) shows the areas and the volumes of the houses studied. The average area of the houses, including the basement, was 242 m^2 with a minimum of 104 m^2 and a maximum of 697 m^2. Most of the houses were one-storey bungalows with finished basements. The average volume of the houses including the basement was 593 m^3 with a minimum of 254 m^3 and a maximum of 1699 m^3. These volumes are approximate.

Tables 3.4 and 3.5 (following pages) show the equipment used for heating and air conditioning the houses. The brand names of the systems and fans vary and cover all those available on the market. The fans had variable speed adjustments going from one to three. The fan motors had an average power of 0.27 kW with a maximum of 0.56 kW and a minimum of 0.10 kW.

All the tests, except one, were carried out with the motors at their maximum speed. For the houses as a whole, 39% were heating with electricity, 39% with oil heating and 12% with dual energy (oil and electricity or natural gas and electricity as energy sources) and 9% with natural gas. As additional equipment, 36% had heat pumps, 48% electrostatic filters and 24% had humidifiers. One house had an air exchanger and one house had a small electric heating system added by the owner in the furnace plenum.

While measurements were being taken in the houses, the occupants could not smoke, and they had turned on their heating systems before our arrival.

Table 3.2: Description of House Age and Number of Occupants

No.	Category	Construction Date	Age Years	No. of Occupants						Smokers			
				Day	Even.	Dogs	Cats	Other	Total	Day	Even.	Yes	No
M01	N1	1961	32	2	2		1		1				1
M05	N1	1989	4	4	4				0				1
M07	N1	1955	38	2	2				0				1
M12	N1	1970	23	1	4				0		1	1	
M13	N1	1971	22	2	2				0	1	2	1	
M15	N1	1954	39	0	3				0				1
M16	N1	1972	21	1	2	2			2				1
M22	N1	1975	18	2	2				0				1
M04	N2	1974	19	1	2				0				1
M10	N2	1964	29	2	3				0	1	2	1	
M14	N2	1963	30	3	3		1		1				1
M17	N2	1964	29	1	2				0	1	2	1	
M18	N2	1956	37	3	4				0		1	1	
M26	N2	1987	6	0	3		1		1				1
M29	N2	1958	35	2	3	1	1		2	1	1	1	
M06	N3	1961	32		3				0		1	1	
M08	N3	1972	21		2				0		1	1	
M11	N3	1967	26	2	2				0				1
M23	N3	1965	28	1	2		1		1				1
M02	N4	1984	9	1	3		1		1		1	1	
M03	N4	1965	28		3				0				1
M09	N4	1961	32	2	5				0				1
M24	N4	1858	35	1	1				0				1
M25	N4	1968	25	0	2				0		2	1	
M28	N4	1968	25	1	3				0	2	2	1	
M31	N4	1987	6	1	4		2		2				1
M19	V1	1965	28	1	2				0				1
M20	V1	1957	36	3	4		2		2	2	2	1	
M32	V1	1993	0	0	6		1	2	3				1
M21	V2	1963	30	3	4				0				1
M30	V3	1948	45	6	5	1	2	2	5				1
M33	V3	1968	25	1	5				0				1
M27	V4	1963	30	2	2				0				1
Number		33	33	30	33	3	10	2	33	6	12	12	21
Maximum		1993	0	6	6	2	2	2	5	2	2		
Minimum		1948	45	0	0	1	1	2	0	1	1		
Average		1967	26	2	2	1	1	2	1	1	2		

Table 3.3: House Areas and Volumes

No.	Category	Areas (m²)		Basement	Total	Ceiling Height (m)			Volume m³ (approx.)
		Storey 1	Storey 2			Storey 1	Storey 2	Basement	
M01	N1	104		78	182	2.4		2.4	444
M05	N1	242		91	333	2.4		2.4	811
M07	N1	107		107	214	2.4		2.4	521
M12	N1	94		94	187	2.4		2.4	457
M13	N1	97		97	194	2.4		2.3	459
M15	N1	78		78	156	2.4		2.4	381
M16	N1	95		95	190	2.4		2.4	464
M22	N1	121		121	242	2.4		2.4	589
M04	N2	104		78	182	2.4		2.4	444
M10	N2	139		139	279	2.4		2.4	680
M14	N2	106		75	181	2.4		2.4	440
M17	N2	94		94	188	2.4		2.4	459
M18	N2	260		111	372	2.4		2.4	906
M26	N2	148	148	148	445	2.4	2.4	2.3	1062
M29	N2	111		84	195	2.4		2.7	501
M06	N3	102		65	167	2.4		2.4	408
M08	N3	82		82	164	2.4		2.1	376
M11	N3	92		92	184	2.4		2.4	448
M23	N3	105		105	209	2.4		2.4	510
M02	N4	113		113	226	3.0		2.4	619
M03	N4	139		111	251	2.4		2.4	612
M09	N4	232	232	232	697	2.4	2.4	2.4	1699
M24	N4	262		66	328	2.4		2.3	789
M25	N4	104			104	2.4			254
M28	N4	104		71	175	2.4		2.4	426
M31	N4	242		128	370	2.7		2.4	975
M19	V1	111		74	186	2.4		2.4	453
M20	V1	70	70	46	186	2.4	2.4	2.1	439
M32	V1	104		104	208	2.4		2.4	476
M21	V2	120		120	239	2.7		2.4	620
M30	V3	95	68	84	246	2.4	2.4	2.4	600
M33	V3	93	93	93	2179	2.4	2.4	2.4	680
M27	V4	113		113	226	2.4			1552
				Number	33				33
				Maximum	697				1699
				Minimum	104				254
				Average	242				593

Table 3.4: Ventilation and Heating Equipment

System Brand Name	Motor Brand Name	Motor Model	No. of Motor Speeds	Power (hp)	Power (kW)	Speed of Motor During Tests
Lincoln			2	0.50	0.37	MAX
Carrier	Carrier Corp.	38SQ130300	3	0.33	0.25	MAX
Kenmore Keeprite	CGE	5KCP39HG	1	0.33	0.25	MAX
Lincoln Barrier	CGE Philips-Lau	DD 10-10A	1	0.25	0.19	MAX
Trane	GE	01103-500	1	0.25	0.19	MAX
Metroheat	Tamper AC Motor		1	0.25	0.19	MAX
Canadian Coleman			2	0.25	0.19	MAX
Gulf Home Products	Lau Products Ltd.	A 9-9 ACE	1	0.33	0.25	MAX
York	York	N2AH1710A06D	3	0.33	0.25	MIN
Roy	Harrington GE		1	0.25	0.19	MAX
Dyno-Flame	Tamper AC Motor	MSS-2880	1	0.25	0.19	MAX
Atlas Webster	Franklin Electric	1401022411	1	0.33	0.25	MAX
Brock	CGE	7J403GS	1	0.50	0.37	MAX
Lennox	Lennox	P-8-8370	1	0.33	0.25	MAX
Rheem			1	0.25	0.19	MAX
Thermo Radiant	Marathon		3	0.50	0.37	MAX
Trane	GE	7040DAS3	1	0.50	0.37	MAX
Imperial Oil Limited	Magnatek	HG2H002N	3	0.50	0.37	MAX
Thermo Radiant	CGE	5J771GS1	1	0.33	0.25	MAX
Chromalox			2	0.25	0.19	MIN
Dettson AM	Dettson Beckett	AFG	2	0.14	0.10	MAX
Lincoln Barrier	CGE Philips-Lau	DD 10-10A	3	0.50	0.37	MAX
Petrocan Plus	Emerson	SA55NXTE-4513	1	0.33	0.25	MAX
Brock	GE	3J522AX5	1	0.25	0.19	MAX
Brock	GE	EJ519AX5	1	0.33	0.25	MAX
Coleman	Coleman	3300-823	3	0.75	0.56	MAX
Metroheat	CDN Westinghouse		1	0.25	0.19	MAX
Olsen	GE	740AST	1	0.33	0.25	MAX
Brock	Ge	EFF	1	0.33	0.25	MAX
Lincoln Supreme			1	0.25	0.19	MAX
Coleman	Coleman	3300-842	2	0.75	0.56	MAX
Hupp Canada	GE	71403AS2	1	0.50	0.37	MAX
McClary Easy	Presto Liteland	J0A-5504	1	0.25	0.19	MAX
		Number	33	33	33	
		Maximum	3	0.75	0.56	
		Minimum	1	0.014	0.10	
		Average	1.5	0.36	0.27	

Table 3.5: Energy Sources and Additional Equipment

No.	Category	Electric	Oil	Natural Gas	Dual-Energy	Heat Pump	Heat Recovery Unit	Electro-static Filter	Humidifier	Other
M01	N1		1							
M05	N1	1				1		1		Air Exch.
M07	N1	1								
M12	N1				1	1				
M13	N1	1				1		1		
M15	N1				1					
M16	N1			1				1		
M22	N1		1			1		1		
M04	N2	1						1	1	
M10	N2		1						1	
M14	N2		1						1	
M17	N2			1						
M18	N2				1			1		
M26	N2	1						1		
M29	N2	1				1		1		
M06	N3	1				1		1	1	
M08	N3		1			1				
M11	N3	1							1	Electric Heater Plenum
M23	N3	1						1		
M02	N4	1					1	1		
M03	N4		1			1				
M09	N4		1			1		1	1	
M24	N4		1							
M25	N4		1							
M28	N4		1							
M31	N4	1				1		1	1	
M19	V1		1							
M20	V1			1						
M32	V1				1			1		
M21	V2	1						1	1	
M30	V3	1				1		1	1	
M33	V3		1			1				
M27	V4		1							
Number		13	13	3	4	12	1	16	8	
Percentage		39%	39%	9%	12%	36%	3%	48%	24%	

3.2 Measurements of Ventilation Parameters

3.2.1 Pressure, Amps and Voltage Measurement

Table 3.6 shows the results of pressure, amps and voltage measurements before and after duct cleaning. For all the houses, the average difference in pressure was 76 Pa before cleaning and 75 Pa after cleaning for an average difference of nil before and after cleaning. In nearly 50% of the cases, the pressure decreased following cleaning. If we consider category V, where the cleaning of the fan was done separately, an increase of 21 Pa is noted. This increase is not significant with a confidence interval of 95% due to the small number of data. For the other categories, the number of measurements does not allow us to determine whether the differences are significant.

The average fan amperage was 5.06 amperes before cleaning and 4.92 amps after cleaning. The average amperage difference was -0.14 amps for all the houses and this difference is not significant within a confidence interval of 95% (-0.38 to 0.11 amps). The distribution of the motor amperage is presented in an Appendix. For category V, the average difference was -0.46 amps after cleaning only the fan and this difference is not significant within a confidence interval of 95% due to the limited number of data.

