RESEARCH REPORT

Indoor Particulate and Floor Cleaning

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INDOOR PARTICULATE and FLOOR CLEANING

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EXECUTIVE SUMMARY

Short-term respirable and inhalable fine particle matter (PM) exposures appear to be related to health outcomes. Indoor exposures to PM may be more important than outdoor exposures from a dose point of view because the portion of time spent indoors exceeds 90% for most individuals.. Indoor exposure to PM is influenced by "resuspension" activities such as cleaning or walking.

Homeowners are presented with an array of advice from a variety of sources as to type of flooring and type of cleaning device that would best reduce their personal exposure to PM. For a person who is suffering from a respiratory medical condition, this can be considered to be medical advice.

Cleaning effectiveness studies have measured the PM remaining on a surface after cleaning and the airborne PM during cleaning. Some studies evaluated airborne PM change after cleaning by measuring the 8 hour average of PM resuspended by the activity of the house occupants.

The conventional approach to evaluating cleaning effectiveness involves seeding the floor with a known weight of artificial dust. The floor surface is cleaned and the mass of dust remaining is measured. It is possible that the artificial dust does not represent respirable and inhalable PM size fractions appropriately and that the method does not evaluate the extent to which PM is likely to be resuspended from the surface after the cleaning activity is complete.

The objective of this study is to evaluate several cleaning methods on several surfaces with respect to their relative effect on the PM exposure of an individual living in the home. Secondarily, the study seeks to demonstrate a new approach to evaluation of floor cleaning methods by using a "standard activity" to quantify PM resuspension from the floor on the premise that more effective cleaning would result in less resuspension after cleaning.

All of the experiments are based on five homes in Brantford Ontario and the test conditions replicate typical southern Ontario Canadian spring, fall and winter conditions. The cleaning devices were employed in a manner which is representative of normal cleaning practice. Over 1300 experiments involving six electrically powered and four non-powered cleaning devices were carried out. The experiments consisted of a "simulated activity" prior to cleaning, cleaning of the floor and a simulated activity immediately following cleaning. Cleaning was carried out weekly in one room of each house by the same operator using a different device each week. At a pre-determined point in the sequence, the carpeted floor was replaced by a smooth floor and the cleaning program was repeated.

Results show that carpeted floors exhibit higher levels of PM resuspension that smooth floors in all size ranges except that this tendency is not so pronounced for very fine (PM1) particles. The tendency for a floor to accumulate particles over time appears to be much more pronounced for carpeted floors than for smooth floors and is also varies greatly from house to house. Based on limited data, it appears that new carpet exhibits lower PM resuspension rates than old carpet and slightly higher PM resuspension rates than smooth floors. It is possible that the higher accumulation rate for carpets is responsible for their higher resuspension rates with aging.

The ordinary house broom was found to have high PM resuspension rates during use, but the cleaning effectiveness was similar to other devices. Dry or wet pad smooth floor sweeping devices were not found to have better effectiveness than a conventional dust-mop.

Higher-cost vacuum cleaner with special filters and other features were not found to have higher performance than other devices except in one limited case. When cleaning effectiveness after one week's elapsed time was evaluated it was found that the ordinary upright vacuum cleaner had higher cleaning effectiveness on smooth floors than all of the other cleaning devices.

Other than the performance of the ordinary upright vacuum cleaner there was no apparent difference between the performance of vacuum cleaners and sweeping devices on smooth floors.

RÉSUMÉ

LE NETTOYAGE DES PLANCHERS ET LES PARTICULES INTÉRIEURES

L'étude avait pour objectif d'évaluer plusieurs méthodes de nettoyage de surfaces en vue de déterminer l'effet d'exposer l'occupant de la maison à la matière particulaire. En deuxième lieu, l'étude visait à démontrer une nouvelle technique d'évaluation des méthodes de nettoyage des planchers à l'aide d'une « activité standard » pour quantifier les particules du plancher remises en circulation, en fonction du principe qu'un nettoyage plus efficace entraîne moins de remise en circulation des particules après le nettoyage.

Toutes les expériences ont été fondées sur cinq maisons situées à Brantford, en Ontario, et les conditions d'essais ont reproduit les conditions types du sud de l'Ontario au printemps, en automne et en hiver. Les appareils de nettoyage ont été utilisés de façon représentative des méthodes de nettoyage habituelles. Plus de 1 300 expériences menées avec six appareils de nettoyage électriques et quatre appareils manuels ont été effectuées. Les expériences comprenaient une « activité simulée » avant le nettoyage, le nettoyage proprement dit du plancher et une activité simulée tout de suite après le nettoyage. Le nettoyage a été effectué à intervalle hebdomadaire dans une pièce de chaque maison par le même préposé qui faisait usage d'un appareil différent à chaque semaine. À un stade préétabli au cours de la séquence, le plancher revêtu de moquette a été remplacé par un revêtement de sol lisse et le programme de nettoyage a été répété.

Les résultats indiquent que les sols revêtus de moquette affichent des taux plus élevés de matière particulaire remise en circulation que les sols lisses, quelles que soient les gammes de superficies, sauf que cette tendance n'est pas aussi prononcée à l'égard des particules très fines. La tendance qu'un sol accumule les particules au fil du temps semble beaucoup plus prononcée pour les sols revêtus de moquette que pour les sols lisses et varie grandement d'une maison à l'autre. D'après les données limitées, il appert que la moquette neuve enregistre un taux moindre de matière particulaire remise en recirculation que la vieille moquette, mais légèrement plus que les sols lisses. Il est possible que le taux d'accumulation supérieur des moquettes explique leur plus forte quantité de matière particulaire remise en circulation à mesure qu'elles vieillissent.

On a découvert que l'emploi du balai ordinaire entraînait un taux élevé de remise en circulation de matière particulaire, mais que l'efficacité du nettoyage ressemblait à celle des autres méthodes. On n'a pas constaté que les appareils de balayage des sols lisses à l'état sec ou mouillé permettaient d'obtenir une meilleure efficacité que la vadrouille classique.

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CONTENTS

1 OVERVIEW, DISCUSSION OF OBJECTIVES

1.1 Introduction

Other research has identified a relationship between short-term respirable and inhalable particle matter (PM) exposures and health outcomes (Ref. 2). Indoor fine particles can consist of dander, allergens, chemical substances, mineral particulate, viruses and bacteria. Given that the portion of time spent indoors exceeds 90% for most individuals (Ref 23), indoor exposures to fine particles may be more important than outdoor from a total dose point of view. It can be argued that from an indoor air quality point of view, a large portion of a person's exposure to sensitizing, irritating or toxic substances comes from the generation and resuspension of particles inside the home.

Previous studies have shown that personal exposure to PM is influenced by the activities undertaken in the home. In particular, researchers have shown that higher exposure to PM occurs with activities such as cleaning or walking especially if taking place on carpeted floor (Ref. 8, Ref. 1). These activities are generally referred to as "resuspension" activities as opposed to "generation" activities.

Homeowners are presented with an array of advice as to type of flooring, type of cleaning product and cleaning methods that would best reduce their personal exposure to indoor PM. This advice comes from the commercial sector (advertising, product claims) as well as the care-giving sector (medical doctors, public health providers). In the case of a person who is suffering from a medical condition such as asthma, COPD, allergies or chemical sensitivities, this type of advice can be considered to be medical advice.

A search of published research found several studies of cleaning effectiveness (Ref. 12). Some studies examined the quantity of PM remaining on a surface after the cleaning activity (Ref. 13, 12) and other studies reported airborne PM levels during the cleaning activity (Ref. 12, 7, 4, 10, & 8). Some studies, notably reference 9 with respect to carpeted floors and reference 7 with respect to smooth floors, also measured particle rise due to activity before and after the cleaning. Both of these studies used gravimetric (8 hour average) PM level quantification methods and they relied on the random activity level generated by the occupants of the house.

The conventional approach to evaluating floor cleaning effectiveness is reflected in the ASTM Vacuum cleaner test (Ref. 11) and the testing approach used by Consumer's Union in their ongoing tests of vacuum cleaners (Ref. 12). In the conventional testing approach, a floor surface is seeded with a known weight of an artificial dust material. The floor surface is cleaned and then weighed and the amount of artificial dust remaining in the sample is ascertained by comparing the final weight of the sample with the pre-test weight of the same sample.

