REDUCING PARTICULATE LEVELS IN HOUSES

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ABSTRACT
This study started as an evaluation of the effectiveness of different furnace filters in reducing the amount of airborne particulate in houses. The research quantified the filtration efficiencies of a range of residential furnace filters in several houses. The monitoring showed that even good filters had a relatively minor effect on house particulate levels during periods of occupant activity. Subsequent research has looked at alternative methods of lowering indoor particulates. This includes the relative effectiveness of various vacuum cleaners and a comparison of particulate levels in rooms with smooth floors versus rooms with carpets. The filtration effect of the building envelope on incoming air is being studied as well as the effect of house ventilation with and without outdoor air filtering using filtered air. It is likely that it will take a combination of these measures to eliminate high levels of house particulate.

INDEX TERMS
Residential, indoor particulate, air filtration, cleaning, field testing

INTRODUCTION
With the advent of residential forced air furnace filters claiming efficiencies in the order of 90-100%, Canada Mortgage and Housing Corporation (CMHC) launched a research project to measure the effects of higher efficiency filters on house respirable(RSP) and inhalable particulate levels (IHP). CMHC provides advice to Canadians and could not find good information on household particulate reduction through filter use. Since the onset of this filter research in 1996, CMHC now has a better understanding of the quantities of particles in Canadian houses (particularly in heating season conditions) and the various means of reducing residential exposure to particles. This paper discusses the implications of the filter research plus the subsequent investigations of floor cleaning effectiveness, hard floors vs. carpeted surfaces, and the effect of several ventilation strategies on penetration of outdoor particles. Another research paper in this conference looks at ozone production by residential electrostatic precipitators (or "electronic filters"). (Bowser et al 2002).

There has been some excellent research into house particulate levels, including results from the TEAM studies (e.g. Ozkaynak et al 1993) and Dr. Spengler's group (e.g. Abt et al 2000) from Harvard. Particulate testing in Canadian houses has been relatively rare. Particulate measurements are usually tagged on, with rudimentary instrumentation, to an omnibus air quality sampling. Technicians during this survey work have been heard to comment that particle counting was in progress until "... someone walked through the room and screwed up all the measurements." It was not until the current research that CMHC understood how those occupant-induced particulate spikes contributed to the total exposure. In Canadian winters, most houses operate with all or most of their windows closed, in an attempt to limit cold drafts and heating costs. The particulate levels in closed Canadian houses in winter are very different from the concentrations seen in American testing in more benign climates, where the indoor levels are closely tied to the outdoor concentrations due to high house air exchange

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rates. Particulate testing as well has been plagued by a multitude of test devices, test protocol, and particle cut sizes (e.g. TSP, RSP, ISP) making it difficult at times to compare data from different sources.

RESEARCH METHODS

Throughout the recent CMHC research the same particle counting equipment has been used for most of the measurements, providing some consistency of results. The particle sampling rig used a central vacuum pump and five sample lines, one generally to the outside, and four available for inside sampling. The sampling rig generated a continuous flow of 5 L/m (Litres per minute) in each line and rotated sampling sequentially to each line on an interval of 90 or 105 seconds. . The active sampling flow was first passed through an impact separator which removed particles above 10 µm before passing into the particle counting instrument. Two optical (laser) particle counters were used interchangeably, each recording numbers of particles in four channels between 0.3 µm and 10 µm. In some of the experiments, the two particle counters were used simultaneously, with the second counter mounted in a wearable package to gather personal exposure data. The resulting data was used to approximate real-time particulate level data from 5 separate locations on 8 minute intervals.Sampling details are available in various reports (Bowser 1999, Bowser et al 2000).

The furnace filter research consisted of testing ten filters in the first house, with two of the sampling lines counting particles upstream and downstream of the filter in the ductwork, providing an operating filtration efficiency. Three inside sampling lines monitored conditions in a common living area, in a bedroom, and outside. After the monitoring system and protocol were refined, five of the furnace filters were rotated through five sample houses, with different occupancies, etc., to test the in-house effectiveness of the range of filter efficiencies. Each filter was operated for several days only, making the results inappropriate for filter loading effects. Almost all testing took place with the furnace fan operating continuously. All furnace filter testing took place during winter or early spring weather in the Brantford, Ontario region. Outdoor particulate measurements taken at the site were compared to Environment Canada outdoor data from a nearby monitoring station (Dann 2001). The real-time data output allowed the researchers to view the relation of house particulate levels with corresponding occupant activity as well as outdoor particulate levels.