For all the measurements as a whole, the average voltage measured prior to the tests was 126 V and 127 V after cleaning. The maximum voltage difference during the test was 5 V with an average difference of nil.

Table 3.6: Pressure, Amperage and Voltage Measurement

No.	Category	Pressure (Pa)			Amperage (A)			Voltage (V)		
		Before	After	Difference	Before	After	Difference	Before	After	Difference
M01	N1	55	55	1	6.67	6.50	-0.17	123	121	-2
M05	N1	57	64	7	1.84	1.87	0.03	120	117	-3
M07	N1	75	61	-13	3.02	2.78	-0.24	119	115	-4
M12	N1	67	60	-7	4.40	4.48	0.08	120	118	-2
M13	N1	93	84	-9	1.37	1.34	-0.03	238	241	3
M15	N1	115	92	-23	5.04	5.05	0.01	121	120	-1
M16	N1	36	36	0	4.02	3.90	-0.12	114	117	3
M22	N1	93	83	-10	5.70	5.30	-0.40	120	119	-1
M04	N2	57	72	15	1.93	1.77	-0.16	242	245	3
M10	N2	54	67	13	4.26	4.45	0.19	110		
M14	N2	56	72	15	5.16	5.35	0.19	118	117	-1
M17	N2				5.10	5.80	0.70	119	119	0
M18	N2	88	82	-6	8.60	8.37	-0.23	118	116	-2
M26	N2	27	5	-23	1.85	1.82	-0.03	120	121	1
M29	N2	81	72	-10	1.80	1.85	0.05	120	119	-1
M06	N3	80	83	3	9.99	9.66	-0.33	121	121	0
M08	N3	62	56	-6	7.65	7.64	-0.01	119	119	0
M11	N3	90	52	-38	5.80	5.70	-0.10	120	120	0
M23	N3	89	121	33	3.04	3.14	0.10	114	117	3
M02	N4	66	95	30	1.00	1.00	0.00	120	120	0
M03	N4	79	71	-8	7.50	6.95	-0.55	120	118	-2
M09	N4	153	175	21	5.77	5.95	0.18	114	114	0
M24	N4	67	62	-5	5.24	5.40	0.16	118	118	0
M25	N4	98	83	-15	4.85	4.90	0.05	119	118	-1
M28	N4	74	70	-4	6.85	6.58	-0.27	121	119	-2
M31	N4	50	35	-16	4.10	4.13	0.03	118	123	5
M19	V1	31	41	10	7.95	4.11	-3.84	117	118	1
M20	V1	106	106	0	6.60	6.65	0.05	120	121	1
M32	V1	33	42	8	4.79	4.65	-0.14	118	117	-1
M21	V2	91	86	-4	7.69	8.03	0.34			
M30	V3	85	143	58	3.80	3.61	-0.19	120	120	0
M33	V3	148	104	-44	8.19	8.03	-0.16	120	119	-1
M27	V4	64	86	22	5.40	5.65	0.25	119	119	0
Number		32	32	32	33	33	33	32	31	31
Maximum		153	175	58	9.99	9.66	0.70	242	245	5
Minimum		27	5	-44	1.00	1.00	-3.84	110	114	-4
Average		76	75	0	5.06	4.92	-0.14	126	127	0

3.2.2 Ventilation Flow Rate Measurements

Tables 3.7 and 3.8 show the ventilation flow rates measured before and after cleaning the ventilation ducts for the supply and return air ducts measured in the house. Table 3.9 shows the return air flow rates for category V. In most of the cases, flow rate measurements were taken on three supply air ducts and two return air ducts in houses.

For the supply air ducts, before cleaning, the average flow rate measurement was 37 L/s with a maximum average of 73 L/s and a minimum average of 18 L/s. After cleaning, the average flow rate was 37 L/s with a minimum average of 15 L/s and a maximum average of 67 L/s. Comparing the before and after results, an average difference of 1 L/s (0.55 L/s if the values are not rounded off). In over 50% of the cases (17 out of 33) the average flow rates after cleaning were lower. The average increase in supply duct flow rates of 1 L/s is therefore negligible and insignificant.

For category V alone, the difference in the supply duct flow rate is not significant with a confidence interval of 95%. The total flow rate difference is nil after cleaning the fan and the ducts.

For the return air ducts, the average flow rate before cleaning was 55 L/s with an average minimum of 0 L/s and a maximum average of 149 L/s. After having cleaned the ducts, the average flow rate in the return air ducts was 60 L/s with an average minimum of 10 L/s and an average maximum of 170 L/s (360 cfm). The average difference between the measurements before and after cleaning was 3 L/s. In 14 cases out of 32, the return air flow rates decreased and the average difference between the before and after flow rates is not significant with a confidence interval of 95% (-1.2 to 6.6 L/s). For category V (Table 3.9), the difference in flow rates shows an increase of 2 L/s (4 cfm) after cleaning the fan alone. This difference is not significant for a confidence of interval of 95%. For category V, the difference in the return duct air flow rates including also the cleaning of the ducts, shows an increase of 11 L/s but this increase is not significant for a confidence level of 95%.

Table 3.7: Ventilation Flow Rates - Supply Air Ducts

No.	Category	Before						After						Difference					
		L/s	L/s	L/s	L/s	L/s	Avg. L/s	L/s	L/s	L/s	L/s	L/s	Avg. L/s	L/s	L/s	L/s	L/s	L/s	Avg. L/s
M01	N1	25	32	34			30	23	32	34			30	-2	0	0			-1
M05	N1	42	49	43			42	42	38	39			40	0	-2	-5			-2
M07	N1	28	46	27			34	26	50	34			37	-1	4	7			3
M12	N1	26	27	34			29	25	22	31			26	-1	-5	-3			-3
M13	N1	8	42	34			28	24	40	25			30	15	-2	-8			2
M15	N1	22	31	59			37	67	64	39			57	45	34	-20			20
M16	N1	19	36	32			29	21	35	31			29	2	-1	-1			0
M22	N1	13	48	32			31	41	18	15			25	28	-30	-17			-6
M04	N2	31	38	44			38	27	37	44			36	-4	-1	0			-2
M10	N2	19	25	37	222		26	20	23	33	25		25	1	-2	-4	2		-1
M14	N2	65	34	25			41	70	40	34			48	5	6	8			6
M17	N2	8	36	27	123	123	19	23	35	44	23	34	32	15	-1	17	10	22	13
M18	N2	14	38	23			25	13	36	31			27	0	-1	8			2
M26	N2	42	56	26			41	50	55	27			44	8	-1	1			3
M29	N2	74	55	77	864		73	79	51	77	61		67	5	-3	0	-25		-6
M06	N3	50	35	25			37	62	35	27			41	11	0	2			4
M08	N3	23	12	20			18	19	24	25			23	-3	12	5			4
M11	N3	47	42	44			44	44	41	35			40	-2	0	-8			-4
M23	N3	29	22	25			25	32	23	31			29	3	0	6			3
M02	N4	58	42	47			49	59	45	42			49	1	2	-4			0
M03	N4	25	15	26			22	29	15	33			26	4	0	7			4
M09	N4	43	34	17	118		26	41	27	15	12		24	-2	-7	-2	0		-3
M24	N4	39	28	14			27	23	19	5			16	-16	-9	-9			-11
M25	N4	27	21				24	14	16				15	-13	-5				-9
M28	N4	36	50	59			48	54	59				56	18	6	0			8
M31	N4	54	59	51			55	48	49	49			48	-6	-10	-3			-6
M19	V1	19	27	36			27	18	32	36			29	-1	5	0			1
M20	V1	50	53	29			44	48	42	33			41	-1	-11	4			-3
M32	V1	22	50	36			36	25	60	37			41	3	10	1			5
M21	V2	47	50	85			61	42	37	72			50	-5	-14	-13			-11
M30	V3	47	67	44			53	51	80	51			61	4	13	7			8
M33	V3	69	49	54			57	69	53	48			57	0	4	-6			-1
M27	V4	38	35	15			29	39	32	21			31	1	-4	7			1
Number		33	33	32	4	1	33	33	33	32	4	1	33	33	33	32	4	1	33
Maximum		74	67	85	86	12	73	79	80	77	61	34	67	45	34	17	10	22	20
Minimum		8	12	14	12	12	18	13	15	5	12	34	15	-16	-30	-20	-25	22	-11
Average		35	39	37	33	12	37	38	38	36	30	34	37	3	0	-1	-3	22	1

Table 3.8: Ventilation Flow Rates - Return Air Ducts

No.	Category	Before				After				Difference			
		L/s	L/s	L/s	Avg. L/s	L/s	L/s	L/s	Avg. L/s	L/s	L/s	L/s	Avg. L/s
M01	N1	0	-37	-38	25	-12	-17	0	-10	12	-21	-38	-16
M05	N1	-23	-80		51	-24	-76		50	1	-3		-1
M07	N1	-101			-101	-106			-106	6			6
M12	N1	-94	-87		-91	-94	-80		-87	0	-7		-4
M13	N1	-106	-98		-102	-104	-92		-98	-2	-6		-4
M15	N1	-56	-30		-43	-50	-36		-43	-6	6		0
M16	N1	-13	-53		33	-8	-49	-5	-4		-4		
M22	N1	-65			-65	-68			-68	3			3
M04	N2	-38	-64		51	-53	-76		65	16	13		14
M10	N2	-138	-63		-100	-120	-52		-80	-18	-10		-14
M14	N2	-105	-74		-89	-109	-80		-99	4	6		5
M17	N2												
M18	N2	-65	-54		-60	-61	-80			-4	26		13
M26	N2	-71			-71	-59			-59	-13			-13
M29	N2	-170	-34		102	-175	-32		103	5	03		5
M06	N3	-30	-31		-30	-28	-46		-37	-2	16		7
M08	N3	-46	-35		-41	-46	-35		-41	0	0		0
M11	N3	-24	-21		-22	-41	-20		-3	17	-1		3
M23	N3	-34	-20		-27	-45	-28		-37	10	8		9
M02	N4	-34			-34	-44			-44	9			9
M03	N4	-22			-22	-24			-24	2			2
M09	N4	-30			-30	-40			-40	10			10
M24	N4	-27	-21		-24	-19	-15		-17	-8	-6		-7
M25	N4	-26	-21		-23	-24	-23		-23	0-2	2		0
M28	N4	-149			-149	-145			-145	-3			-3
M31	N4	-99	-21		-60	-91	-13		-52	-8	-8		-8
M19	V1	025	-24		-25	-34	-45		-40	9	21		15
M20	V1	-128			-128	-170			-170	42			42
M32	V1	-19	-44		-31	-26	-51		-39	7	8		7
M21	V2	-50	-44		-47	-53	-36		-45	3	-8		-2
M30	V3	-31	-39	-35	-35	-40	-54	-42	-45	9	15	7	10
M33	V3	-111	-12		-62	-99	-8		-53	-12	-4		-8
M27	V4	-42	-69		-56	-47	-89		-68	4	20		12
Number		32	24	2	33	32	24	2	32	32	24	2	32
Maximum		0	-12	-35	0	-8	-8	0	-10	42	26	7	42
Minimum		-170	-98	-38	-149	-175	-92	-42	-170	-18	-21	-38	-16
Average		-62	-45	-37	-55	-64	-47	-21	-60	3	2	-16	3