There are several problems with this approach. The first is that the experimental dust may not represent the environmental PM size fractions that are at issue with respect to the exposure of individual during their normal occupation of a home. The second is that the method does not evaluate the extent to which PM is likely to be resuspended from the surfaces after the cleaning activity has been completed. Simply put, we should be interested in exposure of the occupant to PM rather than the PM that is in the carpet or on the floor.

A better understanding of how various cleaning devices and flooring materials impact on PM exposure of the occupants as they carry out their normal activities would assist homeowners in making informed choices about cleaning devices and practices.

1.2 Objectives

The primary objective of the study is to answer the following questions:

a) Does the floor cleaning method affect the exposure of a person to fine particles:
   -during the cleaning action, or
   -during ordinary activity

b) Does the type of floor material affect the exposure of a person to fine particles:
   -during the cleaning action, or
   -during ordinary activity

The secondary objective of this study is to demonstrate a new approach to evaluation of floor cleaning methods by using a "standard activity" to quantify the effectiveness fo a particular floor cleaning device in reducing the exposure of the occupant to PM.

1.3 Limitations

All of the experiments are based on five homes in Brantford Ontario Canada. The test conditions replicate typical southern Ontario spring, fall and winter conditions. Windows were closed in all rooms for duration of testing. All 5 houses have gas forced air heating systems. No air conditioning systems were operated during any of the testing days. The houses were occupied during the experiments but there were no smokers living in the homes and two of the homes had pets. Additional information on the house characteristics is given in Appendix A.

The cleaning devices used in this study were employed in a manner which the authors deemed to be representative of a person's normal practice in carrying out household cleaning. With the exception of the "Dirt Finder Indicator Light experiment" no attempt was made to carry out intensive or otherwise unusual cleaning procedures.

1.4 Influences on Indoor Fine Particle Levels

The level of indoor fine particles at any given moment in time is influenced by:

a) Entry via House Envelope

Airstreams entering the occupied zone via the house envelope may contain more or less fine particles depending on the level of outdoor fine particles and the removal of particles by the building components as the air passes though them. Some authors (Refs 5 and 6) have estimated the filtration effect to be negligible, while others (Ref. 4) have estimated the filtration rate to vary between 6 and 88%, depending on particle size. Outdoor particle levels may vary by a factor of 10 or more from day to day and from hour to hour.

b) Internal Generation

Internal generation arises primarily from cooking and combustion (candle burning, smoking) activities. Particles are also generated arising from human & pet dander. Chemical substances, such as pesticide residue, and heavy metals can be tracked into the home. Pollen, bacteria, molds, and allergens contribute to biological pollutants. Generation usually occurs when the house is occupied and the occupants are active.

c) Resuspension
Resuspension arises from the movement of the occupants in the home during periods of activity. The re-suspended particles are those which are stored on surfaces and materials, are easily re-suspended and which have low settling rates. These particles may include the afore-mentioned internally generated particles , particles of outdoor origin which have entered by being tracked in by the occupants, or particles which enter as part of an infiltration or ventilation airstream.. It is theorized that if particle entry and generation can be minimized, then resuspension will also be reduced over time, due to the removal of particles from the house by cleaning activities.

d) Removal by Settling
Particles are removed by settlement on the available surfaces in the house. The rate of removal depends on the available surfaces and the settling rate of the individual particles.

e) Storage
Once settled, particles are stored and are then available for resuspension. Carpets are theorized to have greater storage capacity than hard flooring. The deep matrix of the carpet pile and fibers may render the stored particles less able to be re-suspended. Hard flooring, on the other hand, is theorized to have a lesser storage capacity than carpet, however, any stored particles might be more easily re-suspended owing to the lack of deep surface matrix.

f) Removal by Filtration
A central air handling system equipped with a fine-particle air filter, or a local (in-room) fine particle air-filter may be used to remove particles.

g) Removal by Exhaust/exfiltration
Particles are also removed from a space by air which leaves the space by exfiltration through the building envelope or via an intentional device such as an exhaust fan. It should be understood that this only results in a net reduction of indoor particles when the air replacing the removed air contains less particles. In many cases the outdoor level of PM is higher than the indoor level so that the exchange of air may actually increase the indoor PM level.

2 METHODS

2.1 House Selection

Five houses were selected for the experiment. Five physical houses were used and two separate bedrooms were used in house 3. Criteria for inclusion in the study was:

1) Presence of a carpeted room that could be closed off from the rest of the home
2) Owner will replace carpet with smooth floor at appropriate time.
3) Home available for testing for 10 consecutive weeks
4) Non-smoking home.

Detailed information on the house characteristics is given in Appendix A.

2.2 Stage 1: Development of Activity Simulation Method

The normal activities of persons within a home are by nature variable. In order to assess the influence of a cleaning method on "normal" activity, it was necessary to rely on a "standard" activity which was as repeatable as possible. While the standard activity simulation is designed to be representative of normal activity it is not intended to be a strict surrogate, rather it is intended to be tool which allows comparison between cleaning devices and techniques without the need to conduct large numbers of experiments.

The development of this standard activity situation method is described in detail in Appendix B.1. Based on the results of these experiments, two similar "Activity Simulation" Methods were selected for use in the remaining phases of the study:

Method 1 - Battery-Powered Vacuum and Remote-Controlled Vehicle:
A battery-powered remote control vehicle was modified to drag a modified portable battery-powered vacuum cleaner for fifteen minutes in a repeating pattern. Details of modifications to the remote-control vehicle and the battery-powered vacuum cleaner are set out in appendices C.1 and C.2. The researcher controlled the movement of the truck with a remote control device while stationed in one corner of the room. All of these experiments were carried out by a single operator. This method was restricted by the turning radius of the remote-controlled vehicle and was used only in house 2.

Method 2 - Battery-Powered Vacuum and Walk-about:
The modified battery-powered vacuum cleaner used in method 1 was moved in a repeating pattern around the room by a researcher at a "walking" pace for 15 minutes. This method was only repeatable for one operator, that is to say an activity simulation carried out by one operator was not consistent with an activity simulation carried out by another person. In order to remove these inconsistences, each house was assigned a single researcher, who carried out all of the experiments for that house. This method was used in all houses except house 2.

2.3 Stage 2: Pilot Study: 2 Houses

A set of powered and non-powered cleaning devices was chosen to represent a range of products currently on the market. Consideration was given to:

- purchase price,
- presence or absence of filters,
- model characteristics, and
- ease of use.

A total of six electrically powered cleaning devices were tested on both carpeted and smooth floors. Four non-powered cleaning devices were tested on smooth floors only. The powered devices are listed in Table 1 and the non-powered devices are listed in Table 2 following. The experiment sequence is set out in Table 3.

TABLE 1
Powered Cleaning Devices

Code	Type	Description	Notes
V1	Filter cannister	"Samsung Quiet Storm" cannister model VAC9013BP, bag, 5 stage filter system, electric power brush, hand tools	Top-rated cannister vacuum in Consumer Reports[1]
V2	Ordinary upright	"Panasonic QuickDraw" upright model MC 5315C, bag, exhaust filter, beater bar	Example of an ordinary vacuum with regular bag and no special features
V3	HEPA bagless	"Phantom Lightning" model LC91 31, stair cannister model, bagless, HEPA filter, exhaust filter, power brush can be turned on and off, hand tools	Example of HEPA cannister vacuum
V4	Central	"Broan Central Vacuum" model V23C, collection cannister, no bag, exhaust to outside, power brush, w/on-off switch, hand tools	Typical central vacuum
V5	Filter upright	"Hoover Wind-tunnel Supreme" model U5450-955, upright vacuum, 3 layer filter bag, 2 layer exhaust filter, hand tools	Replaced top-rated upright tested (Ultra) by Consumer's Reports[2]
V6	Wet vacuum	Hoover Steam Vac Supreme" model F839-900, Wet/Dry Upright Vacuum, Dirty water collection bucket, No filter per se., 1 hand tool	Example of "wet vacuum"
V7	Dirt-finder upright	"Hoover Wind-tunnel Supreme" model U5450-955, upright vacuum, as for V5 except operated until embedded dirt finder (indicator light) changed to "no dirt" indication	see V5

