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Effectiveness of HEPA Vacuuming on Mold in Houses

INTRODUCTION

There are several major components of fine dust that are relevant to human health such as dust mite allergens, bacterial endotoxins and fungal glucans. The recent introduction of new vacuum cleaning technologies and systems is largely due to the heightened awareness of the health effects associated with indoor contaminants that can accumulate in fine dust. These contaminants can become airborne and inhaled as a result of normal human activity such as walking and exposure has been directly related to the amount of fine dust in homes. Reduction of indoor airborne contaminants such as dust mite allergens, bacterial endotoxins and fungal glucans contained in dust requires that the dust reservoir in homes be lowered by thorough and frequent vacuuming. To effectively remove dust loading on floors, especially carpet, repeated and very thorough vacuuming is required. Current consumer information for cleaning floors to reduce fine dust suggests the use of a central vacuum system equipped with an exhaust port for venting to the outside of the home or a portable vacuum cleaner equipped with a High Efficiency Particulate Air (HEPA) filter.

Two CMHC studies investigated the effectiveness of HEPA filters in reducing the levels of fine dust in residential settings. The first involved conducting a rigorous and intensive HEPA vacuuming of six typical urban homes in the Ottawa area over a six-week period to determine the effectiveness of vacuuming on reducing dust over time. The second involved 15 homes in a remote community in Quebec with an identified mold problem. The goal of the second study was to determine whether intensive vacuuming with a HEPA-filter equipped vacuum would aid in reducing air-borne mold levels as well as the fine dust particles in advance of mold remediation work.

RESEARCH PROJECT OBJECTIVES

The objectives of the first study were:

- To develop and test a cleaning protocol using a HEPA filter-equipped vacuum cleaner; and
- To determine the effectiveness of the HEPA vacuum cleaner in reducing dust and, in particular, fine dust over time.

The objectives of the second study were:

- To test the timed HEPA vacuuming protocol in the field;
- To determine the effectiveness of the HEPA vacuum cleaner in reducing dust and, in particular, fine dust over time, in a less controlled environment; and
- To compare levels of contaminants in fine dust of houses with identified mold problems to average houses without mold.

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TESTING METHODOLOGY

For the first study, six houses in the Ottawa area were selected to participate in a six-week cleaning program. While an existing mold problem was not a requirement, houses with carpeted floors, children and/or pets were preferred. Each homeowner completed an occupant survey to provide information about the house, number of residents, cleaning procedures, any moisture problems, recent leaks, floods or mold issues.

The houses chosen for the first study were typical Ottawa dwellings. Five of the homes were detached one or two-storey homes and the sixth was a two-storey row house. All had partially finished basements and five were at least half carpeted. Three had pets and three had children. Dates of construction ranged from the early 1900s to 2001 and the cleaned areas of the homes ranged from 115 m^2 to 220 m^2 (1200 ft^2 to 2400 ft^2). Most homes had minor moisture and mold problems. The owners reported cleaning their homes three to five times a month using regular vacuum cleaners prior the beginning of the study.

Figure 1 HEPA filter-equipped vacuum cleaner with beater brush attachment ready for action in Study 1

Vacuuming Protocol

A HEPA filter-equipped vacuum cleaner (rated to remove 99.99 per cent of particles 0.3 µm[1] and larger) was purchased for this study. The vacuuming protocol was developed to ensure consistency in the level of cleaning between each visit and between houses. In each house, all finished rooms, including accessible areas of finished basements, were mapped to document the type of flooring and room measurements. The time required to clean each area was calculated on the basis of the type of flooring:

- Wall-to-wall carpet: 1 minute per square meter
- Hard flooring with loose carpets: 45 seconds per square meter
- Hardwood/vinyl/laminate/ceramic: 30 seconds per square meter

A professional cleaner was hired to completely vacuum each room in one direction and then the other (perpendicular to the first), moving any furniture that could easily be moved. The cleaner continued vacuuming until the calculated time for each room was completed. Particular attention was paid to high traffic areas. Between 1.7 and 2.9 hours of continual vacuuming was required to complete each house. The goal was to remove as much dust/dirt as possible.

Four houses were vacuumed once a week for six weeks and two houses were vacuumed twice a week for six weeks. Before each cleaning, a new vacuum bag and intermediate filter, both pre-weighed, were installed in the vacuum. After each house was vacuumed, the beater brush and cleaning parts of the vacuum were vacuumed and the airflow reversed to dislodge any dust in the hose and wand. The vacuum bag and filter were then removed and stored in labelled, sealed plastic bags at room temperature. The testing took place over a six-week period in the spring.

The collected vacuum bags and filters were analysed in a laboratory. The dust was weighed, sieved into three diameter groupings (<150 µm, 150 to 300 µm and >300 µm) and each fraction was weighed. Fine dust was defined as dust with a diameter of less than 300 µm.