Table 3.9: Ventilation Flow Rates for Category V - Return Air Ducts

Before				After Fan Cleaned				Diff. After Fan Cleaned			
L/s	L/s	L/s	Avg. L/s	L/s	L/s	L/s	Avg. L/s	L/s	L/s	L/s	Avg. L/s
-25	-24		-25	-25	-30	-30	-30	5	6		5
-128			-128	-113			-113	-15			-15
-19	-44		-31	-26	-54		-40	7	10		9
-50	-44		-47	-50	-45		-47	0	1		0
-31	-39	-35	-35	-36	-56	-46	-46	5	17	10	11
-111	-12		-62	-106	-9		-58	-6	-2		-4
-42	-69		-56	-49	-80		-64	6	11		8
7	6	1	7	7	6	1	7	7	6	1	7
-19	-12	-35	-25	-26	-9	-46	-30	7	17	10	11
-128	-69	-35	-128	-113	-80	-46	-113	-15	-2	10	-15
-58	-39	-35	-55	-58	-46	-46	-57	0	7	10	2
After Cleaning Ducts				Diff. Between Fan and Duct Cleaning				Total Difference			
L/s	L/s	L/s	Avg. L/s	L/s	L/s	L/s	Avg. L/s	L/s	L/s	L/s	Avg. L/s
-34	-45		-40	4	15		10	9	21		15
-170			-170	57			57	42			42
-26	-51		-39	0	-3		-1	7	8		7
-53	-36		-45	4	-9		-3	3	-8		-2
-40	-54	-42	-45	4	-2	-3	0	9	15	7	10
-99	-8		-53	-7	-2		-4	-12	-4		-8
-47	-89		-68	-2	9		4	4	20		12
7	6	1	7	7	6	1	7	7	6	1	7
-26	-8	-42	-39	57	15	-3	57	42	21	7	42
-170	-89	-42	-170	-7	-9	-3	-4	-12	-8	7	-8
-67	-47	-42	-66	9	1	-3	9	9	8	7	11

3.3 Dust Measurement

The results of the dust measurements are analyzed for duct surface dust measurement, airborne dust measurement at supply duct exit and house airborne dust. The results of the measurements taken in the project's preliminary phase are discussed in the first section.

3.3.1 Direct Readings, Preliminary Project Phase

In the project's preliminary phase, dust measurements were taken in the houses to determine how long it takes for dust to settle after duct cleaning. These measurements were taken with a direct reading device in only two houses. These results were taken to be able to measure variations in dust level while the ducts were being cleaned.

The direct reading device was left in two houses over several days to determine typical dust level variations while the ducts were being cleaned. The detector's voltage measurement results are presented in Illustrations 3.1 and 3.2. In Illustration 3.1, the voltage variations indicate that the dust concentrations increased during the cleaning period and then rapidly decreased. The time interval from 9:00 to noon corresponds to the period during which the house was empty. The system's fan did not function during the cleaning. Illustration 3.2 shows voltage readings for two days in another house. The day the ducts were cleaned, dust concentrations did not vary significantly. Subsequently, domestic cleaning activities caused the concentrations to increase and they decreased rapidly. The occupants of the house confirmed that cleaning the ducts did not produce dust in the house.

These tests demonstrated that dust concentration levels generated by the cleaning increased in the house but decreased rapidly after the cleaning. The decreasing phase is less than one day in the cases studied which corresponds to the results in one of the reviews in our bibliographical research.(2)

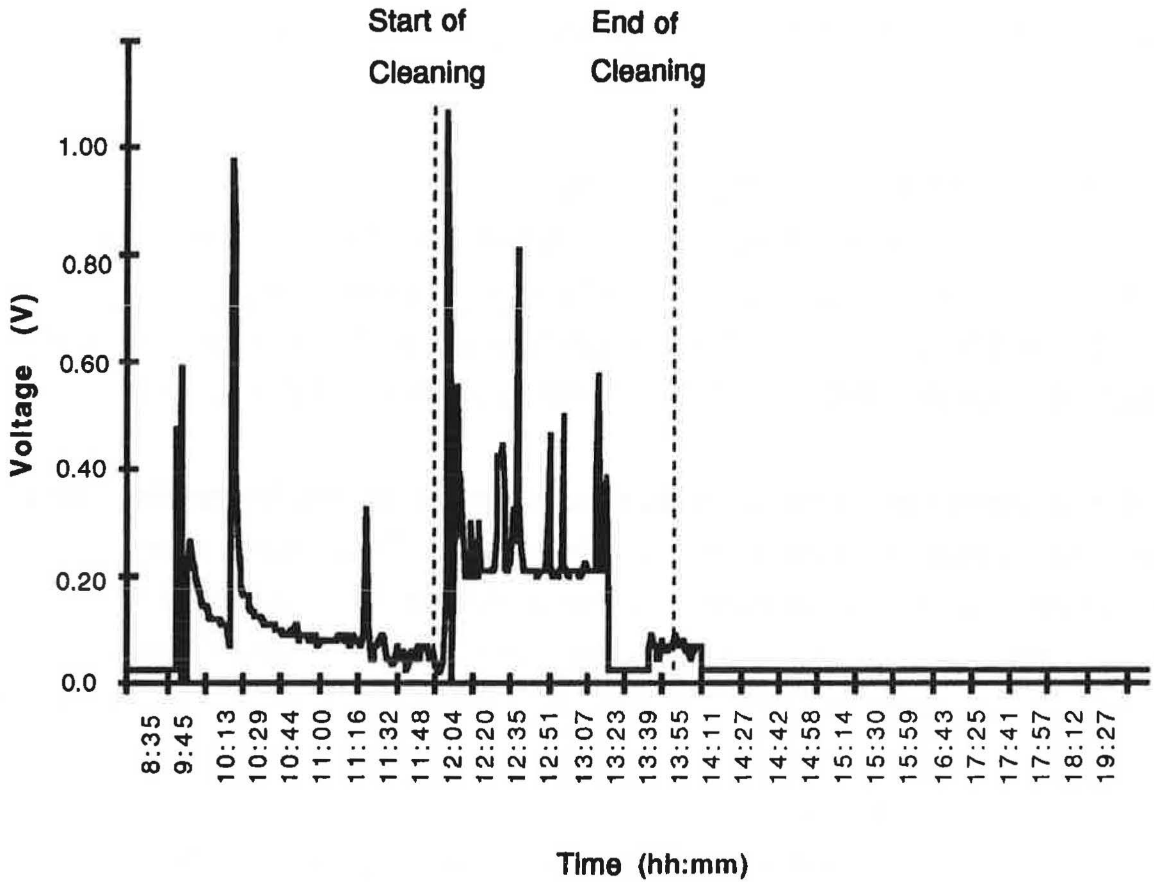


Illustration 3.1: Voltage Variation in Dust Monitor, Case 1

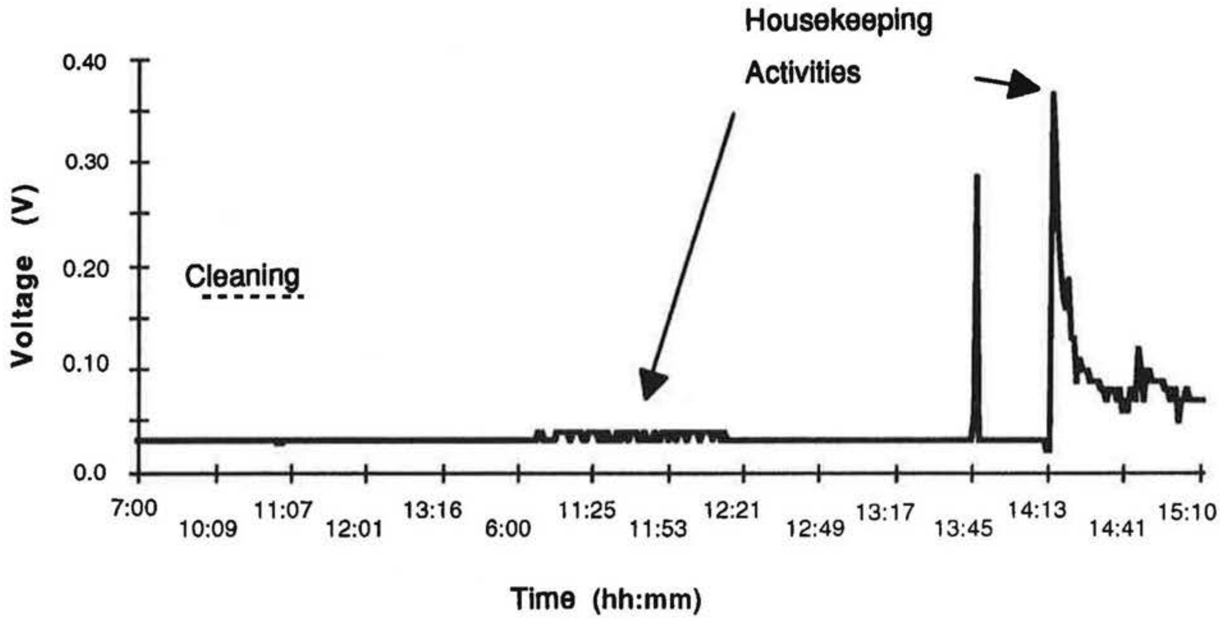


Illustration 3.2: Voltage Variation in Dust Monitor, Case 2

3.3.2 Duct Surface Dust

The analysis of the duct surface dust was carried out two stages. First of all, the values were analyzed assuming that the dust was distributed normally. Experience has shown however, that most dust measurements taken in on-site studies show that dust is not distributed normally but rather lognormally. A lognormal distribution occurs when a large number of values are near to nil and the rest are distributed in intervals of 10, 100 or 1,000 times higher.

Analysis of Gross Values

Table 3.10 presents the gross results of duct surface dust measurements on the supply and return air ducts in the ventilation systems.