TABLE 2
Non-Powered Cleaning Devices

Code	Type	Description	Method
B1	Dry pad	"Swiffer" disposable dry cloths inserted onto stick broom with articulating pad	Swipe floor with 2 strokes and move to next area. Use one per room.
B2	Wet pad	"Swiffer Wet" disposable damp cloths inserted onto stick broom with pad	Swipe floor with 2 strokes and move. Use 1 per room
B3	Dust mop	Cedar "Zoom a-Lon". Yellow cotton yarn attached to removable articulating head that can be removed to be washed	Swipe floor with 2 stroke and move to next area. Pick up any dust piles not on mop.
B4	Broom	"Rubbermaid" angled polybristle broom	Sweep 2 strokes towards cleaner, lift and move to next area. Pick up dust pile

1 Consumers Reports January 2001

2 Consumers Reports January 2001

TABLE 3 Pilot Study (Stage 2, 2 House) Devices & Sequence		
Week	**Device**	**Floor**
1	V1 - Filter cannister	carpet
2	V2 - Ordinary upright	carpet
3	V3 - HEPA bagless	carpet
4	V4 - Central	carpet
5	V5 - Filter upright	carpet
6	V6 - Wet vacuum	carpet
7	V7 - Dirt finder upright	carpet
8	V1 - Filter cannister	Smooth
9	V2 - Ordinary upright	Smooth
10	V3 - HEPA bagless	Smooth
11	V4 - Central	Smooth
12	V5 - Filter upright	Smooth
13	B1 - Dry pad	Smooth
14	B2 -Wet pad	Smooth
15	B3 - Dust mop	Smooth
16	B4 - Broom	Smooth

The wet vacuum (V6) was not tested on smooth floors. One vacuum cleaner (V5) was equipped with a dirt indicator light. One additional test was conducted to assess the effect of vacuuming until the dirt indicator light changed from "dirty" to "clean". This cleaning technique was used in Stage 2 of the study only and was assigned the code "V7".

One experiment with a new carpet was carried out in House 2. In one of the Stage 3 cases (H3U) was a new carpet was installed in place of a smooth floor. The results are reported in Section 3.6.

2.4 <u>Stage 3: Follow-on study of 4 additional houses</u>

Based on the results of Stage 2, a reduced set of cleaning devices was selected. B3 was removed from the experiment cycle as the stage 1 results were virtually identical to the results for B1. V1 was removed from the experiment on the basis that it's Stage 2 results were similar to V3 and V4. V5 was removed from the experiment cycle because it's results were significantly poorer than the other upright vacuum in the program (V2).

In fact, only three physical houses were tested in Stage 3. The experiment is presented as four houses because two separate bedrooms were tested in house #3. These rooms appear in the experimental data as H3U (upstairs bedroom) and H3D (downstairs bedroom).

One of the Stage 3 houses (H3U) did not have a smooth floor experiment. In this house, the old carpet was replaced by a new carpet rather than a smooth floor.

The cleaning schedule for the Stage 3 houses is set out in Table 4 following:

TABLE 4
Follow-on Study (Stage 3, 4 House) Devices & Sequence

Week	Device	Floor
1	V2 - Ordinary upright	carpet
2	V3 - HEPA bagless	carpet
3	V6 - Wet Vacuum	carpet
4	V4 - Central	carpet
5	V2 - Ordinary upright	smooth
6	V3 - HEPA bagless	smooth
7	V4 - Central	smooth
8	B1 - Swiffer pad	smooth
9	B2 -Wet pad	smooth
10	B4 - Broom	smooth

2.5 Particulate Sampling Method

Particle concentrations were measured using a laser particle counter with the sampling point located in the subject bedroom approximately 1.2 metres above the floor. Counts were obtained in 4 size ranges beginning at 0.3 µm at intervals of 75 seconds. Sampling was carried out continuously during each experiment, and the experimental values were extracted from the data by comparing the researcher's recorded time and activity descriptions with the output data. Additional details concerning the sampling instrumentation can be found in Appendix C.3.

2.6 Experiment Sequence

A detailed account of the experiment is set out in appendix B.3. An abbreviated description of the experiment sequence is as follows:

1) Prepare Test Room
- set up particle counter
- seal air ducts
- close windows and doors
- begin particle level measurement
- exit room for minimum 15 minutes

2) Pre-Cleaning Activity Simulation
- re-enter room and carry out 15 minute activity simulation

3) Device Testing
- enter room 15-20 minutes after activity simulation completed
- carry-out device cleaning activity,
- cleaning intensity 0.67 to 1.0 minutes per m^2
- record start and stop times
- exit room for minimum 15 minutes

4) Post Cleaning Activity Simulation
- re-enter room and carry out 15 minute activity simulation

5) Take-Down
- re-enter room after 15 minutes.
- stop particle measurement, recover instruments
- return room to normal

2.7 Data Quality

A protocol was established to identify excessive variations in the experimental results due to variations in the airflow of the activity simulator. These variations might arise due to changes in battery charge-status and accumulation of fibrous dander (fluff) in the activity simulator. The protocol consisted of measuring starting suction pressure (correlated to flow) and voltage before and after each activity simulation. Go/no go levels of 6.0 volts and 5.8 L/s flow were established for the start of each experiment. Post experiment voltage and airflow was compared to the pre-experiment levels and drops of greater than 1.1 volts and 1.8 L/s airflow were not accepted. Using these criteria, 25 of the original 1311 activity simulation experiments were removed from the main data-set.

Of the 25 experiments removed due not meeting the criteria, 20 were removed due to accumulation of fluff in the blower assembly of the activity simulator which in turn caused significant flow reduction. Notably, this occurred in the first two weeks for the new carpet installation in House 3U. The fibrous material appeared to originate from the carpet itself. House 4 also experienced this phenomenon frequently.

The following table sets out the variability observed in the quality control criteria.

Table 5				n=106
Criteria	Max.	Min.	Average	Std. Dev.
Battery Voltage Drop	1.1 volts	0.32 volts	0.5 volts	+/- 0.2 volts
Air Flow at Start	6.7 L/s	5.8 L/s	6.3 L/s	+/- 0.2 L/s
Air Flow Drop	1.8 L/s	0.0 L/s	0.7 L/s	+/- 0.4 L/s

Statistical significance was determined by apply a 95% confidence interval (p =/< 0.05) to the calculated means. A result was judged to be statistically significant if the range of possible means at 95% confidence did not over-lap the range of other results.

2.8 Data Organization

Data is presented as mass concentrations per unit volume (μg/m^3) in three different cut-sizes as follows:

PM10 Particulate matter 10 μm diameter and less.
PM5 Particulate matter 5 μm diameter and less.
PM1 Particulate matter 5 μm diameter and less.

Approximation of the mass concentration values from the particle counting data was carried out according to the method described in reference 1.

Of the three size ranges reported, only PM10 is a regulatory size definition. PM5 and PM1 are not regulatory size definitions, however due to the cut-size limitations of the particle counter used for the experiments, they could be approximated from the particle counter data with more certainty than could the more commonly used PM2.5 size definition.

Although the data was recorded as absolute airborne concentrations, the most of the results are analyzed in terms of the change in room concentration produced by a specific action such as an activity simulation or cleaning activity. As such all of the values can be considered being corrected for background levels. The exceptions to this rule are Sections 3.4 and 3.6 where peak concentrations are reported.

For activity simulations, the minimum particle concentration always occurred immediately prior to the simulated activity and the maximum value always occurred near the end of the activity.

During the cleaning process particle concentrations often rose at the beginning and then declined before the cleaning activity was complete. In order to capture this, the change in particle concentration during cleaning was taken as the slope of the particle concentration during the cleaning multiplied by the elapsed time of the cleaning process. This approach was intended to capture the trend in particle concentrations rather than give an absolute comparison of beginning and ending concentration values.

Measured data for two typical experiments, one for a high peak and one for low peak are shown in figures 1 and 2. The values extracted from the data is detailed in the corresponding tables.