Dust mite allergens, fungal glucans (from fungal cell walls, a measure of mold contamination) and bacterial endotoxins (from bacteria originating from the outdoors or pets) were analyzed from the fine dust fractions (< 300 µm) collected during each vacuuming session. Dust mite allergens and glucan content were analyzed only from the first vacuuming session, since their percentage content in dust (both originate indoors) was not expected to change with successive cleaning. All samples were analyzed for endotoxins to determine variability with time.

[1] A µm is a micron—one-millionth of a metre, or one thousandth of a millimetre. A micron equals 0.00004 of an inch.

Airborne Dust during HEPA Vacuuming

A Micro-Orifice Uniform Deposit Impactor (MOUDI) collected airborne dust in each house during the first vacuuming. The MOUDI was set up in the middle of the most active room in the house and collected airborne particles at 18 µm, 5.6 µm, 3.2 µm, 1.8 µm, 1.0 µm, 0.56 µm, 0.32 µm and 0.18 µm. The size-fractionated aerosol particle samples gathered from each house were sent to a laboratory for glucan analysis.

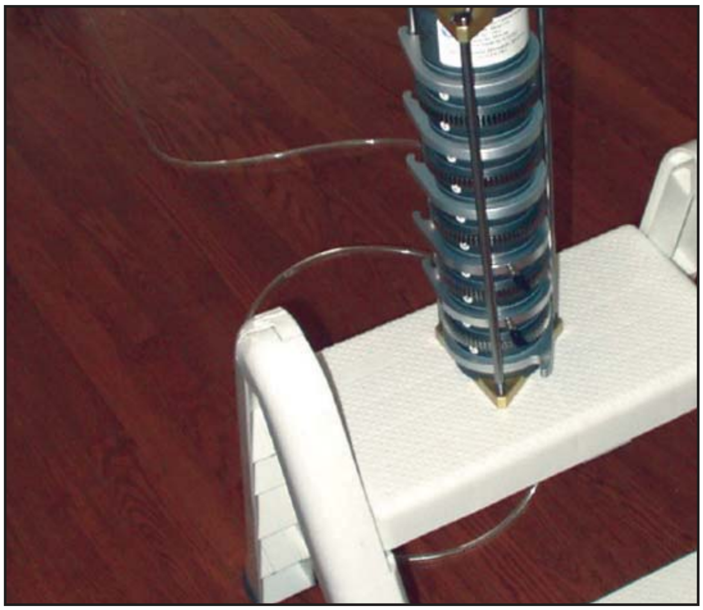

Figure 2 The MOUDI collected airborne dust during the first vacuuming of the homes in the first study

Adjustments to Methodology for Second Study

For the second study, the same cleaning protocol and the same type of vacuum cleaner were used. The 15 houses selected for the second study were all located in the same remote community of central Quebec. Six of the houses were ranch-style single-detached homes with finished or unfinished basements. Three of the homes were semi-detached ranch-style homes with partially finished basements. Three homes were bungalows with unfinished basements and one was a raised bungalow with a split-level entry and an unfinished basement. One home was a two-storey double with a finished basement and the last was a single storey with no basement. A number of the homes had common layouts including some of the ranch-style single homes and the bungalows.

The homes were wood-frame construction with wood or vinyl cladding and all were built within the past 40 years. None of the homes had wall-to-wall carpeting and seven had no carpets at all. No information was provided on the number or age of the occupants. The cleaned areas of the homes ranged from 97 m^2 to 184 m^2 (1050 ft^2 to 2000 ft^2). The homes were reported to have moisture and mold problems.

The local housing manager coordinated the cleaning sessions including selection of the fifteen homes, obtaining permission from the occupants, documenting the floor surfaces, ensuring the vacuuming was carried out according to the protocol and the vacuum was cleaned between uses, and collecting and shipping the samples to Ottawa. However, because of the remote location, some minor adjustments were required. A professional cleaner was not available. Since consistency in the cleaning was an important requirement, one local person was hired and trained to conduct all the cleaning. As well, the airborne dust was not sampled using the MOUDI as it had been during the first study.

None of the houses in the second study had carpeted floors (there were only hard surfaces with some area carpets). Therefore, the beater attachment of the vacuum was not used and the cleaning times were based on the hard surfaces with loose carpets and hard surface timings only. Vacuuming times per house ranged from just under 1.0 hour to 1.7 hours of continual vacuuming. Originally, the houses were to be cleaned and tested over a six-week period in the late summer. However, the time frame of the cleaning stretched to nine weeks due to the occasional absence of the occupants.

Figure 3 HEPA filter-equipped vacuum cleaner configured for use in Study 2

For each vacuuming, a new, pre-weighed vacuum bag and filter were installed. After the completion of each vacuuming session, the bag and filter were removed and stored in sealed plastic bags at room temperature. In preparation for the next cleaning, the vacuum's brush was combed and the airflow was reversed to dislodge any dust in the hose and wand.