Before cleaning, the average duct surface dust concentration in the return air ducts varied from 0.12 to 516 mg/100 cm^2 with an average of 63.9 mg/100 cm^2. Before cleaning, 79% of the values were above the NADCA recommendation of 1 mg/100 cm^2. After cleaning, average dust concentration in the return air ducts was 10.1 mg/100 cm^2 with a maximum of 168.6 mg/100 cm^2 and a minimum of 0.0 mg/100 cm^2. After cleaning, 50% of the dust concentrations were still above the NADCA's recommendation of 1 mg/100 cm^2. The average difference between the concentrations before and after cleaning shows a reduction of 55.7 mg/100 cm^2 and this difference is significant for a confidence interval of 95% (-10 to -101 mg/100 cm^2). In 28% of the cases, duct surface dust concentrations in return air ducts increased. This increase indicates that the return air ducts were not cleaned or that additional dust deposits appeared after cleaning.

Table 3.10: Duct Surface Dust (NADCA Tests)

No.	Category	Return Air (mg/100 cm²)			Supply Air (mg/100 cm²)		
		Before	After	Difference	Before	After	Difference
M01	N1	516.01	2.04	-513.97	1.29	0.10	-1.19
M05	N1	52.75	0.09	-52.66	2.39	0.80	-1.59
M07	N1	151.89	3.32	-148.57	1.87	0.33	-1.54
M12	N1	4.58	0.78	-3.80	2.48	0.00	-2.48
M13	N1	4.58	0.53	-4.05	0.12	0.00	-0.12
M15	N1	4.24			0.15		
M16	N1	0.18	20.27	20.09	26.96	3.40	-23.56
M22	N1	102.53	3.26	-99.27	0.21	2.05	1.84
M04	N2	4.38	8.82	4.44			
M10	N2	11.40	4.26	-7.14	0.94	0.27	-0.67
M14	N2	0.12	0.50	0.38	0.00	0.00	0.00
M17	N2	0.89	0.30	-0.59	0.24	0.92	0.68
M18	N2	51.42	12.44	-38.98	0.83	0.05	-0.78
M26	N2	1.64	6.78	5.14	1.43	0.15	-1.28
M29	N2	11.09	0.27	-10.82	5.77	0.30	-5.47
M06	N3	432.14	168.58	-263.56	0.58	2.54	1.96
M08	N3	1.47	3.25	1.78	0.16	0.18	0.02
M11	N3	0.74	0.53	-0.21	0.66	0.15	-0.51
M23	N3	9.19	0.54	-8.65	1.04	0.27	-0.77
M02	N4	0.38	0.16	-0.22	0.31	0.08	-0.23
M03	N4	140.69	0.10	-140.59	0.66	0.04	-0.62
M09	N4	6.04	0.37	-5.67	0.48	0.35	-0.13
M24	N4	15.95	0.05	-15.90	0.18	0.09	-0.09
M25	N4	1.18	32.28	31.10	0.20	0.32	0.12
M28	N4	0.34	4.29	3.95	0.34	0.36	0.02
M31	N4	1.50	0.13	-1.37	6.43	1.84	-4.59
M19	V1	6.37	11.87	5.50	1.89	0.33	-1.56
M20	V1	123.60	0.29	-123.31	0.84	0.99	0.15
M32	V1	0.77	28.67	27.90	0.25	0.98	0.73
M21	V2	5.91	3.06	-2.85	0.59	1.03	0.44
M30	V3	9.01	0.00	-9.01	0.37	0.00	-0.37
M33	V3	5.52	0.24	-5.28	0.86	0.07	-0.79
M27	V4	430.41	4.46	-4.25.95	0.90	0.21	-0.69
Number		33	32	32	32	31	31
Maximum		516.01	168.58	31.10	26.96	3.40	1.96
Minimum		0.12	0.00	-513.97	0.00	0.00	-23.56
Average		63.91	10.08	-55.69	1.92	0.59	-1.39
No. of values > mg/100cm²		26	16		10	5	
% of values > 1mg/100cm²		79%	50%		31%	16%	

N B. Values below 0 02 mg considered as 0 0 mg, n m. not measured, _ missing data

As shown in Illustration 3.3, the largest reductions in dust occurred in the return air vents where the initial concentrations were the highest. The results where the concentrations increased indicate above all that the return air ducts were not cleaned. For after cleaning tests, the measurement apparatus was placed a few centimeters in from the area chosen for the post-cleaning test and the results indicate normal variations in dust levels for a given duct. In many cases, the spaces cleaned during the NADCA test were still apparent after the cleaning indicating that the surface hadn't even been affected by the cleaning.

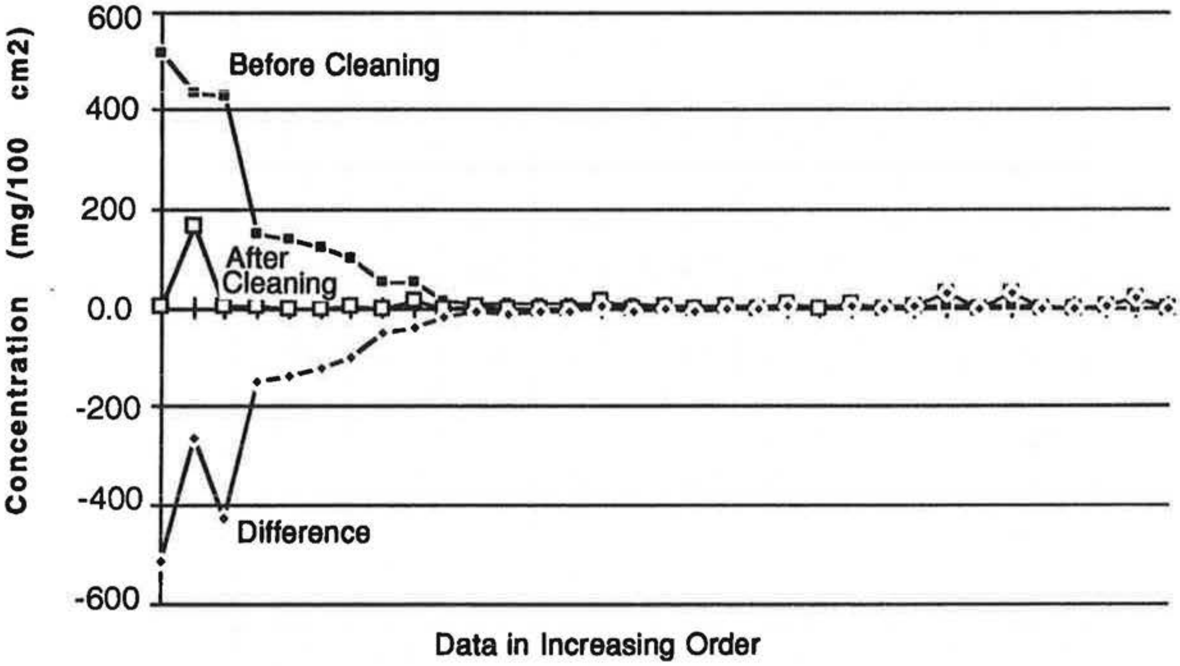


Illustration 3.3: Duct Surface Dust Concentration

Before cleaning, the average dust concentration in the supply air ducts was 1.92 mg/100 cm^2 with a minimum of 0.0 mg/100 cm^2 and a maximum of 27.0 mg/100 cm^2. In 31% of the cases, the supply duct concentrations were higher than the 1 mg/100 cm^2 as recommended by the NADCA. After cleaning, the average dust concentration in the supply ducts was 0.6 mg/100 cm^2 with a maximum of 3.4 mg/100 cm^2 and a minimum of 0.0 mg/100 cm^2. After cleaning, the average concentration in the supply air ducts decreased by 1.4 mg/100 cm^2 and only 16% of the concentrations were above the NADCA recommendation. The reduction in concentration in the supply air ducts is not significant for a confidence interval of 95% (-3.0 to 0.2 mg/100 cm^2).

Analysis of Logarithmic Values

Illustration 3.4 presents a comparison of the duct surface dust concentration distribution in the return air ducts for the gross and logarithmic values. As can been seen, the logarithmic distribution provides a better approximation of concentration values. It is noted that the logarithmic values of the differences indicate a ratio between the before and after concentrations and not the absolute value of the differences.

Before cleaning, the logarithmic average of the dust concentrations in the return air duct is 8.1 mg/100 cm^2, and 0.9 mg/100 cm^2 in the supply air ducts. After cleaning, the logarithmic average of the dust concentrations in the return air ducts is 2.0 mg/100 cm^2, and 0.4 mg/100 cm^2 in the supply air ducts.

Using the logarithmic values, the difference in concentrations in the return air ducts shows a reduction of 6.1 mg/100 cm^2 (compared to a reduction of 55.7 mg/100 cm^2 calculated based on gross values) and a reduction of 0.5 mg/100 cm^2 in the supply air ducts (compared to a reduction of 1.4 mg/100 cm^2 calculated based on gross values). The confidence intervals for the reductions in the logarithmic values of the concentrations in the return air ducts (reduction of 8% to 61%) are significant.