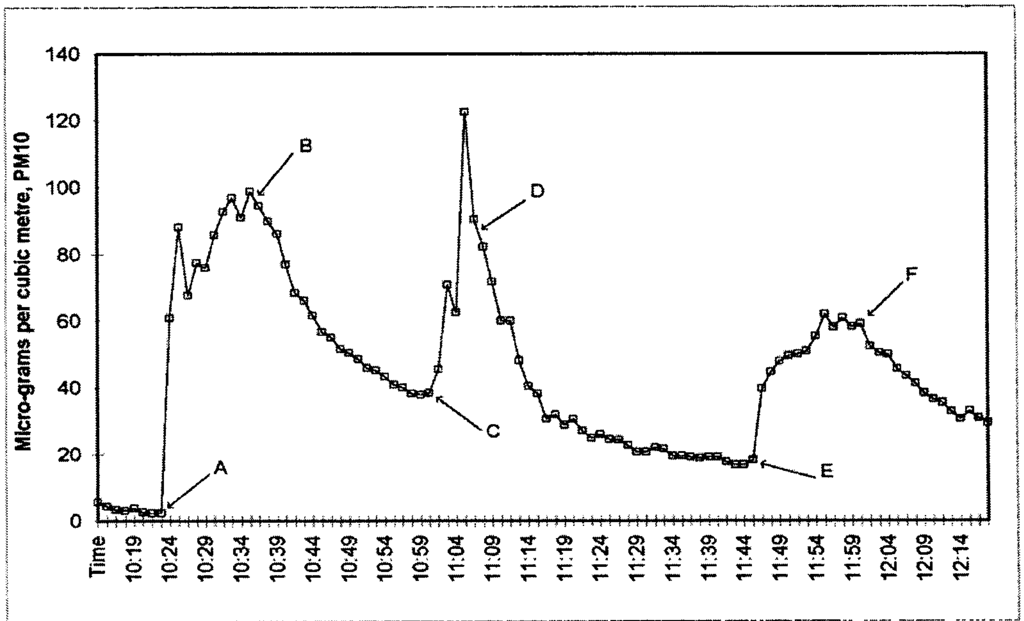

Figure 1
House 1, Vacuum 2, Carpeted Floor, Real-Time Experimental Data, PM10 only

Table 6 House 1, Vacuum 2, Carpeted Floor, Data Extraction, PM10			
Window	**Beginning**	**End**	**Data**
Before cleaning-rise	A: 2 μg/m³	B: 98 μg/m³	96 μg/m³ (note 1)
During cleaning-change	C: 38 μg/m³	D: 82 μg/m³	+41 μg/m³ (note 2)
During cleaning-peak	C: 38 μg/m³	D: 82 μg/m³	122 μg/m³ (note 3)
After cleaning-rise	E: 17 μg/m³	F: 62 μg/m³	45 μg/m³ (note 4)

Notes:
1) B minus A,
2) slope of data between C and D multiplied by elapsed time between C and D
3) maximum of data points C and D
4) F minus E

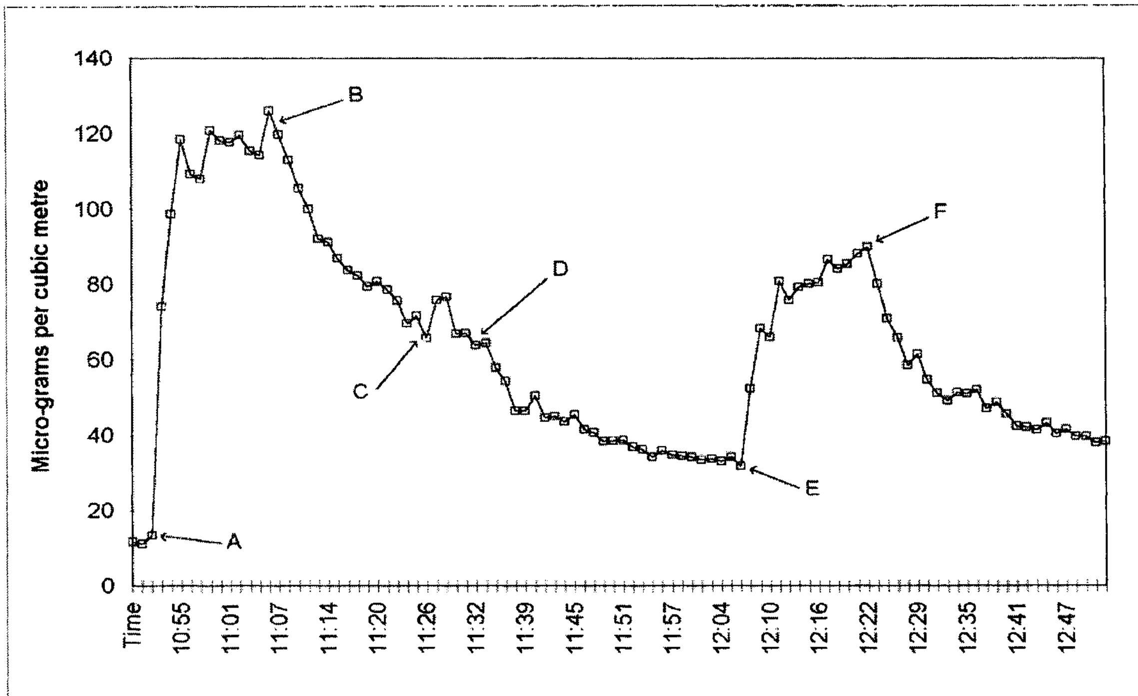

Figure 2
House 1, Vacuum 3, Carpeted floor, Real-Time Experimental Data, PM10 Only

Table 7 House 1, Vacuum 3, Carpeted Floor, Data Extraction, PM10			
Window	**Beginning**	**End**	**Data**
Before cleaning-rise	A: 11 µg/m³	B: 126 µg/m³	114 µg/m³ (note 1)
During cleaning-change	C: 66 µg/m³	D: 64 µg/m³	-6 µg/m³ (note 2)
During cleaning-peak	C: 66 µg/m³	D: 64 µg/m³	77 µg/m³ (note 3)
After cleaning-rise	E: 32 µg/m³	F: 90 µg/m³	58 µg/m³ (note 4)

Notes:
1) B minus A
2) slope of data between C and D multiplied by elapsed time between C and D
3) maximum of data points C and D
4) F minus E

The data extracted from each experiment is grouped with the data from other experiments and presented as means in the results section. For example, the "during cleaning change" value of -6 µg/m³ from table 7 above, is one of the component values of the PM10 mean for V3 presented in figure 3 and table 8 in section 3.1.

The peak concentrations obtained during the cleaning activity (occurring between C and D in figures 1 and 2) appear to be influenced by the simulated activity carried out before cleaning. It can be seen that point C occurs during the decay of particle concentration after the simulated activity. During the conduct of the experiments, the elapsed time between the end of the simulated activity and the beginning of the cleaning process was not strictly controlled. Peak concentrations during the cleaning process are reported in sections 3.4 and 3.6.

3 RESULTS/DISCUSSION

3.1 Resuspension of PM During Cleaning

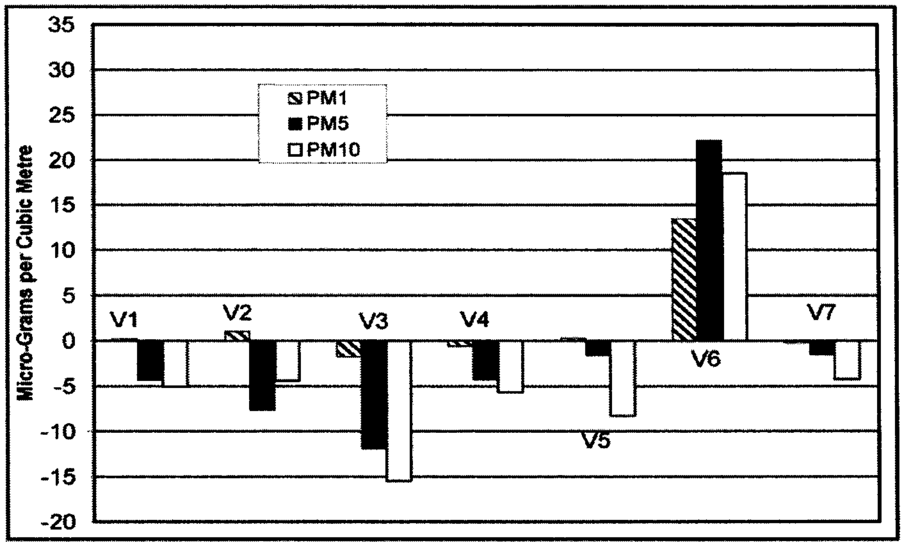

Figure 3
Change in PM Level During Cleaning Activity, Powered Devices, Carpeted Floors Only

Table 8 Change in PM Level During Cleaning Activity, Powered Devices, Carpeted Floors							
Device	n	PM10 μg/m³		PM5 μg/m³		PM1 μg/m³	
		mean	95% CI	mean	95%CI	mean	95%CI
V1	2	-5	31	-4	17	0	1
V2	6	-4	22	-8	8	+1	1
V3	5	-15	11	-12	8	-2	1
V4	6	-6	9	-4	7	-1	2
V5	1	-8	n/a	-2	n/a	0	n/a
V6	6	+19	36	+22	14	13	10
V7	1	-4	n/a	–2	n/a	0	n/a

Figure 3 and Table 8 set out the experimental results from Stage 2 and Stage 3 testing of all electrically powered devices on carpeted floors.