Collected vacuum bags and filters were sent to a laboratory for analysis. The dust bags were weighed, sieved into three diameter groupings (<150 μm, 150 to <300 μm and >300 μm) and each fraction was weighed. In addition to dust weights, contents of the first vacuum bags collected in each house were analyzed for fungal glucan, bacterial endotoxin and dust mite allergens (*Der f* 1 and *Der p* 1).

FINDINGS

For the first study, the collected dust weights per square metre of floor area from Houses 3 and 6 are presented in Figures 4 and 5. House 3 is illustrative of the results from the four houses that were vacuumed once a week for six weeks and House 6 is illustrative of the two houses vacuumed twice a week over the same period of time. With successive vacuumings, the total amount of dust extracted by the vacuum cleaner decreased significantly in each of the houses.

Generally, it took three to four vacuuming sessions before the vacuumed dust particles attained a steady lower level as compared to the initial level. This was the case regardless of the level of dust at the beginning of the study.

Of particular interest is the fine dust, <300 μm, (the sum of the two upper portions in each bar of Figures 4 and 5). This is the respirable fraction of the dust (should it become airborne and inhaled). The most dramatic drops in the weight of the fine dust occurred over the first three weeks of the study. In all cases, the drop in fine dust levels was more than three-fold between the beginning and end of the study.

The level of bacterial endotoxins, fungal glucans and mite allergen (*Der f* l) in dust were measured in the samples collected from the first vacuum session in the six houses. As shown in Figure 6, the results varied from house to house. Glucan and dust mite allergen levels were highest in House 1, but similar in the five other houses. The higher levels in House 1 were likely related to elevated levels of mold. House 1 had five times more dust mites than the other houses and the highest levels of glucans. It was the one house with a musty smell in the basement and a reported ongoing mold problem. Endotoxin levels were high in all houses except for House 2.