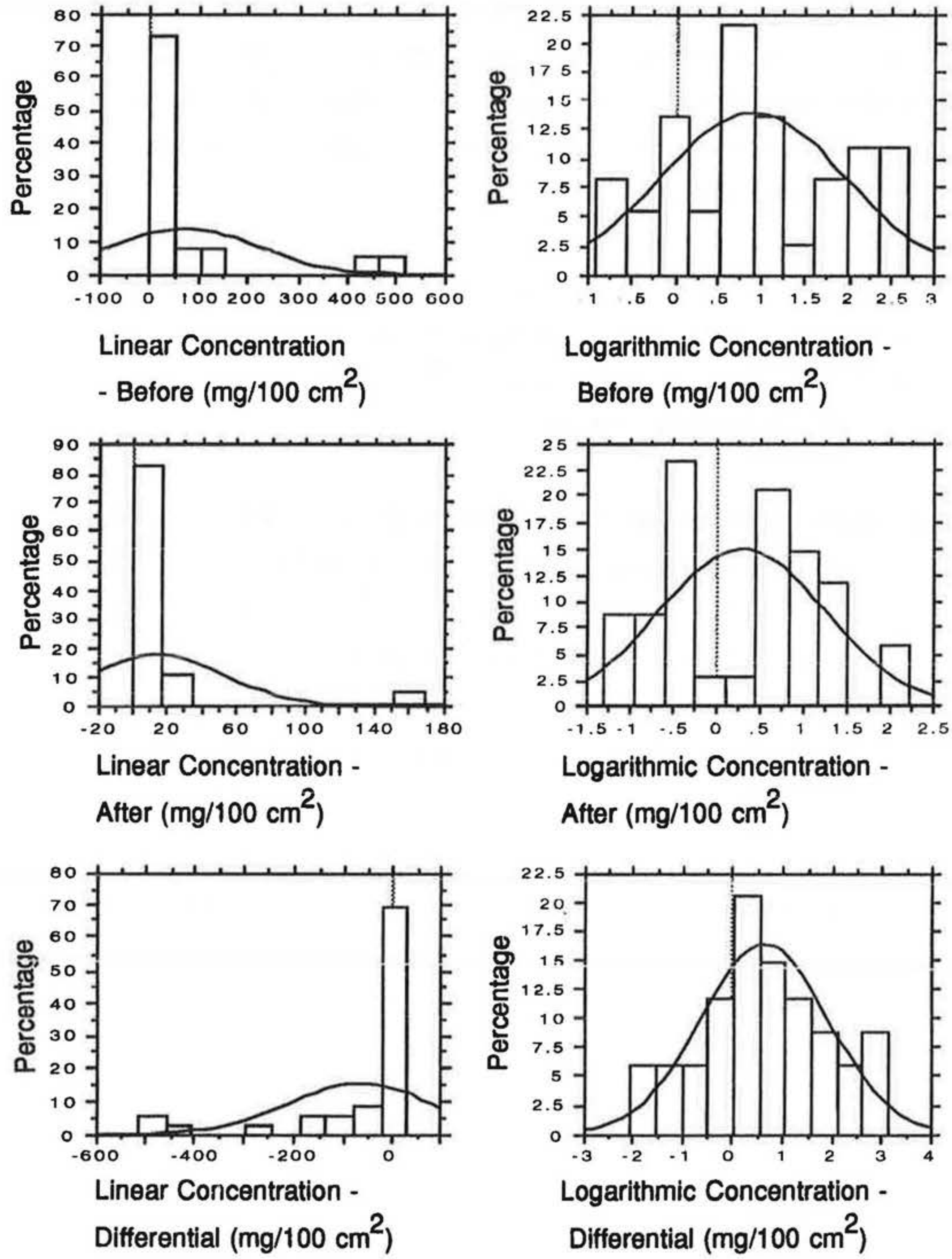


Illustration 3.4: Comparison of linear and logarithmic values of dust on return air duct surface

3.3.3: Dust Measurement at Duct Exit

Table 3.11 provides the results of the dust concentration measurements as the air leaves the supply ducts. The average concentration before cleaning was 0.06 mg/m^3 with a maximum of 1.15 mg/m^3 and a minimum of 0.0 mg/m^3. After cleaning, the average concentration was 0.09 mg/m^3 with a maximum of 2.02 mg/m^3 and a minimum of 0.0 mg/m^3. The average difference before and after the duct cleaning was an increase of 0.03 mg/m^3 with a maximum increase of 1.08 mg/m^3 and a maximum reduction of -0.63 mg/m^3. The increase in dust concentrations is not significant for a confidence interval of 95%. In 55% of the cases, the concentrations had increased after duct cleaning. Before cleaning, 45% of the values were in excess of 0.05 mg/m^3 compared to 48% of the values after cleaning.

The high concentrations of dust as the air leaves the ducts may be caused by several factors. The concentrations will be high if the cleaning loosened up dust in the ducts. Also, when the readings are taken, as the systems were all on, a part of the dust which accumulated on the surfaces could have come loose. Finally, the measurement filters could have drawn in part of the air on the floors or on adjacent surfaces. The effect of the cleaning operation on airborne dust concentrations is discussed in greater detail in the following section.

Table 3.11: Airborne Dust Concentration at Duct Exit

No.	Category	Before			After			Difference		
				Avg.			Avg.			Avg.
M01	N1	0.12	0.09	0.11	0.03	0.05	0.04	-0.09	-0.03	-0.06
M05	N1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M07	N1	0.11	0.04	0.08		0.09	0.09		0.04	0.04
M12	N1	0.07		0.07	0.10	0.11	0.10	0.02	0.11	0.07
M13	N1		0.00	0.00		0.10	0.10		0.10	0.10
M15	N1	0.00	0.04	0.02	0.09	0.00	0.05	0.09	-0.04	0.02
M16	N1		0.06	0.06	0.00	0.06	0.03	0.00	0.00	0.00
M22	N1		0.00	0.00	0.20	0.03	0.11	0.20	0.03	0.11
M04	N2	0.08	0.00	0.04	0.06	0.11	0.09	-0.02	0.11	0.05
M10	N2	0.04	0.08	0.06	0.00	0.05	0.03	-0.04	-0.03	-0.04
M14	N2	0.26	0.00	0.13	0.41	0.00	0.20	0.15	0.00	0.07
M17	N2	0.04	0.03	0.03	0.00	0.04	0.02	-0.04	0.01	-0.01
M18	N2	0.00	0.00	0.00	0.11	0.02	0.06	0.11	0.02	0.06
M26	N2	0.07	0.00	0.04	0.00	0.00	0.00	-0.07	0.00	-0.04
M29	N2	0.07	0.06	0.07	0.00	0.00	0.00	-0.07	-0.06	-0.07
M06	N3	0.00	0.00	0.00	0.03	0.02	0.03	0.03	0.02	0.03
M08	N3	0.02	0.07	0.05	0.07	0.10	0.09	0.05	0.03	0.04
M11	N3	0.21	0.00	0.11	0.00	0.04	0.02	-0.21	0.04	-0.09
M23	N3	0.00	0.00	0.00	0.03	0.00	0.02	0.03	0.00	0.02
M02	N4	0.00	0.00	0.00	0.05	0.08	0.06	0.05	0.08	0.06
M03	N4	0.09	0.00	0.05	0.06	0.05	0.05	-0.04	0.05	0.01
M09	N4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M24	N4	0.02	0.12	0.07	0.07	0.05	0.06	0.05	-0.07	-0.01
M25	N4	0.00	0.08	0.04	0.00	0.03	0.02	0.00	-0.05	-0.03
M28	N4	0.06	0.00	0.03	0.00	0.00	0.00	-0.06	0.00	-0.03
M31	N4	0.00	0.00	0.00	0.34	0.03	0.18	0.34	0.03	0.18
M19	V1	0.00	0.00	0.00	0.06	0.10	0.08	0.06	0.10	0.18
M20	V1	1.15	0.21	0.68	0.03	0.08	0.06	-1.12	-0.13	-0.63
M32	V1	0.06	0.02	0.04	0.02	0.00	0.01	-0.04	-0.02	-0.03
M21	V2	0.00	0.00	0.00	2.02	0.15	1.08	2.02	0.15	1.08
M30	V3	0.02	0.00	0.01	0.07	0.02	0.04	0.05	0.02	0.03
M33	V3	0.02	0.00	0.01	0.15	0.04	0.09	0.12	0.04	0.08
M27	V4	0.11	0.09	0.10	0.04	0.02	0.03	-0.07	-0.06	-0.07
Number		30	32	33	31	33	33	31	33	33
Maximum		1.15	0.21	0.68	2.02	0.15	1.08	2.02	0.15	1.08
Minimum		0.00	0.00	0.00	0.00	0.00	0.00	-1.12	-0.13	-0.63
Average		0.09	0.03	0.06	0.13	0.04	0.09	0.05	0.01	0.03
% > 0.05 mg/m^3		43%	28%	33%	45%	39%	48%			

N.B.: Values below 0.02 mg considered as being 0.0 mg; __ : Missing values or extremely high values

3.3.4 House Airborne Dust Measurement

Measuring airborne dust in houses is discussed in relation to the results obtained by the gravimetric measurements.

The results of dust measurement using the gravimetric method are presented in Table 3.12. In Table 3.12, values in excess or equal to 0.10 mg/m^3 were removed from the final column. These extreme values were removed as they did not correspond to values which were usually posted in studies of dust concentrations in houses. With the extreme values removed, the average concentration before cleaning was 0.03 mg/m^3 and after cleaning the average was 0.02 mg/m^3. The average differential after cleaning was -0.01 mg/m^3 and is not significant at a confidence interval of 95% (-0.3 to 0.02 mg/m^3). If the extreme values are kept, the difference is 0.19 mg/m^3 and is not significant at a confidence interval of 95% (-0.31 to 0.69 mg/m^3). In approximately 60% of cases (extreme values removed or not) dust concentrations increased or remained the same after cleaning. If we compare this to a reference value of 0.05 mg/m^3, used by ASHRAE for office buildings, 33% of the values were above this reference point prior to cleaning and 48% were above this after cleaning. (6)

Table 3.12: Gravimetric Measurements of Airborne Dust

No.	Category	Gross Results			Extreme Values Removed		
		Before	After	Difference	Before	After	Difference
M01	N1	0.09	0.02	-0.07	0.03	0.02	-0.01
M05	N1	0.00	0.03	0.03	0.00	0.03	0.03
M07	N1	0.03	0.17	0.14	0.03		
M12	N1	0.09	0.11	0.02	0.09		
M13	N1	0.00	0.00	0.00	0.00	0.00	0.00
M15	N1	0.06	0.19	0.13	0.06		
M16	N1	0.06	7.69	7.62	0.06		
M22	N1	0.00	0.00	0.00	0.00	0.00	0.00
M04	N2						
M10	N2	0.07	0.04	-0.03	0.07	0.04	-0.03
M14	N2	0.10	0.52	0.42			
M17	N2	0.06	0.00	-0.06	0.06	0.00	-0.06
M18	N2	0.00	0.05	0.05	0.00	0.05	0.05
M26	N2	0.26	0.00	-0.26		0.00	
M29	N2	0.06	0.05	-0.01	0.06	0.05	-0.01
M06	N3	0.00	0.07	0.07	0.00	0.07	0.07
M08	N3	0.07	0.18	0.11	0.07		
M11	N3	0.00	0.00	0.00	0.00	0.00	0.00
M23	N3	0.06	0.00	-0.06	0.06	0.00	-0.06
M02	N4	0.00	0.00	0.00	0.00	0.00	0.00
M03	N4	0.39	0.12	-0.28			
M09	N4	0.00	0.00	0.00	0.00	0.00	0.00
M24	N4	1.56	0.08	-1.47		0.08	
M25	N4	0.11	0.03	-0.08		0.03	
M28	N4	0.23	0.14	-0.09			
M31	N4	0.00	0.10	0.10	0.00		
M19	V1	0.23	0.15	-0.09			
M20	V1	0.00	0.00	0.00	0.00	0.00	0.00
M32	V1	0.00	0.10	0.10	0.00		
M21	V2	0.00	0.00	0.00	0.00	0.00	0.00
M30	V3	0.09	0.00	-0.09	0.09	0.00	-0.09
M33	V3	0.05	0.09	0.04	0.05	0.09	0.04
M27	V4	0.26	0.03	-0.23		0.03	
Number		32	342	32	24	21	17
Maximum		1.56	7.69	7.62	0.09	0.09	0.07
Minimum		0.00	0.00	-1.47	0.00	0.00	-0.09
Average		0.12	0.31	0.19	0.03	0.02	-0.01
% > 0.05		56%	44%		38%	14%	

N.B.: Values under 0.02 mg were entered as being 0.0 mg; __: Extreme values removed

3.4 Measurement of Micro-Organisms

3.4.1 Micro-Organism on Duct Surface

The results of duct surface micro-organism measurements are presented in Table 3.13.