Negative values indicate that the PM concentration was reduced during the cleaning activity. This effect is theorized to result from the filtration effect of the vacuum cleaner. That is to say, the vacuum cleaner operates as an in-room air filter during the cleaning operation. Removal of particles from the room air by the vacuum cleaner and normal settling can be greater than the resuspension caused by the motion of the cleaning device and it's operator, resulting in a net reduction in the measured in-room particle concentration. Some researchers have found that vacuuming carpet tends to increase in-room PM concentrations (Ref. 10). Other researchers have found that vacuuming in bedrooms did not raise PM concentrations. (Ref. 8).

The only powered cleaning devices which did not produce a net reduction in PM concentration is V6. There is a very high proportion of micro fine particles (PM1) which probably arise from the water spray system of the device. For the other devices, there is no statistically significant difference between them when the variability of the results and sample size is considered.

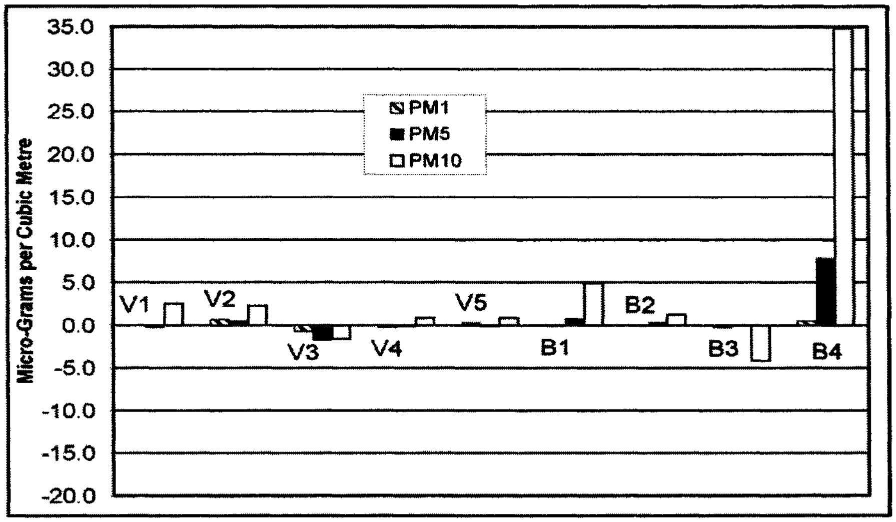

Figure 4
Change in PM Level During Cleaning Activity, Powered and Non-Powered Devices, Smooth Floors Only

Table 9 Change in PM Level During Cleaning Activity, All Devices, Smooth Floors							
Device	**n**	**PM10 µg/m³**		**PM5 µg/m³**		**PM1 µg/m³**	
		mean	**95% CI**	**mean**	**95%CI**	**mean**	**95%CI**
V1	2	3	2	0	3	0.0	1.0
V2	5	2	3	1	2	+0.7	0.6
V3	5	-2	3	-2	2	-0.7	0.5
V4	2	1	6	0	4	-0.3	1.0
V5	2	1	0.2	0	1	+0.3	0.2
B1	5	5	5	1	1	-0.1	0.2
B2	5	1	1	0	1	0.0	0.2
B3	2	-4	4	0	2	-0.2	0.1
B4	5	35	26	8	5	+0.5	0.5

Figure 4 and Table 9 set out experimental results from Stage 2 and Stage 3 testing in all houses for smooth floors only. It can be clearly seen that the broom resuspends substantial quantities of PM10 and PM5 during cleaning when compared to most of the other cleaning devices. For the other devices and for the broom (B4) in the PM1 size range, there is no statistically significant difference between them when the variability of the results and sample size is considered.

3.2 Resuspension of PM Immediately Following Cleaning

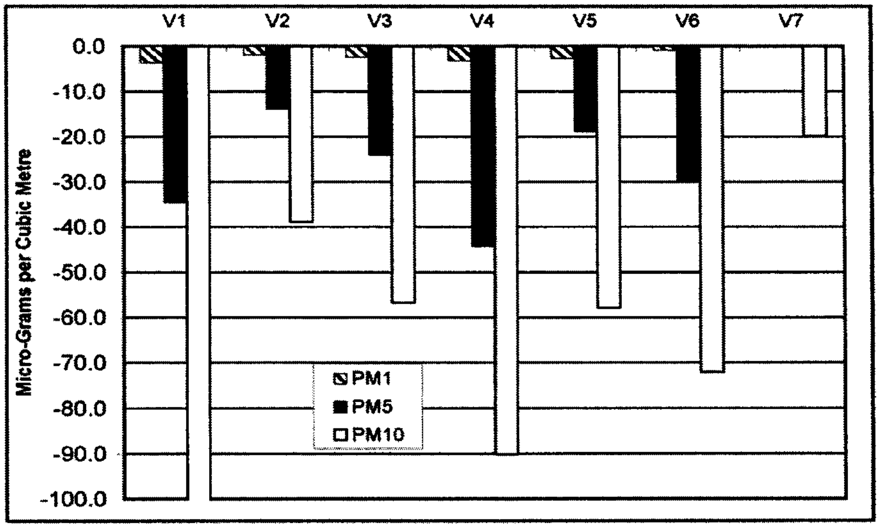

Figure 5
Change in PM Rise Immediately Following Cleaning
Carpeted Floors Only

Table 10
Change in PM Rise Immediately Following Cleaning
Powered Devices, Carpeted Floors

Device	n	PM10 µg/m³		PM5 µg/m³		PM1 µg/m³	
		mean	95% CI	mean	95%CI	mean	95%CI
V1	2	-101	31	-35	13	-3.7	1.5
V2	2	-39	8	-14	4	-2.0	0.5
V3	1	-57	n/a	-24	n/a	-2.4	n/a
V4	1	-90	n/a	-44	n/a	-3.2	n/a
V5	2	-58	28	-19	2	-2.7	0.8
V6	2	-72	25	-30	19	-0.9	0.6
V7	1	-20	n/a	+1	n/a	-0.7	n/a

Figure 5 and Table 10 set out the difference between the rise of PM concentration attributable to the simulated activity immediately before and the rise of PM concentration immediately after the cleaning activity on carpeted floors. The sample set is reduced due to the elimination of several experimental results due to accumulation of carpet fluff in the activity simulator. All of the cleaning devices showed some cleaning effectiveness when evaluated in this manner. V1 is noticeably more effective than V2 in the PM10 size range, and more effective than V2 and V5 in the PM5 size range. V6 is less effective than all of the other devices in the PM1 size range. There are no other statistically significant difference between the devices.

It is notable that the "Dirt Finder" experiment (V7) resulted in a smaller decrement in PM than most of the other devices. This is consistent with the fact that the vacuuming time using the "Dirt Finder" (4 minutes) was substantially less than the vacuuming time using the standard protocol (7 minutes).