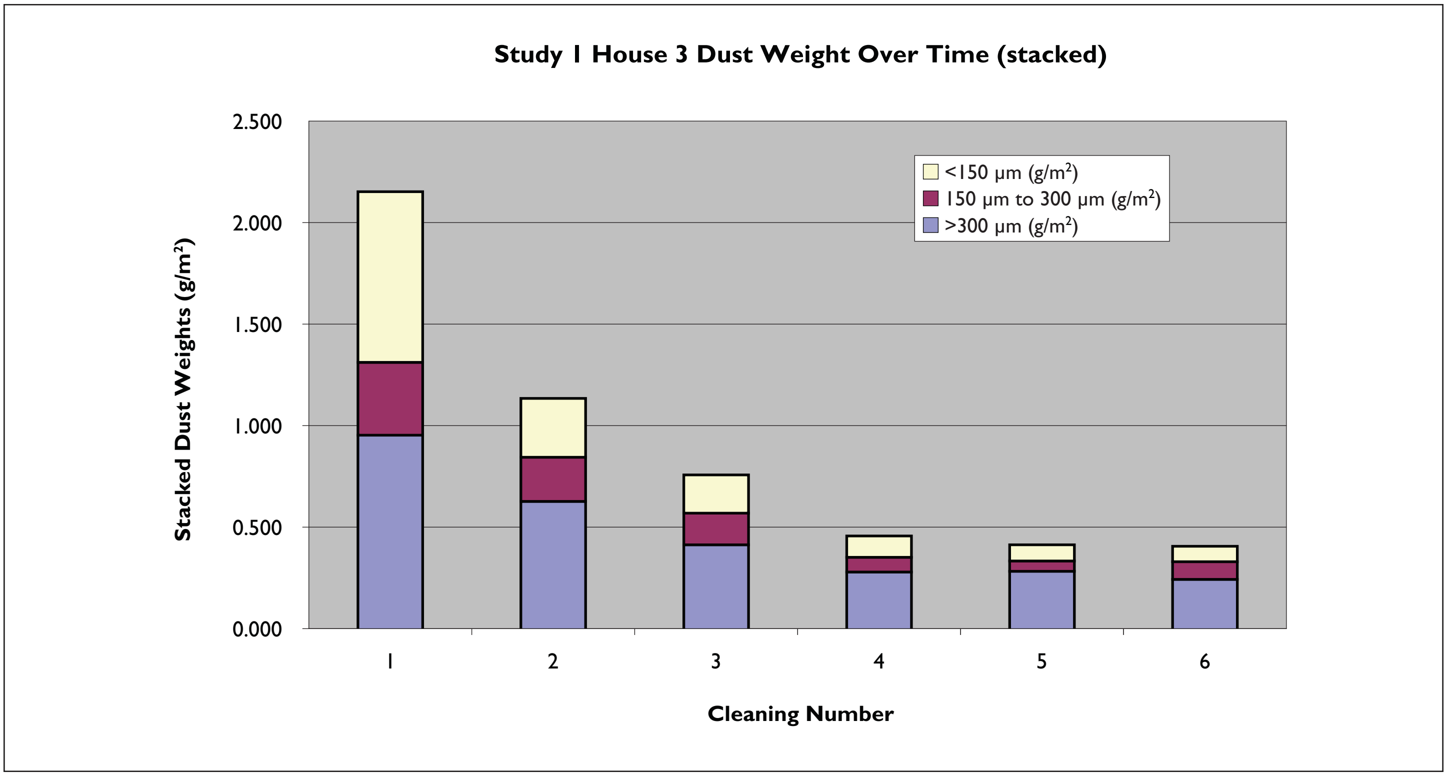

Figure 4 Vacuum bag dust weights for Study 1 House 3 over a six-week period

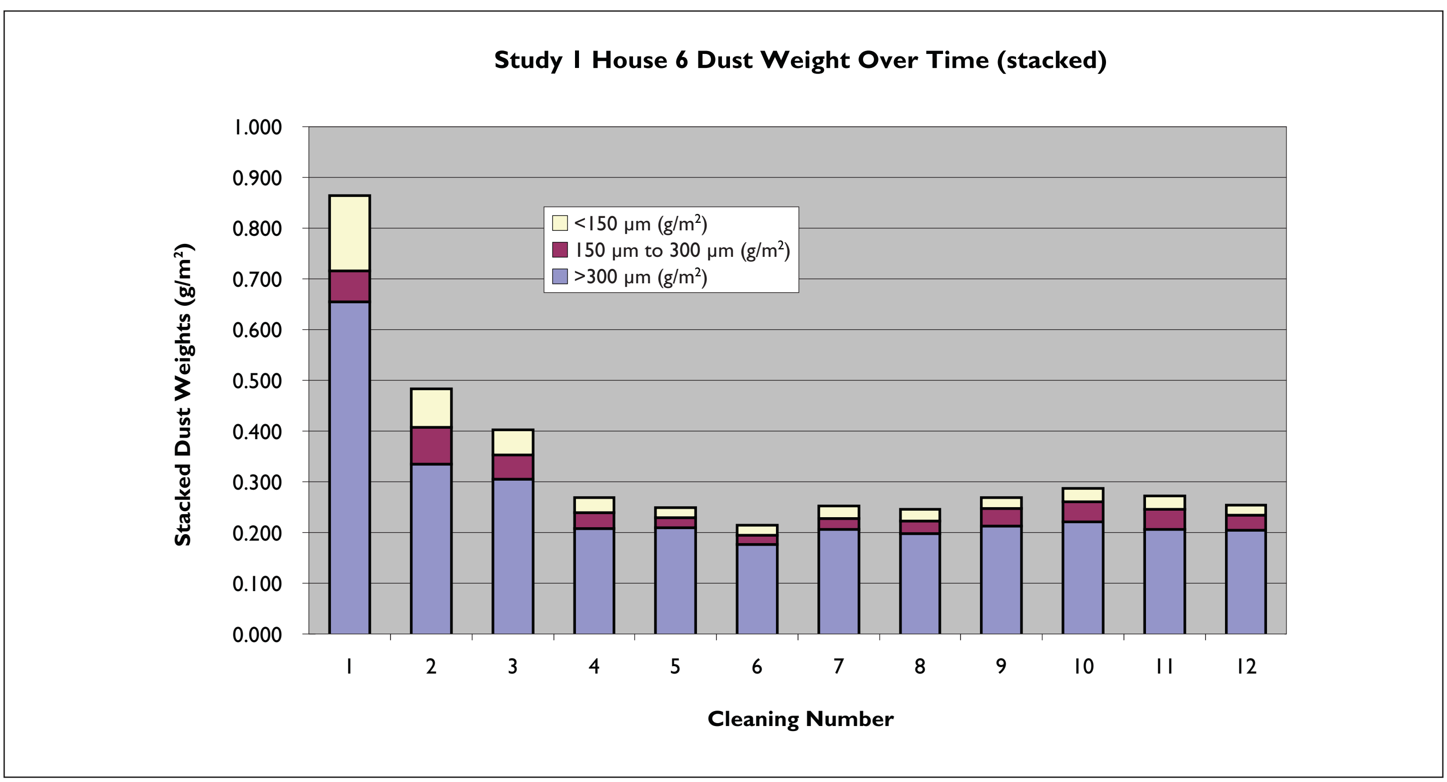

Figure 5 Vacuum bag dust weights for Study 1 House 6 over a six-week period

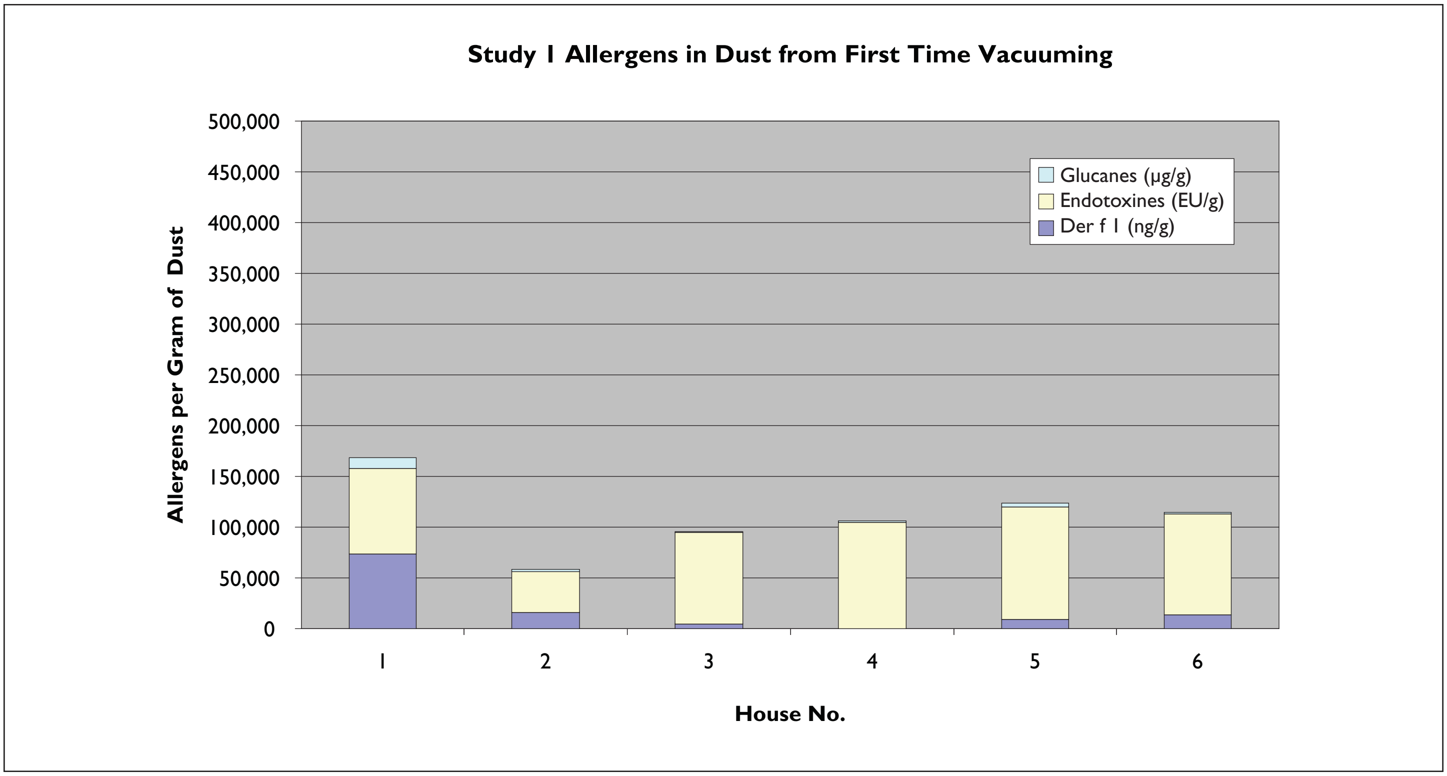

Figure 6 Levels of mite allergen (*Der f* 1), endotoxin and glucan in first time vacuumings from the six houses of Study 1

Endotoxin loading (endotoxin units/g of fine dust/m^2) over the six-week period in each house was fairly constant, with the exception of one house where a spike in endotoxin level occurred that was attributable to a visit that included pets.

The air particulates collected by the MOUDI from the first time vacuuming of each house consisted of dust particles ranging from 0.18 µm to 18 µm. Since the HEPA filter in the vacuum cleaner is expected to trap virtually all particles larger than 0.3 µm, the airborne particulates captured (except for the 0.18 µm ones) were assumed to be generated from the agitation of the surface being cleaned. This result was similar to the findings in a previous study of lead in dust[2]. Glucans were present and distributed evenly in the different size fractions.

The findings from the second study build upon those of the first study.