Subsequent studies investigated the effects of floor cleaning devices and floor surfaces on re-suspended particulate concentrations. In these experiments, activity was simulated through the towing of a battery-powered vacuum cleaner, with filter removed, through a repeatable pattern by a remote control. The test pattern repeatably created particulate similar to human usage of the space. This work, unpublished at the time this paper was written, includes comparisons of the particulate reductions due to cleaning by a variety of vacuum cleaners on carpets, and by vacuum cleaners, mops, and brooms on hard surfaced floors. The research has also investigated several house ventilation arrangements with and without filtering of incoming air.

RESULTS

The measured efficiencies in the ducts of the five houses is shown in Table 1 for the filters tested. One of the five filters tested in each house was a usually a bypass HEPA filter. While this filter approached 100% filtration efficiency within the bypass duct, its rated efficiency depended upon how much of the return air flow it treated. For instance, a 100% effective filter which operates in a bypass which treats only 40% of the furnace airflow would be rated equivalent to 40% effective filter.

Table 1. Upstream-DownStream Efficiency, Average of all Houses
(Excluding House #5 and House #4 Auto-Fan data)

	PM_{10} (%)	PM_1 (%)
None	5	0
Bypass	30	27
Electronic pad	30	17
100 mm pleated	36	21
25 mm electrostatic	45	21
ESP	90	84

Note that, as has been found in other testing (Offermann 1992), the electrostatic precipitator filter was the most effective, coming close to 90% filtration efficiency for both PM_{10} and PM_1. The other filters fell into a group of 20-50% filtration efficiency during the five house testing. Table 2 below shows the actual reduction of particulates measured in these five houses when these filters were installed.

Table 2. Particulate reduction in five houses over "no filter" case (PM_{10})

Filter	Occupied Space Active		Occupied Space Non Active	
	Particulate reduction (µg/m^3)	% Improvement	Particulate reduction (µg/m^3)	% Improvement
None	N/A	N/A	N/A	N/A
Bypass	2.5	23	1.4	38
Electronic pad	1	9	1.1	29
100 mm pleated	1	9	0.5	13
25 mm electrostatic	2.3	21	2.0	57
ESP	3.4	31	2.6	71

The absolute particulate reductions are fairly small as the mean particulate levels were generally low. The distinction of "active" vs. "non-active" refers to house activity. Non-active data is during periods where the occupants were absent or asleep. Active periods encompassed all other situations. The trends are clear. The higher in-duct efficiency of the filter, the greater the particulate reduction in house air. However the magnitude of particle removal in the space is significantly lower the in-duct removal, particularly during the active periods. While Table 1 shows an in-duct efficiency of the electrostatic precipitator of roughly 90%, the reduction of airborne particulate measured in the houses during active periods was only reduced about 30%. These results are from houses where the furnace fans were operated continuously (with some minor exceptions). The indoor air particulate reduction of the filters would be even smaller if the furnace fans operated only when the burner operated, as is common in most Canadian houses.

The reasons for this seeming discrepancy can be found in Figure 1. This shows the measured PM_1 and PM_{10} concentrations in House 3 with the ESP operating, over a period of 24 hours.

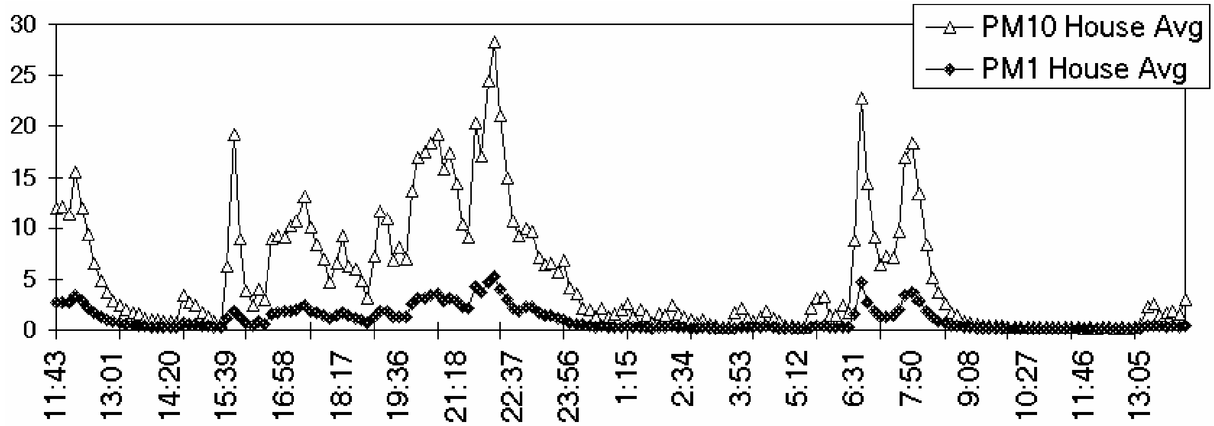

Figure 1. Typical household particulate concentrations over 24 hours with ESP in operation