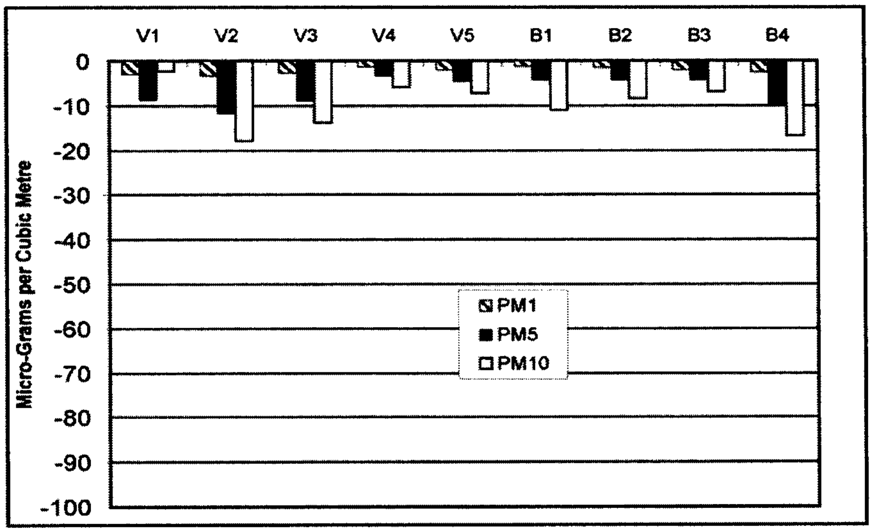

Figure 6
Change in PM Rise Immediately Following Cleaning
Smooth Floors Only

Table 11
Change in PM Rise Immediately Following Cleaning Activity, All Devices, Smooth Floors

Device	n	PM10 µg/m³		PM5 µg/m³		PM1 µg/m³	
		mean	95% CI	mean	95%CI	mean	95%CI
V1	2	-2	35	-9	16	-3.0	3.7
V2	5	-18	10	-12	7	-3.4	7.2
V3	5	-14	2	-9	3	-2.6	2.6
V4	1	-6	n/a	-3	n/a	-1.3	n/a
V5	2	-7	6	-5	6	-2.0	2.8
B1	5	-11	2	-4	2	-1.2	0.2
B2	5	-8	5	-4	5	-1.5	1.5
B3	2	-7	2	-4	2	-2.0	0.5
B4	5	-17	5	-10	5	-2.5	0.8

Figure 6 and Table 11 set out the difference between the rise of PM concentration produced by the simulated activity immediately before and the rise of PM concentration immediately after the cleaning activity on smooth floors. While all of the cleaning devices showed some cleaning effectiveness when evaluated in this manner, the only statistically significant (greater than 95% confidence) differences are as follows: V3 and B4 are more effective than B3 in the PM10 size range. V3 is more effective than B1 in the PM5 size range. B4 is more effective than B1 in the PM1 size range. Notably, there is no discernable trend which would differentiate powered from non-powered devices.

Surprisingly, the effectiveness of the broom (B4) is at the upper end of the scale. This seems to be inconsistent with the high disturbance levels observed in the concentrations measured during the cleaning activity.

3.3 Resuspension of PM 1 Week Following Cleaning

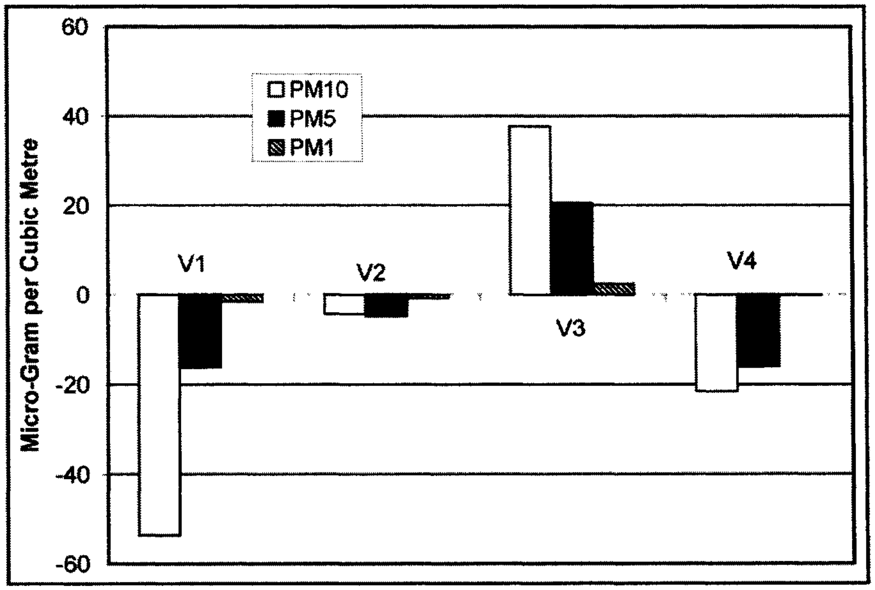

Figure 7
Change in PM Rise 1 Week after Cleaning
Carpeted Floors Only

Table12 Change in PM Rise 1 Week After Cleaning Powered Devices, Carpeted Floors							
Device	n	PM10 µg/m³		PM5 µg/m³		PM1 µg/m³	
		mean	95% CI	mean	95%CI	mean	95%CI
V1	2	-54	38	-16	17	-1.5	1.7
V2	2	-4	15	-5	9	-0.8	0.7
V3	2	38	26	20	15	2.4	1.9
V4	2	-21	14	-16	10	-0.1	0.8

Figure 7 and Table 12 show the difference between the particle rise due to activity simulation prior to a cleaning activity and the particle rise due to activity simulation on the same carpeted floor after one week has passed. Such a comparison should give an indication as to whether or not a particular cleaning device produces a lasting effect. This analysis shows a statistically significant (95% confidence) difference for V3 only. The indicated result (poor cleaning performance) is not consistent with results of the tests immediately following the cleaning activity which showed the performance of V1 and V3 to be approximately equal. In view of this, the small sample size, and the possibility of soiling rates confounding the results, it is possible that this is not a valid result.

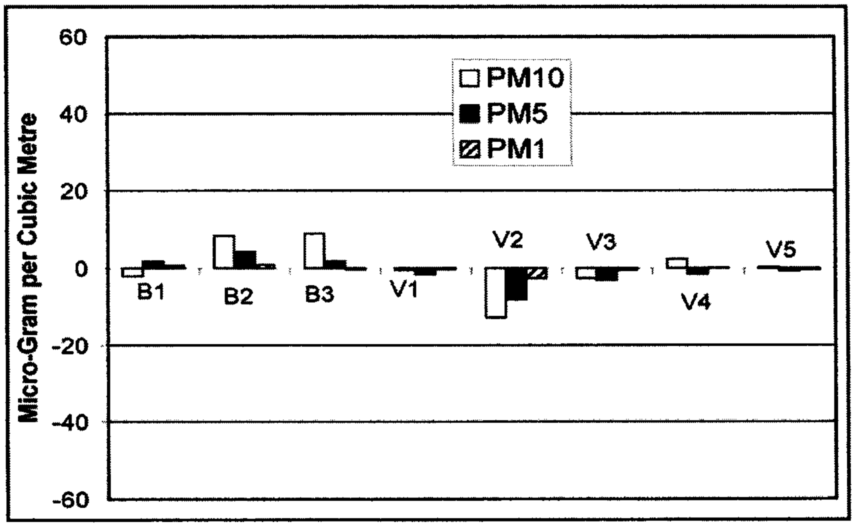

Figure 8
Change in PM Rise 1 Week after Cleaning
Smooth Floors Only

Table13 Change in PM Rise 1 Week After Cleaning All Devices, Smooth Floors							
Device	n	PM10 µg/m³		PM5 µg/m³		PM1 µg/m³	
		mean	95% CI	mean	95%CI	mean	95%CI
B1	5	-2.1	4.3	1.8	1.8	0.7	0.4
B2	5	8.4	1.8	4.3	1.0	0.8	0.3
B3	2	9.0	3.8	1.8	0.3	-0.3	0.1
V1	1	-0.5	n/a	-1.6	n/a	-0.3	n/a
V2	4	-12.8	3.5	-8.3	2.3	-2.6	1.0
V3	4	-2.6	2.8	-3.1	1.8	-0.5	0.4
V4	2	2.3	3.5	-1.6	0.1	0.1	0.1
V5	2	0.2	0.2	-0.7	0.2	-0.4	0.1

Figure 8 and Table 13 show the difference between the particle rise due to activity simulation prior to a cleaning activity and the particle rise due to activity simulation on the same smooth floor after one week has passed. V2 shows better performance in all particle size ranges than all of the other devices in this analysis (95% confidence or better). Within the non-powered devices, B1 is more effective than B2 or B3 when PM10 only is considered. B3 is more effective than B2 when PM5 is considered, B3 is also more effective than B1 and B2 when PM1 is considered.