Thirteen of the 15 houses in the second study had total dust weights (per square metre of floor area) from the first-time cleaning of over 1 g/m^2, with eight houses approaching or exceeding 2 g/m^2. The total dust weights ranged from 0.78 - 2.81 g/m^2, and averaged 1.67 g/m^2. The amount of dust collected did not correlate with the presence of carpeted areas in some of the houses. The dust weights were comparable to those in the first study of six urban houses at 0.86 - 2.47 g/m^2, with an average of 1.51 g/m^2. However, the floors of the six urban houses were mostly carpeted and the dust, therefore, would have been extracted not only from the surface but also from the reservoir within the carpet fibres. In the 15 houses of the second study, dust was mostly collected from the surface of the hard-finish floors. This suggests relatively higher dust loadings on the surface of floors in the 15 houses. This may be partly due to the absence of a vacuum cleaner in many of the households and/or infrequent vacuuming.

[2] CMHC, "Effectiveness of clean-up techniques for leaded paint dust / Efficacité des techniques de nettoyage de la poussière de peintures à base de plomb" Research Highlight, CMHC, 1992.

In the 15 houses of Study 2, the proportion of the <300 μm dust to the total dust from the first vacuuming session averaged 10% (range 4.2 - 18.2%). The dust in the 15 houses consisted mainly of the larger size fraction (>300 μm). In contrast, the proportion of <300 μm dust to the total dust in the six urban houses from the first vacuuming study averaged 38% (range 19.4 - 58.7%). Thus, in the six urban houses with higher percentages of carpet, the fraction of fine dust (<300 μm) to the total dust was markedly higher than in the 15 houses with mostly hard-surface floors.

Figure 7 shows the dust weights in three different size fractions: <150 μm, 150 to 300 μm and >300 μm for House 8 of Study 2. The results for House 8 are representative of the results from the other houses in the study. The >300 μm dust-weight fraction progressively decreased with each vacuuming, except for the sixth session, which was four weeks after the previous session. The 300 μm to 150 μm and the <150 μm dust-weight fractions also decreased, but not consistently.

The total dust weights and the fine dust fractions decreased with successive vacuumings in the second study. However, the changes in the levels of fine dust with successive cleanings were small and not as noticeable as those in the six urban houses of Study 1.

