THE EFFECTS OF IMPROVED RESIDENTIAL FILTRATION ON PARTICULATE EXPOSURE

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ABSTRACT

Forced air furnaces are a common Canadian heating system. Traditionally, filters placed in the circulating air ductwork were designed to protect the furnace and fans. Over the last several years, there has been increased emphasis on improving the filtration efficiency with the goal of reducing occupant exposure to respirable particulate. The current research project rotated several filters through six houses in southern Ontario during the heating season. Particulate levels were continuously monitored in the outside air, before and after the filter in the ducting system, and in the air in two rooms of each house. The results show that air passing through the filters was cleaned generally in accordance with rated filtration efficiency. The integrated breathing zone exposure, however, reflects both dust generation and dust removal mechanisms. Breathing zone exposure reductions were therefore not as significant as reductions seen in the ducting systems. A study of 15 additional houses with air cleaning by electrostatic precipitation looked at the levels of ozone found in these houses.

INTRODUCTION

Canada Mortgage and Housing Corporation (CMHC) is the federal department that deals with housing policy and research. It commissioned a project investigating furnace filter efficiency so that it could better advise the public on filter selection. Over 60% of Canadian houses have forced air heating [1], and the usual filtration in the forced air system is an inexpensive fibreglass throwaway filter. The function of these filters is largely to protect the fan and the furnace heat exchanger, and the manufacturers make no claim on their efficiency of dust removal. In recent years, with an increasing consciousness of indoor air quality issues, more efficient filters have appeared. These range from mild upgrades, such as pleated "medium efficiency" disposable filters, up to high efficiency particulate (HEPA) filters, with a bewildering variety of products being offered. Filter efficiency can be rated by a number of standards, such as arrestance, dust-spot, and D.O.P. [2,3], and there is no agreement on which rating system is most appropriate for household filters. It is difficult for a homeowner to select a filter suitable for their needs and to know what effects can be expected in their house.

CMHC planned to create a consumer document on filter selection. This research project was undertaken to provide the data necessary for formulating this advice. Essentially the full range of filters were tested in six occupied houses, which represented a variety of occupancies, locations (urban and rural), and dust sources. At least five different filter types were tried in each house. The measured indoor particulate levels could then be compared to the filter efficiencies. One caveat: each filter was in use in each house only for a matter of days. Questions about the effects of filter loading or long term house particulate trends can not be answered by the data generated in this study.

METHODS

The first house was used for pilot testing of the test protocol and of the filters. This house was also used to compare station vs. personal monitoring results and the effects of household activities on particulate generation. Some filters were tested with the furnace fan cycling rather than being on continuously. Such experiments were continued, to some degree, in other dwellings. All filters were installed in-line (except for the two by-pass filters) in the return air ducting system, with modifications being made to the sheet metal to accommodate different filter thicknesses. Furnace flow rates and pressure drops across the filters were measured in each house. There was no attempt made to modify the furnace fan flow rate to compensate for differing filter flow resistances. While this might be a good idea in some installations, for the most part the filters did not obstruct flow to an extent where furnace performance would be jeopardized.

The ten filters tried in the first house included a standard throwaway $2 filter, a $6 pleated filter, and various upgraded, higher efficiency filters. From these ten, five were selected for testing in the remaining houses, including:

1. Higher cost 25 mm pleated, with factory-applied passive electrostatic charge
2. DC current, charged-media type
3. 100 mm pleated media filter
4. Electrostatic precipitator or "electronic" (plate & wire type)
5. By-pass HEPA or a by-pass proprietory device with an internal filter bank

The five houses had these filters installed sequentially. The house indoor and outdoor air were monitored, usually for a total of 2-3 weeks. All testing took place during the winter and early spring, to minimize atmospheric dust entry that might increase due to opening of windows.

In separate testing, fifteen houses with existing electrostatic precipitators were tested to determine the ozone generation rates of these units, as found and after cleaning. If the research showed that electrostatic precipitators performed well, then CMHC needed some data on their levels of inadvertent ozone production prior to recommending them to consumers.

Particle measurement was carried out for fixed stations using a central vacuum pump, valve, and switching apparatus which obtained samples from 5 stations sequentially at up to 15 m distance. Sampling lines were 6 mm internal diameter copper and teflon with iso-kinetic inlets, used at a constant air-flow rate of 5 Lpm. A complete sample set was obtained at 8.75 minute intervals. An in-line Airmetrics greased-plate impact separator was used to remove particles larger than 10 micrometers in aerodynamic diameter and the remaining particles were counted using either a MET-ONE Model 237B, or a BIOTEST 1000 APC Optical Laser particle counter. Output data consisted of real-time particles concentrations in three ranges being 0.5 to 1.0 micrometers, 1.0 to 5.0 micrometers; and 5.0 to 10 micrometers. Both particle counters were calibrated using Latex-Polystyrene spheres by their respective approved calibration lab.