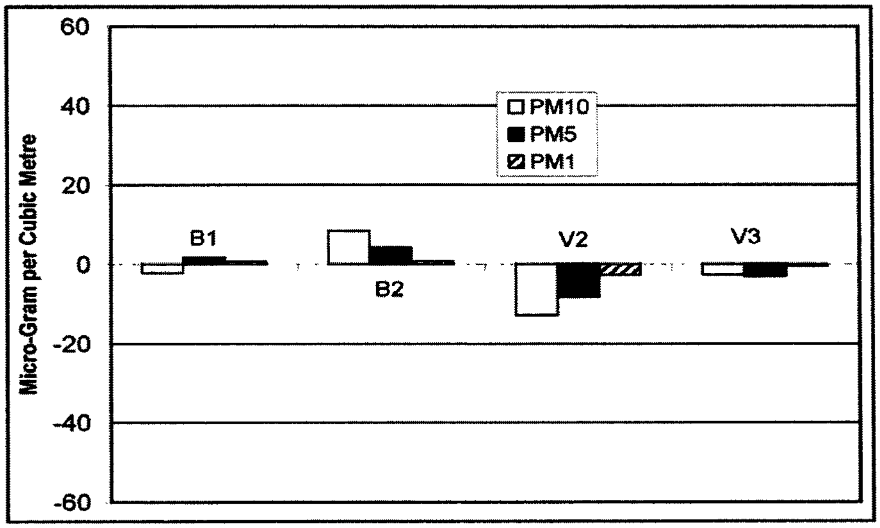

Figure 9
Change in PM Rise 1 Week after Cleaning, Smooth Floors, Means by Device n=4

Figure 9 is a sub-set of the data previously set out in Figure 7 and Table 11 in that the data is restricted to instances where the number of valid experimental results is 4 or more.

3.4 Smooth vs Carpeted Floors, Occupant Exposure

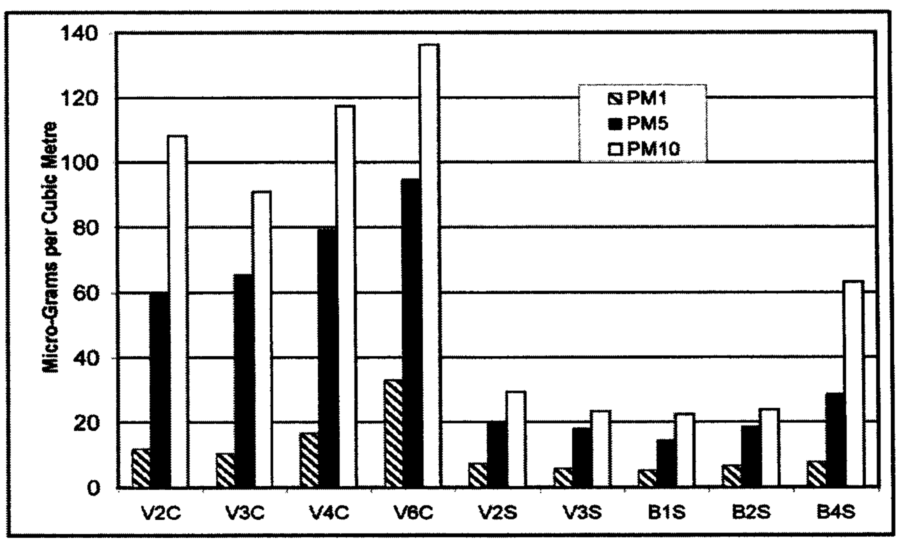

Figure 10
Peak PM During Cleaning, All Devices, All Surfaces, C = Carpet, S = Smooth, n = 4+

Table 14
Peak PM During Cleaning, All Devices, All Surfaces, n = 4+

Device/ Surface	n	PM10 µg/m³		PM5 µg/m³		PM1 µg/m³	
		mean	95% CI	mean	95%CI	mean	95%CI
V2C	6	108	33	60	17	11.9	2.7
V3C	5	91	16	65	19	10.5	3.5
V4C	6	117	63	79	43	16.8	9.9
V6C	6	136	40	95	6	33.1	24.5
V2S	5	29	13	20	9	7.3	3.1
V3S	5	23	6	18	5	5.9	1.3
B1S	5	23	9	14	5	5.2	1.6
B2S	5	24	5	19	3	6.6	0.9
B4S	5	63	32	29	8	7.7	2.2

Figure 10 and Table 14 show the peak concentration values recorded during the cleaning activity for all data-sets for which there are 4 or more valid experiments. The nomenclature for each data group combines the cleaning device and the floor surface. For example V2C is the V2 device on carpeted floors. V2S is the V2 device on smooth floors.

Concentrations measured for the carpeted floors in the PM10 size range are clearly higher than for smooth floors, often by a factor of two or more. Higher concentrations for carpeted surfaces were also measured for the PM5 size range, but only if the B4 cleaning device is not included in the smooth floor group. There is only a slightly higher (not statistically significant at 95% confidence) concentration of PM1 for the carpeted surfaces. This difference is reduced if the V6 device is not included in the data. It is notable that except for B4, there is no apparent difference between the powered and non-powered devices when cleaning a smooth floor.

3.5 PM Accumulation

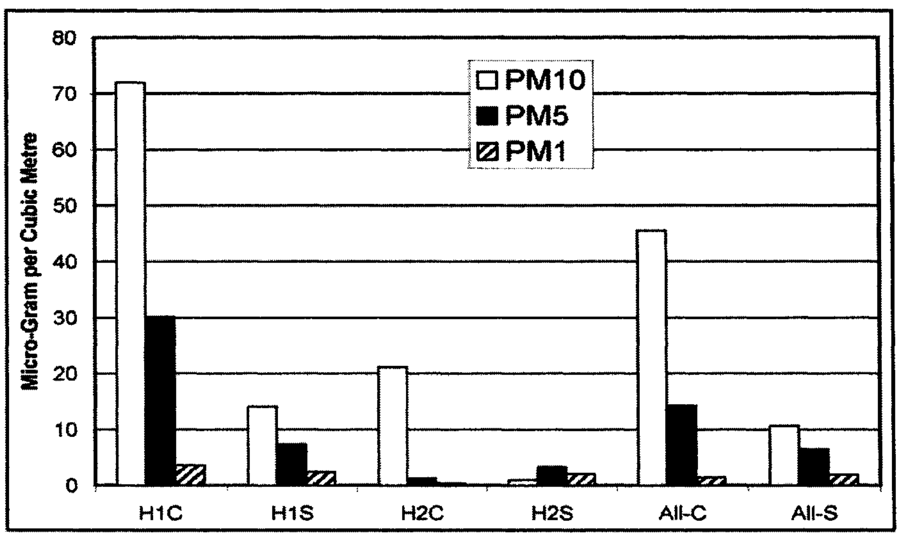

Figure 11
PM Accumulation for 1 Week, House 1 & 2, All Surfaces,
C = Carpet, S = Smooth, n = 4+

Table 15
PM Accumulation for 1 Week, House 1 & 2, All Surfaces, n = 4+

House/ Surface	n	PM10 µg/m³		PM5 µg/m³		PM1 µg/m³	
		mean	95% CI	mean	95%CI	mean	95%CI
H1C	4	72	15	30	9	3.6	0.9
H2S	6	14	3	7	1	2.4	0.3
H2C	4	21	16	1	9	0.3	0.8
H2S	6	1	3	3	1	2.1	0.7
All-C	9	46	11	14	6	1.4	0.7
All-S	24	11	2	7	1	1.9	0.2

Figure 11 and Table 15 show the difference between PM rise caused by activity simulation and the PM rise caused by activity simulation the following week without intervening cleaning activity. This comparison should be influenced by the rate at which PM is accumulating on the floor surfaces. H1C and H1S refer to house 1, carpeted and smooth surfaces respectively. H2C and H2S refer to house 2. All-C and All-S refer to all of the data carpeted and smooth floors for which there are valid experimental results.