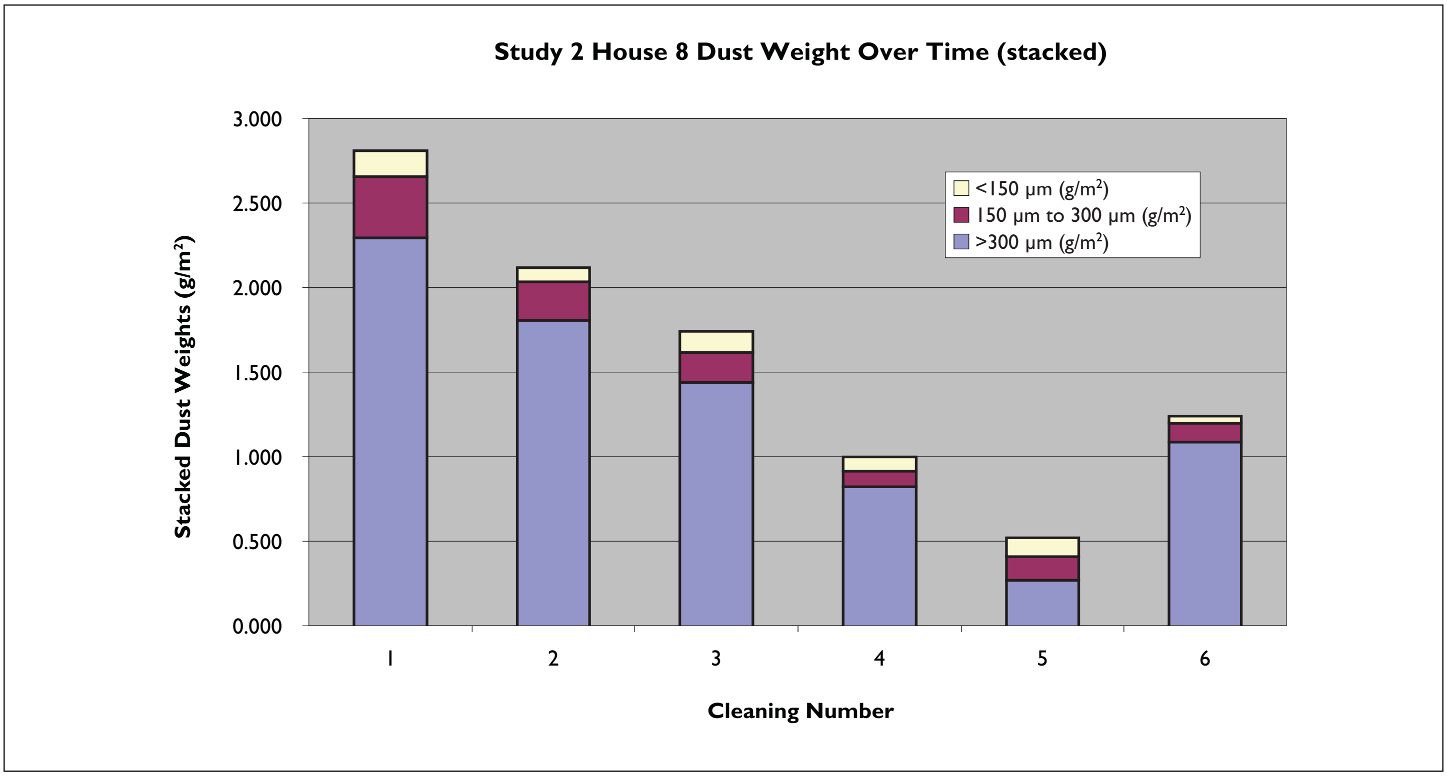

Figure 7 Vacuum bag dust weights for Study 2 House 8 over a nine-week period

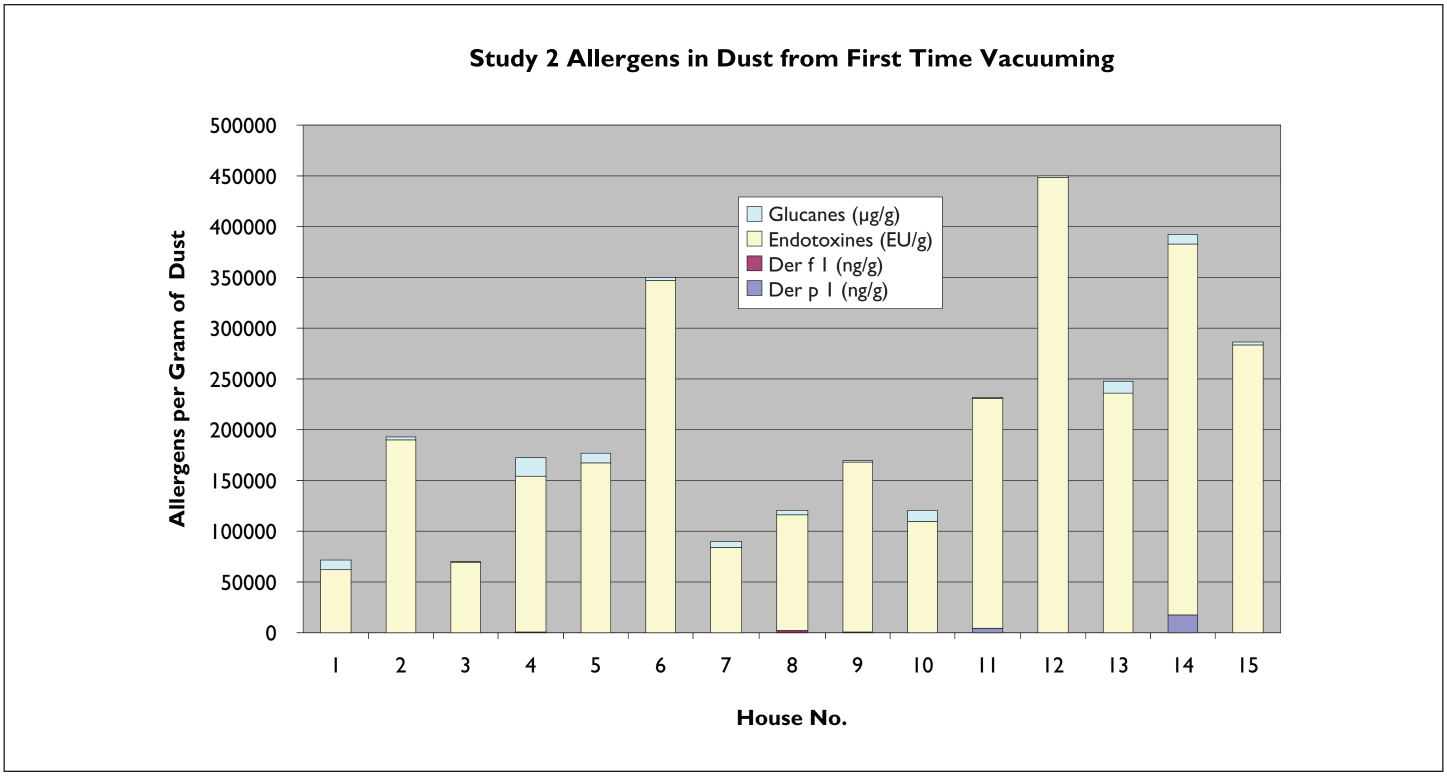

Figure 8 Levels of mite allergen (*Der f* 1), endotoxin and glucan in first time vacuumings from the 15 houses of Study 2

Figure 8 shows dust mite allergen (*Der f* 1 and *Der p* 1), bacterial endotoxin and fungal glucan levels from first time vacuumings of the 15 houses in the Quebec community.