The concentrations represent the mean particulate levels measured in a bedroom and the living room. Note that during activity periods concentrations of PM_{10} rise up to 30 µg/m^3. During periods of occupant absence or sleep, the "non-active" periods, the PM_{10} concentrations are near zero. The figure shows that predominant particulate exposure occurs during the active periods. Furnace filters cannot immediately remove the dust created by activity. Occupant exposure to these "clouds" of dust is therefore quite similar regardless of the quality of filter installed. Note that PM1 levels also seem to respond to household activity.

Because these findings showed that furnace filters had a limited effect on indoor particulate levels, CMHC widened its investigation to look at some of the other factors. Testing of a variety of vacuum cleaners on carpeted and bare floors shows several trends. See Figure 2 below. The floor surfaces are mechanically agitated prior to air particulate measurement. The first bar in each set of three is the increase in room air particulate levels due to floor surface agitation. The second bar is the increase in particulate levels during the cleaning activity. The third bar is the increase in particulate levels during floor agitation, following the cleaning activity.

This particulate level, especially for the PM_{10} and PM_5, shows a decrease after the floor surface has been cleaned. Analysis is so far incomplete on comparing the relative cleaning efficiencies of the different vacuum cleaners. However, some conclusions can be made.

1. The particulate levels during vacuum cleaner operation are dependent upon the cleaner used. For instance, an inexpensive portable vacuum (or a broom on a bare floor) can create room air particulate levels in excess of those measured when the floor surface is mechanically agitated. Conversely, a central vacuum vented to outdoors or a HEPA vacuum significantly reduces room air particulate concentrations during its operation.
2. The room air particulate levels over a bare floor are an order of magnitude less than over a carpeted floor in the same house, during periods of agitation. Particulate increases over a bare floor during mechanical agitation are in the 10 to 50 µg/m^3 range, for PM_{10}. During agitation of carpeted floors, values rise 50 to 250 µg/m^3.
3. The trends in PM_1 during periods of agitation and cleaning are not consistent.

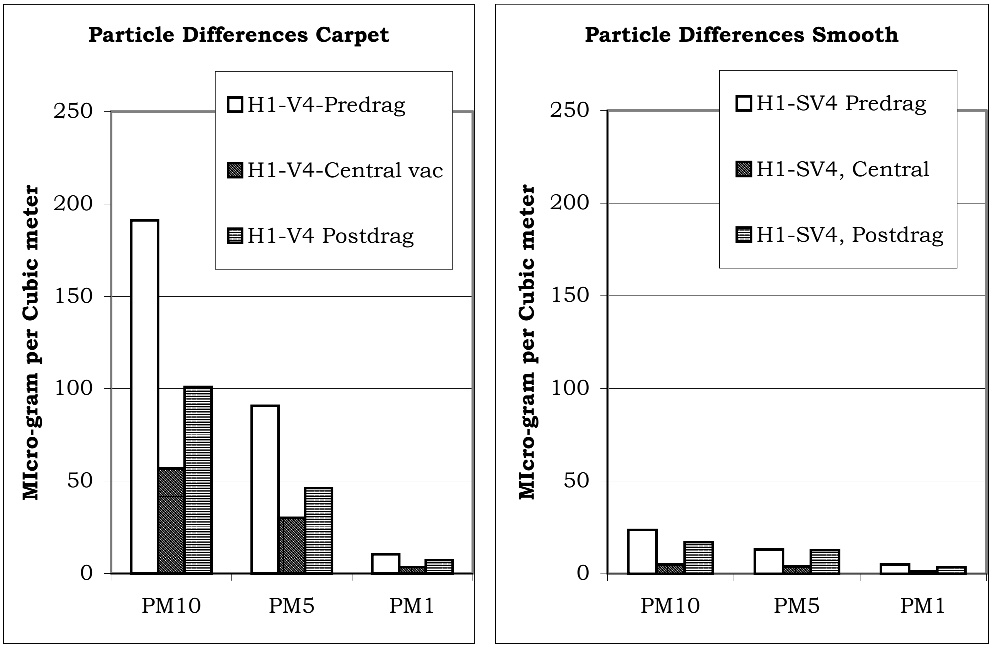

Figure 2. Effects of vacuuming on carpeted floors and bare floors

Experiments with house ventilation strategies may lead to strategies which can be useful in reducing indoor particulate levels in spite of high outdoor levels. For example, Figure 3 represents an April day with high exterior particulate concentrations ($PM_{10} > 35$ µg/m^3) and minimal activity in the test house, except for a floor agitation around 2:15 p.m.. The house was pressurized with 169 L/s of outside air passed though a HEPA filter, creating a nominal house pressure of between 4 and 5 Pa . Note that house concentrations of PM_{10} averaged less than 1 µg/m^3.