In the PM10 size range, the carpeted surfaces appear to accumulate particles at a rate of at least 4 times greater than for smooth surfaces. In the PM5 size range, the carpet surfaces appear to accumulate particles at least two times faster than smooth floors. In the PM1 size range however, there is no apparent difference between the smooth and carpeted surfaces. There also appears to be a substantial difference between houses as the data for House 1 shows higher accumulation rates than House 2 for all conditions of floor surface and particle size except for PM1 on smooth surfaces.

3.6 New Carpet

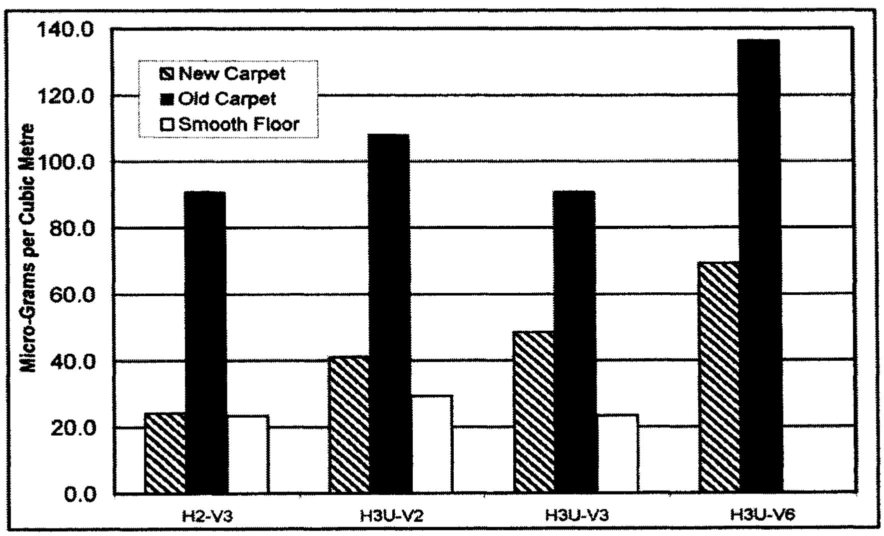

Figure 12
PM10 Peak During Cleaning,
New Carpet vs Old Carpet and Smooth Floor, Limited Data

Table 16 PM Peak During Cleaning, New Carpet vs Old Carpet and Smooth Floor									
House/ Device	**PM10 µg/m³**			**PM5 µg/m³**			**PM1 µg/m³**		
	New Carpet	**Old Carpet**	**Smooth Floor**	**New Carpet**	**Old Carpet**	**Smooth Floor**	**New Carpet**	**Old Carpet**	**Smooth Floor**
H2-V3	24	91	23	20	18	18	7.6	10.5	5.9
H3U-V2	41	108	29	25	20	20	8.0	11.9	7.3
H3U-V3	49	91	23	36	18	18	7.0	10.5	5.9
H3U-V6	69	136	n/a	50	95	n/a	16.1	33.1	n/a
Note:	New carpet values are from one experiment per case. Old carpet and Smooth floor values are mean values as reported in Section 3.4 according to surface type and device designation.								

Figure 12 and Table 16 set out the limited results available for a new carpet. The data is organized to compare the peak concentration recorded during the cleaning activity with the mean of peak data for the corresponding cleaning device in other houses. Most of the data concerning cleaning effectiveness is not available due to out of bounds performance of the activity simulator which was caused by accumulation of fluff from the new carpet.

The results show that for the PM10 and PM5 size ranges, the new carpet results in less resuspension than the old carpets. In the PM1 size range, the tendency for the new carpet to have lower peaks remains, but it is not so clear cut. The smooth floor peaks during cleaning tend to be lower than the peak for new carpet in the PM10 and PM5 size range. In the PM1 size range the new carpet peaks are similar to those for smooth floors.

3.7 Wet vs Dry Cleaning Devices

The wet vacuum was the poorest performer with respect to PM5 and PM1 levels during cleaning, and resuspension immediately following cleaning was more than for other devices in the PM1 size range. PM resuspension 1 week later data is not available for this device. No detergent was used in the cleaning solution during the experiments. It is theorized that the high level of fine particles measured during the testing arise due to the water spray system. During the immediately following testing it was noted that the carpet was not completely dry and this may have influenced the results.

The wet-pad non-powered cleaning device did not perform noticeably better than the other non-powered smooth floor cleaning devices. It is notable that for smooth floors measure 1 week after cleaning, the ordinary dust mop (B3) is more effective than the wet-pad device in the PM5 and PM1 size ranges.

4 CONCLUSIONS

4.1 Flooring Material

Airborne PM concentrations have been shown to be significantly less for smooth floors than for carpeted floors in the PM10 and PM5 particle size ranges. This appears to be true for resuspension of PM by activity as well as during cleaning. This does not appear to be true for the PM1 particle size range, where it appears than smooth and carpeted floors have similar characteristics.

4.2 PM Accumulation

There appears to be significant differences in the accumulation rates of PM in the PM10 and PM5 size ranges between houses and between carpeted and smooth floors. Carpeted floors appear to accumulate PM10 and PM5 at a significantly higher rate than smooth floors. The cause of this is not known.

4.3 New Carpet

Based on limited data, it appears that new carpet resuspends PM at a significantly lower rate than older carpet, but at a somewhat higher rate than smooth floors, particularly in the PM10 and PM5 size ranges. It is possible that the higher resuspension rates for old carpet are related to the higher accumulation rates which are associated with carpets.

4.4 Powered Devices vs non-Powered Devices on Smooth Floors

There does not appear to be a difference between the performance of powered cleaning devices and non-powered cleaning devices on smooth floors with respect to either cleaning performance or resuspension of PM during the cleaning activity. The exception to this statement is the standard house broom (B4), which has noticeably higher PM resuspension rates during cleaning than other devices in the PM10 and PM5 size range, but not in the PM1 size range. The cleaning effectiveness of the broom appears to be similar to the other devices.

4.5 Disposable Pad Type Sweeping Devices

Disposable dry-pad (B1) or wet-pad (B2) type floor sweeping devices did not demonstrate an apparent advantage over a dust mop (B3), a standard house broom (B4), or each other with respect to cleaning effectiveness. With respect to PM resuspension during cleaning, the house broom was higher than the pad-type devices in the PM10 and PM5 size ranges. The dust mop showed better performance than both pad-type devices in the PM1 size range when effectiveness after 1 week was tested.

4.6 Performance Comparison Between Vacuum Cleaners

If the wet-vacuum is not considered, there were very few statistically significant (95% confidence) differences between vacuum cleaners on smooth or carpeted floors. One of the statistically significant results is the somewhat higher performance of the V1 device on carpeted floors when tested immediately following the cleaning activity. This higher performance is evident in the 1 week later effectiveness testing, but it is not statistically significant. The other statistically significant result (95% confidence) showed that the ordinary upright vacuum cleaner (V2) out-performed all of the powered and non-powered cleaning devices on smooth floors, in all size ranges in the 1 week later cleaning effectiveness testing. This higher performance trend was evident, but not statistically significant, in the test of effectiveness on smooth floors immediately following cleaning.

4.7 Wet-Vacuum Performance

Testing of the wet-vacuum showed significantly higher levels of PM5 and PM1 size range particles during operation. There was also a tendency (but not statistically significant above 95% confidence) for the PM10 particles to be higher than other devices during operation. These high levels also appeared as reduced PM1 effectiveness immediately following the cleaning activity. The results for one week after cleaning are not available. It is possible that the high fine particle levels arise due to the operational characteristics of the device and are not reflective of the actual cleaning effectiveness.

4.8 Validity of Method

The simulated activity method used in this study shows promise as a simple technique that can be used to evaluate the effectiveness of cleaning methods for floors. This study has shown that because of the variability of accumulation rates of individual rooms and surfaces, characterization of the resuspension and decay characteristic of individual rooms is required. Experimental results should be considered as they affect specific rooms rather than as components of pooled data. Such an approach, coupled with more repetitious experiments with fewer variables should result in more precise evaluations and may identify performance differences between one vacuum cleaner and another.

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