Dust mite allergen levels (*Der f* 1 and *Der p* 1) in the dust collected during the vacuuming sessions, were generally low (between 10 to 498 ng/g), with the exception of three houses, which had 2.0 µg/g, 3.9 µg/g and 17.7 µg/g.

Endotoxin levels, which are produced by gram-negative bacteria and come from pets or accumulate from the outdoors, were much higher in the fifteen houses, averaging 1,579.75 ± 856.85 EU/g/m^2 compared to 594.6 ± 187.9 EU/g/m^2 found in the six urban houses.

Glucans, cell-wall components of fungi and markers for the presence of mold in houses, were higher in the fifteen Quebec houses in comparison with the six urban Ottawa houses. This reflected higher levels of mold contamination. In the fifteen houses, four had glucan levels below 20 µg/g/m^2, two houses had levels between 20 and 30 µg/g/m^2 and nine had glucan levels between 40 and 108 µg/g/m^2. In five of the six urban houses from the first study, glucan levels in dust extracted from first-time cleaning sessions were low, ranging from 7 to 23 µg/g/m^2. As noted earlier, one of the six houses was an exception, it had a musty smell and it had a glucan level of 85 µg/g/m^2 indicating the presence of mold.

CONCLUSIONS

The vacuuming protocol developed for these studies demonstrated that a rigorous vacuuming program using a HEPA filter-equipped vacuum cleaner could significantly lower dust loading in the study homes. The protocol required continuous vacuuming for 1 minute/m^2 of carpeted areas, 45 seconds/m^2 for hard surfaces with area rugs and 30 seconds/m^2 for hard-surface floors. The studies showed that a one-time vacuuming session removed a substantial portion of the total dust extracted over the six weeks. However, three to four vacuuming sessions following this strict protocol were required to reduce the level of fine dust to a low and steady value. A reduction in the level of fine dust is desirable, as other studies have correlated exposure to airborne contaminants contained in fine dust to the amount of settled dust per unit area in homes.

The duration of vacuuming sessions in this protocol is likely much longer than the amount of time homeowners typically spend vacuuming their floors. However, to get maximum benefits from a HEPA filter-equipped vacuum cleaner, longer vacuuming times are required to remove more dust.

The results of the air sampling with the MOUDI in Study 1 revealed that particulates are dispersed in the air during the vacuuming sessions despite the use of the HEPA filters on the vacuum outlet due to the disturbance of settled dust. This points to the potential exposure to fine particulates and contaminants by the individual who is vacuuming as well as other people in the house.

The dust samples from the first vacuuming session of the fifteen Quebec community homes in the second study showed low dust-mite allergen levels but higher endotoxin and glucan levels compared to samples from the first study of six urban homes in the Ottawa area. The higher glucan levels are consistent with the presence of mold in the houses of the second study.

The total dust weights per square metre of floor area collected in the homes of the two studies were similar. However, the dust collected from the mainly carpeted surfaces of the six urban houses had a higher fraction of fine dust while the dust from the fifteen remote community homes consisted mainly of the larger size fraction (>300 µm). The dust weights declined with successive cleanings, but the decrease in fine dust was small in the homes of the second study.

The second study revealed the amount of fine dust removed by thorough HEPA vacuuming was a smaller fraction of the total dust found in houses with predominantly hard surface floors (the fifteen houses) than in houses examined in the first study with predominantly carpeted floors (the six urban houses). This supports the idea that carpets can act as dust reservoirs and accumulate fine dust.

The studies showed that thorough weekly vacuuming with a HEPA vacuum cleaner effectively reduced all fractions of dust weights. As would be expected, extended intervals between vacuuming resulted in an increase in dust levels.

The levels of endotoxin in dust from any given house were specific to that house and remained unchanged by successive cleanings. However, reducing the amount of dust would be expected to decrease the level of dust mite allergens and glucans.

IMPLICATIONS FOR THE HOUSING INDUSTRY

Floors with carpets act as dust reservoirs and repeated and thorough cleaning with a HEPA filter-equipped vacuum cleaner is needed to reduce their dust loading. Using a HEPA filter-equipped vacuum cleaner together with specific vacuuming times can reduce exposure to indoor allergens and contaminants. However, even vacuums equipped with HEPA filters can cause particulates to become airborne. Sensitive individuals and children should not be in the rooms being vacuumed. Using N95 respirator masks should minimize exposure to airborne dust during vacuuming.

A practical application of these results relates to houses with a mold problem that cannot be immediately addressed. Very thorough and frequent vacuuming with a HEPA filter-equipped vacuum cleaner is an interim measure that can be taken prior to remediation to help reduce the risks associated with exposure to mold. The findings also indicate that, in the event a house is contaminated with mold, the occupants of non-carpeted houses are less likely to be exposed to mold spores, fragments or debris that may become airborne and inhaled during vacuuming or other activities.

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Housing Research at CMHC

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