Prior to cleaning, the average concentration of bacteria on the duct surface was 38 CFU/25 cm^2 with a maximum of 793 CFU/25 cm^2 and a minimum of 0 CFU/25 cm^2. After cleaning, the average concentration of bacteria on duct surfaces was 38 CFU/25 cm^2 with a maximum of 227 CFU/25 cm^2 and a minimum of 0 CFU/25 cm^2. The average difference between the before and after tests was nil.

Prior to cleaning, the average concentration of yeast and mould on duct surfaces was 39 CFU/25 cm^2 with a maximum of 200 CFU/25 cm^2 and a minimum of 0 CFU/25 cm^2. After cleaning, the average concentration of yeast and mould on duct surface was 20 CFU/25 cm^2 with a maximum of 104 CFU/25 cm^2 and a minimum of 0 CFU/25 cm^2. The average difference between the before and after tests was -15 CFU/25 cm^2 and was not significant for a confidence interval of 95% (-31 to 1 CFU/25 cm^2).

Adding together the measurements for bacteria, yeast and mould produces a total measurement of the micro-organisms. Prior to cleaning, the average concentration of total micro-organisms on the duct surface was 79 CFU/25 cm^2 with a maximum of 889 CFU/25 cm^2 and a minimum of 1 CFU/25 cm^2. After cleaning, the average concentration of total micro-organisms on the duct surface was 58 CFU/25 cm^2 with a maximum of 320 CFU/25 cm^2 and a minimum of 0 CFU/25 cm^2. The average difference between the before and after tests was -26 CFU/25 cm^2 and was not significant for a confidence interval of 95% (-57 to 4 CFU/25 cm^2).

Table 3.13: Micro-Organisms on Duct Surface

No	Category	Bacteria (CFU/25 cm^2)							Mould (CFU/25 cm^2)							Total Micro-Organisms (CFU/25 cm^2)						
		Before		After		Difference			Before		After		Difference			Before		After		Difference		
		Ret	Supp.	Ret.	Supp.	Ret.	Supp	Avg.	Ret	Supp.	Ret	Supp	Ret	Supp.	Avg.	Ret	Supp	Ret	Supp.	Ret.	Supp.	Avg
M01	N1	80	41	7	45	-73	4	-35	200	200	95	22	-105	6	-50	280	241	102	67	-178	-174	-176
M05	N1	20	37	227	31	207	-6	101	200	200	24	20	-176	-180	-178	220	237	251	51	31	-186	-78
M07	N1		15						4	29						19	39					
M12	N1	71	5	133	0	62	-5	29	38	7	50	6	12	-1	6	109	12	183	6	74	-6	34
M13	N1	23	12	62	6	39	-6	17	81	9	26		-55		-55	104	21	88		-16		-16
M15	N1	18	19	34	49	16	30	23	27	8	26	45	-1	37	18	45	27	60	94	15	67	41
M16	N1		13	10	5	10	-8	1	4	7	7	6	3	-1	1		20	17	11		-9	-9
M22	N1	200	5	66	11	-134	6	-64	200	8	8	4	-192	-4	-98	400	13	74	15	-326	2	-162
M04	N2	56	793	225	156	169	-637	-234	6	96	95	34	89	-62	14	62	889	320	190	258	-699	-221
M10	N2	21	3	24	3	3	0	2	100	8	46	11	-54	3	-26	121	11	70	14	-51	3	-24
M14	N2	12	0	9	11	-3	11	4	1	21	1	3	0	-18	-9	13	21	10	14	-3	-7	-5
M17	N2	4	5	96	20	92	15	54	7	2	7	9	0	7	4	11	7	103	29	92	22	57
M18	N2	13	4	5	16	-8	12	2	8	1	6	1	-2	0	-1	21	5	11	17	-10	12	1
M26	N2	6	11	162	22	156	11	84	17	10	29	13	12	3	8	23	21	191	35	168	14	91
M29	N2	26	11	11	4	-15	-7	-11	55	19	2	10	-53	-9	-31	81	30	13	14	-68	-16	-42
M06	N3	16	6	0	11	-16	5	-6	0	1	0	4	0	3	2	16	7	0	15	-16	8	-4
M08	N3	61	62	110	81	49	19	34	12	14	59	22	47	8	28	73	76	169	103	96	27	62
M11	N3	3	4	1	16	-2	12	5	61	47	8	80	-53	33	-10	64	51	9	96	-55	45	-5
M23	N3	11	3	61	8	50	5	28	80	3	18	16	-62	13	-25	91	6	79	24	-12	18	3
M02	N4	7	106	1	11	-6	-95	-51	6	23	2	104	-4	81	39	13	129	3	115	-10	-14	-12
M03	N4	6	7	0	0	-6	-7	-7	200	6	5	1	-195	-5	-100	206	13	5	1	-201	-12	-107
M09	N4	0	6	28	80	28	74	51	3	12	80	17	77	5	41	3	18	108	97	105	79	92
M24	N4	0	6	34	4	34	-2	16	6	4	10	0	4	-4	0	6	10	44	4	38	-6	16
M25	N4	11	5	0	3	-11	-2	-7	1	2	9	2	8	0	4	12	7	9	5	-3	-2	-3
M28	N4	4	5	16	80	12	75	44	3	1	18	3	15	2	9	7	6	34	83	27	77	52
M31	N4	8	36	2	13	-6	-23	-15	80	80	6	24	-74	-56	-65	88	116	8	37	-80	-79	-80
M19	V1	31	1	9		-22	-1	-12		3	3	1	3	-2	1		4	12				
M20	V1	38	200	80	56	42	-144	-51		9	6	4	6	-5	1		209	86	60		-149	-149
M32	V1	1	1	9	3	8	2	5	0	23	80	2	80	-21	30	1	24	89	5	88	-19	35
M21	V2	0	0	7	19	7	19	13	80	9	7	19	-73	10	-32	80	9	14	38	-66	29	-19
M30	V3	10	4	131	8	121	4	63		2	2	7	2	5	4		6	133	15		9	9
M33	V3	12	20	27	16	15	-4	6	20	21	3	7	-17	-14	-16	32	41	30	23	-2	-18	-10
M27	V4	200	5	0	54	-200	49	-76	2		8	2	6		6	202		8	56	-194		-2194
Number		31	33	33	31	32	32	32	29	32	33	31	32	30	32	28	32	33	30	28	29	31
Maximum		200	793	227	156	207	75	101	200	200	95	104	89	81	41	400	889	320	190	258	79	92
Minimum		0	0	0	0	-200	-637	-234	0	1	0	0	-195	-180	-178	1	4	0	1	-326	-699	-221
Average		31	44	48	27	19	-19	0	52	27	23	16	-24	-6	-15	85	72	72	44	-11	-34	-26

3.4.2 House Airborne Micro-Organisms

The results of measuring house airborne micro-organisms are presented in Table 3.14.

Before cleaning, the average concentration of bacteria in house air was 313 CFU/m^3 with a maximum of 1062 CFU/m^3 and a minimum of 22 CFU/m^3. After cleaning, the average concentration of house airborne bacteria was 232 CFU/m^3 with a maximum of 1144 CFU/m^3 and a minimum of 0 CFU/m^3. The average difference between the before and after tests was -75 CFU/m^3 and was not significant at a confidence interval of 95% (-164 to 15 CFU/m^3). The average concentration of airborne bacteria was higher in the basement (329 CFU/m^3) compared to concentrations measured on the ground floor (296 CFU/m^3).

Before cleaning, the average concentration of yeast and mould in house air was 199 CFU/m^3 with a maximum of 947 CFU/m^3 and a minimum of 6 CFU/m^3. After cleaning the average concentration of yeast and mould in house air was 144 CFU/m^3 with a maximum of 1262 CFU/m^3 and a minimum of 6 CFU/m^3. The average yeast and mould concentration difference between the before and after tests was -45 CFU/m^3 and was not significant at a confidence interval of 95% (-120 to 30 CFU/m^3). The average concentration of yeast and mould was higher in the basement (210 CFU/m^3) compared to concentrations measured on the ground floor (188 CFU/m^3).

Before cleaning, the average concentration of total house airborne micro-organisms was 513 CFU/m^3 with a maximum of 1432 CFU/m^3 and a minimum of 112 CFU/m^3. After cleaning, the average total house airborne micro-organisms concentration was 380 CFU/m^3 with a maximum of 1487 CFU/m^3 and a minimum of 12 CFU/m^3. The average difference between the before and after tests was -167 CFU/m^3 and was significant at a confidence interval of 95% (-293 to -240 CFU/m^3). The average concentration of total micro-organisms was higher in the return air ducts (72 CFU/m^3) compared to a concentration in the supply air duct (44 CFU/m^3). Before cleaning, 11% of the results were in excess of 1000 CFU/m^3 and 5% of the results after cleaning were in excess of 1000 CFU/m^3. The 1000 CFU/m^3 limit is that prescribed by the ACGIH for total micro-organisms.(7)