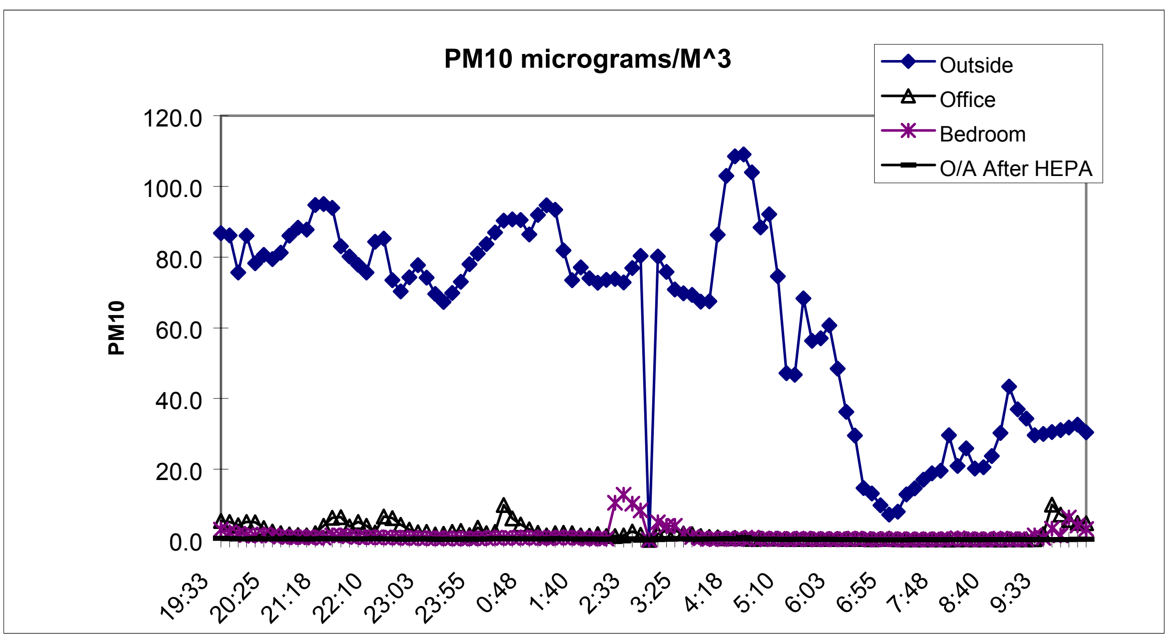

Figure 3. Indoor particulate levels with HEPA-filtered supply air

DISCUSSION

A drawback of the electrostatic precipitator filter is the incidental ozone creation by these devices. Tests of a number of Brantford houses with ESPs showed an increase in duct ozone levels in the range of 10 ppb. Discussion of this work will be covered in a separate CMHC report and in another paper in this conference titled "Indoor Ozone and Electronic Air Cleaners".

Specific house ventilation strategies such as balanced ventilation or pressurization with outdoor, filtered air can significantly reduce the ingress of outdoor origin fine particulate and thereby reduce the total exposure of individuals to these pollutants. The effectiveness of a balanced ventilation approach may depend on the degree of airtighness of the house envelope Heat recovery from exhausted air is feasible. House pressurization is not recommended in cold climates during heating seasons, as moist interior air may be forced into walls or attic and condense, although small positive pressures may not be harmful, and pressurization during spring, summer, and fall should pose no problem to the house envelope. Heat recovery is usually not feasible for pressurization type ventilation systems.

CONCLUSIONS

1. Measured house particulate levels during Canadian winter conditions (with closed windows) were lower than data from American studies.
2. Testing of furnace filters showed that even high efficiency filters will have a minimal effect on house airborne particulate levels when occupants are active. Good filters were seen to reduce particulate levels up to 70% during non-active periods, such as during sleep.
3. Cleaning floor surfaces will reduce the amount of particulate produced by floor agitation. The particulate re-suspension due to activity is far lower over a hard floor than over a carpet.
4. Some specific methods of mechanical house ventilation have the potential to reduce indoor particulate levels by protecting against the ingress of outdoor particles and may be practical for application to Canadian houses.

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