Table 3.14: Airborne Micro-Organisms

No.	Category	Bacteria (CFU/m)									Mould (CFU/m)								Total Micro-Organisms (CFU/m)							
		Before			After 3			Difference			Before			After 3		Difference			Before			After 3		Difference		
		1st Fl.	Base	Ext.	1st Fl.	Base	Ext.	1st Fl.	Base	Avg	1st Fl	Base.	Ext	1st Fl.	Base.	1st Fl	Base.	Avg	1st Fl.	Base	Ext	1st Fl.	Base	1st Fl.	Base.	Avg
M01	N1	300	412	75	200	325		-100	-87	-94	294	394	150	200	325	-94	-69	-82	594	806	225	400	650	-194	-156	-175
M05	N1	244	875	225	19	200		-225	-675	-450	112	162	531	12	44	-100	-118	-109	356	1037	758	31	244	-325	-793	-559
M07	N1	288	69	62	9	8		-279	-61	-170	131	94	438	206	56	75	-38	19	419	163	500	215	64	-204	-99	-152
M12	N1	506	219	38	562	125		56	-94	-19	94	62	169	294	169	200	107	154	600	281	207	856	294	256	-13	135
M13	N1	187	562	6	162	69		-25	-493	-259	125	538	631	444	469	319	-69	125	312	1100	637	606	538	294	-562	-134
M15	N1	175		150	100	106		-75	106	16	947		481	231		-716	0	-358	1122		631	331		-791		-791
M16	N1	569	612	188	331	600		-238	-12	-125	150	162	794	212	169	62	7	35	719	774	982	543	769	-176	-5	-91
M22	N1	406	525	88	350	806		-56	281	113	225	294	994	69	344	-156	50	-53	631	819	1082	419	1150	-212	331	60
M04	N2	56	793		225	156		169	-637	-234	200	175		1262	812	1062	637	850	256	968		1487	968	1231	0	616
M10	N2	519	506		175	425		-344	-81	-213	744	187		387	212	-357	25	-166	1263	693		562	637	-701	-56	-379
M14	N2	431	381	25	131	19		-300	-362	-311	100	275	394	38	19	-62	-256	-159	531	656	419	169	38	-362	-618	-490
M17	N2	75	81		156	306		81	225	153	112	31	150	31	88	-81	57	-12	187	112		187	394	0	282	141
M18	N2	256	368	75	331	531		75	143	109	369	388	401	69	62	-300	-326	-313	625	776	506	400	593	-225	-183	-204
M26	N2	591			84		19	-507	0	-254	175		125	141		-34	0	-17	766			225		-541		-541
M29	N2	119	200	19	112	562		-7	362	178	6	138	125	44	62	38	-76	-19	125	338	144	156	624	31	286	159
M06	N3	525	538	19	212	238		-313	-300	-307	12	19	94	6	19	-6	0	-3	537	557	113	218	257	-319	-300	-310
M08	N3	106	338	181	194	306		88	-32	28	81	119	688	31	100	-50	-19	-35	187	457	869	225	406	38	-51	-7
M11	N3	38	75	6	44	44		6	-31	-13	406	344	262	131	194	-275	-150	-213	444	419	268	175	238	-269	-181	-225
M23	N3	88	44	19	131	150		43	106	75	138	138	400	44	69	-94	-69	-82	226	182	419	175	219	-51	37	-7
M02	N4	944	381	94	262	350		-682	-31	-357	488	888	1019	112	175	-376	-713	-545	1432	1269	1113	374	525	-1058	-744	-901
M03	N4	81	188	244	0	25		-81	-163	-122	62	62	681	12	50	-50	-12	-31	143	250	925	12	75	-131	-175	-153
M09	N4	157		38	50			-107	0	-54	38		238	19		-19	0	-10	195		276	69		-126		-126
M24	N4	138	138	19	406	238		268	100	184	119	225	194	25	25	-94	-200	-147	257	363	213	431	263	174	-100	37
M25	N4	281		75	22			-259	0	-130	113		425	9		-104	0	-52	394		500	31		-363		-363
M28	N4	1062	231		125	300		-937	69	-434	212	138	144	75	144	-137	6	-66	1274	369		200	444	-1074	75	-500
M31	N4	22		144	44			22	0	11	110		69	75	38	-35	38	2	132		213	119		-13		-13
M19	V1		175	75	306						69	112	81	288		219		219		287	156	594				
M20	V1	647		38	266			-381	0	-191	188		356	25		-163	0	-82	835		394	291		-544		-544
M32	V1	231	159	12	25	25		-206	-144	-175	100	106	75	31	75	-69	-31	-50	331	275	87	56	100	-275	-175	-225
M21	V2	62	131	81	138	138		76	7	42	112	69	188	81	69	-31	0	-16	174	200	269	219	207	45	7	26
M30	V3	69	331	62	69	144		0	-187	-94	69	206	288	25	31	-44	-175	-110	138	537	350	94	175	-44	-362	-203
M33	V3	131	369		25	119	12	-106	-250	-178	25	156	144	31	12	6	-144	-69	156	525		56	131	-100	-394	-247
M27	V4	168	144	162	1144	975		976	831	904	75	175	725	12	75	-63	-100	-82	243	319	887	1156	1050	913	731	822
Number		32	27	27	33	27	2	32	32	32	33	27	31	33	27	33	32	33	32	27	27	33	26	32	26	32
Maximum		1062	875	244	1144	975	19	976	831	904	947	888	1019	1262	812	1062	637	850	1432	1269	1113	1487	1150	1231	731	822
Minimum		22	44	6	0	8	12	-937	-675	-450	6	19	69	6	12	-716	-713	-545	125	112	87	12	38	-1074	-793	-901
Average		296	329	82	194	270	16	-105	-44	-75	188	210	370	142	145	-46	-51	-45	488	538	487	336	425	-160	-123	-167

3.5 Participants' Comments

Comments by the participants were not collected in a systematic manner during the study. Most of these comments were provided spontaneously when their respective houses were visited.

On the whole, the participants did not have a firm opinion concerning the efficiency of the cleaning process but those who did express their opinions said that they were very satisfied or very unsatisfied. The satisfied people said that the cleaning had been done in a professional manner by courteous and clean staff. Among the reasons for dissatisfaction mentioned, the following comments are found:

- the appointment for the cleaning wasn't respected,
- the cleaning caused dust in the house and disrupted normal activities,
- the cleaning team didn't seem to be very concentrated on their work, and
- it smelled like something was burning after the heating was turned on again.

In only one case, a homeowner had the cleaning company come back to do the work over again. Most of the other owners did not feel that they were in a position to judge whether or not the work was acceptable. These homeowners said that they didn't have the tools necessary to check the work.

4. COMBINED ANALYSIS OF RESULTS

This section combines the results of the preceding section to analyze the relations between the various parameters. The main parameters studied are dust and micro-organisms. The results of the analyses are presented in Appendix at the end of the report.

4.1 Duct Surface Dust and Electrostatic Filters

If the duct surface dust concentrations are analyzed based on the presence of an electrostatic filter, it is possible to determine the effect of this filter on the concentrations. The average concentration of return air duct surface dust is 43.4 mg/100 cm^2 for houses with filters compared to a figure of 83.3 mg/100 cm^2 for houses without filters.

The average difference is -40 mg/100 cm^2 but is not significant for the number of data for a confidence interval of 95% (difference of 56 through -135 mg/100 cm^2). The average supply duct surface dust concentration is 3.19 mg/100 cm^2 for houses with filters compared to a figure of 0.80 mg/100 cm^2 for houses without filters. The average difference is 2.4 mg/100 cm^2 but is not significant for the number of data for a confidence interval of 95% (difference of 5.8 to -1.0 mg/100 cm^2).

4.2 Airborne Dust and Electrostatic Filters

The average concentration of airborne dust is 0.04 mg/m^3 for houses with filters compared to a figure of 0.20 mg/m^3 for houses without filters. The average difference is 0.16 mg/m^3 but is not significant for the number of data for a confidence interval of 95% (difference from 0.03 to -0.36 mg/m^3).

4.3 Airborne Dust and Return Air Duct Surface Dust

House airborne dust concentrations were analyzed based on the concentrations of dust on duct surfaces. The results of a regression analysis show that there is no correlation between these two values with a correlation coefficient (r^2) below 0.1.

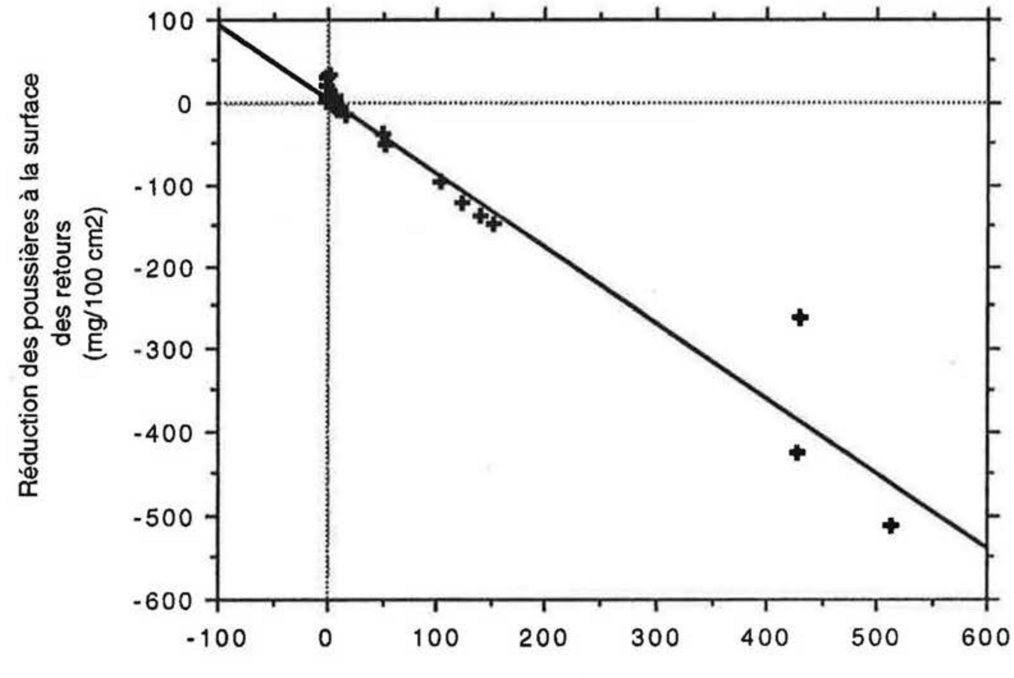
4.4 Dust and House Age

Duct surface dust concentrations were analyzed based on house age. The regression curve used is a linear regression curve with an initial intercept value of 0 mg/100 cm^2 in the year 0.

For both the return air and supply air ducts, the regressions calculated do not show a significant correlation between dust concentration and house age and, at most, they explain 23% of the return air duct measurements and 9% of the supply air duct measurements. However, if we use the values obtained, we obtain a dust concentration increase in the return air ducts of 2.56 mg/100 cm^2 per year, and at this rate, we would obtain a value in excess of 1 mg/100 cm^2 after only 5 months. If we use a regression without arbitrarily choosing the initial intercept value as zero, we obtain a different equation which predicts an accumulation of over 1 mg/100 cm^2 after four years ($Y = -10.589 + 2.917 \times X$; $r^2 = .054$). In the supply air ducts, this accumulation amounts to 0.06 mg/100 cm^2 per year and we would obtain a value of 1 mg/100 cm^2 after only 2 months.

4.5 Reduction in Duct Dust and Dirt

Illustration 4.1 shows reductions in dust concentration on return air duct surfaces which were analyzed by comparing them with the initial dust concentration. A regression which was charted shows that the reduction in concentrations are dependent on the initial concentrations. The dirtier the ducts to begin with the more effective the cleaning will be. The linear regression shows a reduction of 0.9 mg/100 cm^2 for each mg/100 cm^2 of dust initially found on the ducts and explains 95% of the results. According to the equation, the reduction in dust on duct surfaces is obtained only for concentrations above 4 mg/100 cm^2.



Initial dust on Return Duct Surfaces (mg/100 cm^2)

$Y = 3.636 - .902 * X; R^2 = .954$

Illustration 4.1: Reduction in Return Air Duct Dust and Initial Concentrations

4.6 Increase in Flow Rates and Dust Concentrations on Duct Surfaces

To compare the efficiency of duct cleaning using increases in return air flow rates, the ducts with initial concentrations in excess of 20 mg/100 cm^2 are classified as being "dirty" and the others as being clean.

The calculations indicate that the return air flow rates in the "dirty" ducts increased an average of 7 L/s compared to 1 L/s for the clean ducts. On the average, the flow rates for "dirty" ducts increased over 6 L/s in relation to clean ducts but this difference is not significant at a confidence interval of 95% (-2 to 14 L/s).

The calculations made for all the return air flow rate differences and the dust concentrations initially found in the return air ducts (not presented) did not indicate any correlation.

4.7 Micro-Organisms and Dust

A multiple correlation was run to determine if the quantities of total (airborne and surface) micro-organisms present prior to the cleaning were related to dust concentrations on duct surfaces, at duct exits or in the house air. Calculations show that only the micro-organisms on duct surfaces increased in proportion to the amount of dust on the return air duct surfaces.

4.8 Micro-Organisms and Humidifier

Calculations compared total micro-organism concentrations for the houses with humidifiers. The results showed that concentrations of total micro-organisms on duct surfaces was 26 CFU/25 cm^2 higher for houses with humidifiers. The 95% confidence interval indicates that the difference is not significant (-58 to 111 CFU/25 cm^2). The concentrations of total micro-organisms in the air was 70 CFU/m^3 lower for houses with humidifiers but the 95% confidence interval indicates that the difference is not significant (-182 to 324 CFU/m^3).

5. DISCUSSION OF RESULTS

5.1 Ventilation

On the average, the differences in fan pressure did not increase subsequent to cleaning the ducts but rather remained the same. The pressure difference posted by the fan cleaning category (category V) was +21 Pa but is not significant for a confidence interval of 95% due to the number of data available. These results indicate that, on the average, duct cleaning does not increase the pressure differences available for fans and that fan cleaning alone may be more efficient to attain this objective.

The -0.14 A fan amperage differential was not significant to a confidence interval of 95%. For Category V, the difference was -0.46 A but was not significant due to the number of data available. The voltages measured did not vary any more than 5 V during the tests. Since the voltages measured were relatively constant, the fact of cleaning the ducts did not significantly reduce energy consumption and may even have increased it.

The supply air flow rates increased by 1 L/s but this increase is not significant at a 95% confidence interval. In 50% of cases, the supply air flow rates were reduced. Cleaning the fan alone generated an increase of 3 L/s (6 cfm) but this increase is not significant. Thus cleaning the ducts did not have a significant influence on the supply air flow rates.

The return air flow rates increased by 3 L/s but this increase is not significant at a 95% confidence interval. In 44% of cases, the return air flow rates were reduced. Cleaning the fan alone generated an increase of 2 L/s but this increase was not significant. Thus cleaning the ducts did not have a significant influence on return air flow rates.

Measuring ventilation parameters serves to identify the combined effects of a number of factors which influence variations in pressure, amperage and flow rates. These factors include effects produced by dust (see following sections) but also those produced by the changes made in the systems dampers and registers. One may assume that the affects of the modifications in the dampers and registers may be more important than those due to the dust. It would thus be more profitable for the owners to have the ventilation dampers and registers adjusted than to have the system cleaned if they wanted to improve the air distribution in their houses.

5.2 Dust

Dust concentrations in the ducts decreased significantly in the return air ducts but not significantly in the supply air ducts. In the return air ducts, the reduction was 56 mg/100 cm^2 for the gross values and 6.1 mg/100 cm^2 if we use a lognormal distribution. In the supply air ducts, the reduction was 2.3 mg/100 cm^2 (not significant) for gross values of 0.5 mg/100 cm^2 if we used a lognormal distribution.

For the return air ducts, 28% of the concentrations after cleaning had increased and 31% of the concentrations in the supply air ducts. These increases indicate, as we have observed in the field, that certain ducts were not even touched by the cleaning.

According to NADCA recommendations, 79% of the return air ducts needed to be cleaned and 31% of the supply air ducts. Even after the cleaning, 50% of return air ducts and 16% of the supply air ducts required further cleaning. These results throw into doubt the value used by the NADCA in their recommendation indicating either that the recommendation is too strict or that the cleaning companies are not capable of attaining this objective. The duct surface dust measurements indicate that duct cleaning must be a priority for owners and that the supply air ducts are likely to require cleaning.

Dust measurement tests with a direct reading instrument demonstrated that dust concentrations generated by cleaning increased in the house but decreased rapidly after the cleaning. The period during which the dust concentration declined was less than one day in the cases studied.

Dust concentrations at duct exits increased by 0.03 mg/m^3 (an insignificant difference) subsequent to duct cleaning. This increase may be due to cleaning activities which contributed to loosen the dust on the duct surfaces.

House airborne dust measurement results show that the concentrations were reduced by 0.01 mg/m^3 (not significant) following the fan cleaning procedure. Cleaning did not have a significant effect on house airborne dust concentrations.

5.3 Micro-Organisms

Micro-organism measurements included measurements taken on duct surfaces and house airborne measurements. The total micro-organisms on duct surfaces were reduced by 26 CFU/25 cm^2 after cleaning but this difference was not significant. Concentrations on the return air duct surfaces were slightly higher than those in the supply air ducts. Cleaning the ducts thus did not have a significant affect on duct surface concentrations. The total quantity of house airborne micro-organisms was reduced by 167 CFU/m^3 after cleaning and this difference was significant. Basement concentrations were slightly higher than those on the ground floor. The reduction in airborne micro-organisms may have been caused by cleaning but may also be due to other facts such as lower outdoor concentrations or the increased ventilation of the house due to the duct cleaning. On the whole, most of the concentrations observed were below the recommendations mentioned above and the cleaning improved a situation which, to begin with, was not alarming.

5.4 Combined Analyses

The combined analyses made it possible to identify the effect of cleaning on a series of factors considered together. The most significant results of the analysis were the results obtained for dust.

Dust reduction in return air ducts is influenced directly by the quantity of dust initially on the duct surfaces and this influence is significant. An average reduction of 0.9 mg/100 cm^2 for each milligram per 100 cm^2 of accumulated dust can be expected. Based on the same relation, dust reductions for all the cleaning techniques together are only effective for concentrations in excess of 4 mg/100 cm^2. In other terms, all the cleaning techniques are only effective for concentrations in excess of 4 mg/100 cm^2.

It is also observed that, if ducts with more than 20 mg/100 cm^2 of dust in the return air ducts are considered "dirty", cleaning the "dirty" return air ducts will increase the return air duct air flow rate by 7 L/s compared to 1 L/s for clean ducts. The difference is not significant but indicates nevertheless that cleaning the dust in the "dirty" return air ducts produces a larger air flow rate increase than in "clean" ducts.

6. SUMMARY

The study made it possible to measure and compare the parameters influenced by cleaning house ventilation ducts. The study concludes that there is no significant change in the flow rates (return air and supply air ducts) nor in the heating system's amperage nor in duct airborne dust concentrations, neither for house airborne dust concentrations nor surface dust concentrations in the supply air ducts. For all the parameters measured and for the average measurements, cleaning produced significant improvements in only two parameters, i.e., dust concentration in the return air ducts and airborne micro-organisms concentrations. For dust concentration in the return air ducts, the cleaning techniques proved to be efficient to reduce the concentrations below 4 mg/100 cm^2. Reductions in airborne micro-organisms could not be linked dust measurements and this reduction may be due to seasonal temperature variations, to the aspiration effect produced by cleaning the ducts or to an unknown factor.

For the consumer, the results indicate that **a cleaning technique which concentrates on the return air ducts and the fan may be the most efficient solution**. To verify the quality of a cleaning operation, a visual assessment of the state of the return air ducts by the owners may be sufficient. However, the technical means used by our study are too complex and expensive to be used by consumers, and simplified methods should be developed based on results of our study.

According to the results presented here, a certain number of parameters would merit further study in the future. As for the cleaning techniques, a larger sampling would make it possible to determine the effectiveness of the various cleaning techniques identified, something which could not be done in this study. If we can validate the relation between dust removal in the return air ducts and initial dust concentration, we could develop an easy test for determining whether the concentrations are in excess of 4 mg/100 cm^2. This value could also be used by the NADCA as a reference point, as it indicates the real concentration which is feasible for the cleaning companies. Finally, the effect of cleaning on the concentrations of airborne micro-organisms is not clear and would merit a more detailed study.

REFERENCES

1. Luoma, M., et al., "Duct Cleaning - a Literature Survey," Air Infiltration Review, volume 14, No. 4, September 1993.

2. Ahmad, I., Tansel, B., Mitriani, J.D., "Case Study of HVAC Sanitation procedures on Indoor Air Quality of Selected Residential Buildings," ASHRAE Transactions, 1993.

3. W.C. McDonald M.D. Ph.D, "Report on the Reduction of Microorganisms on Hard Surfaces in Air in an Urban Residence Following the Proprietary Steamatic Cleaning Process", STEAMATIC, July 1988.

4. W.C. McDonald M.D. Ph.D, "Report on the Reduction of Microorganisms in Air in an Urban Residence Following the Proprietary Steamatic Cleaning Process", STEAMATIC, September 1988.

5. "Mechanical Cleaning of Non-Porous Air Conveyance System Components," NADCA, 1992-01.

6. "Ventilation for Acceptable Indoor Air Quality," American Society for Heating, Refrigerating, and Air-Conditioning Engineers, ASHRAE Standard 62-1989.

7. "Report of the Committee on Bioaerosols," Annual American Conference of Governmental Industrial Hygienists, volume 13, 1985.

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