A general record of activity was kept with identification of at least the following activities: sleeping vs waking, type of activity, cooking, and vacuuming. Personal monitoring was conducted using the BIO-TEST Particle Counter in a body-pack with an iso-kinetic sampler mounted in the breathing zone of the individual. Ozone monitoring was conducted using a DASIBI 1000AH Ambient Ozone Monitor (UV sampling chamber photometer). Airflow in ducts was measured using Environmental Control Technologies flow-sensing elements, cross verified with detailed pitot-tube traverse measurements. Other parameters measured on a continuous basis (maximum 15 minute intervals) include air-handler status (on/off/hi/low), indoor temperature and RH, outdoor temperature, and wind-speed.

RESULTS

The particle count data is converted to a gravimetric concentration value expressed in microgram/m3 of air using the following assumptions:

a) Average particle sizes are:
   for 0.5 to 1.0 micrometre particles. . . . . 0.75 micrometres
   for 1.0 to 5.0 micrometre particles. . . . . 2 micrometres
   for 5.0 to 10 micrometre particles. . . . . 6 micrometres

b) Particles are spherical and have densities of:
   7,000 kg/m3 for particles 1 micrometre and below,
   2,500 kg/m3 for particles between 1 and 5 micrometre,
   1,000 kg/m3 for particles above 5 micrometre.

c) Results are expressed in gravimetric terms whenever possible, as follows:
   PM1. . . . . .the particle mass concentration below 1 micrometre
   PM10 . . . . the particle mass concentration below 10 micrometre

Gravimetric estimates were verified using co-location tests with conventional gravimetric sampling techniques using impact separators with 10 micrometre and 2.5 micrometre cut-sizes. Based on the data from the upstream and downstream in-duct sampling points, filter efficiency is derived for PM10 and PM1 values and expressed as a percentage efficiency.

Results are summarized graphically below. Figure 1 shows the mean efficiency of the filters as installed. This was determined by the PM10 mass calculated prior to and following the installed filter. There are essentially three separate resulting efficiencies. The "no filter" efficiency is greater than zero, suggesting that there are deposition or dilution effects which are not fully understood. The efficiency of the electrostatic precipitator (ESP) was significantly and consistently better than the other filters. The rest of the filters tested can be classified as those of intermediate efficiency, falling between the no filter/standard filter baseline and the high efficiency shown by the ESP. Their relative efficiencies varied from house to house. It would take a far bigger sample, with longer sampling periods, to clearly differentiate between these "medium efficiency" filters.

Figure 2 shows the clean air delivery rate (CADR) of the filters, averaged over the six houses. Clean air delivery rate (CADR) was derived by multipyiung the system airflow in L/s by the measured filter efficiency. CADR is the volume of completely clean air which is required to produce the same particle removal effect as the filter being tested. Again, there is a distinct pattern of near zero for "no filter", 200-300 L/s for the ESP, and a mid-range of CADR flows for the four other filters. Hoever, despite these reasonable efficiencies and some substantial clean air delivery rates, having a good filter in the house does not necessarily result in a big decrease in indoor particulate.

Figure 1: Mean Efficiency (PM10)

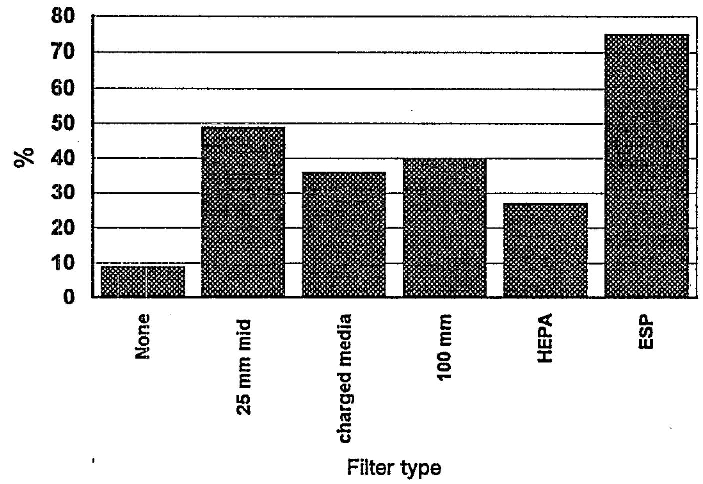


Figure 2: Mean CADR

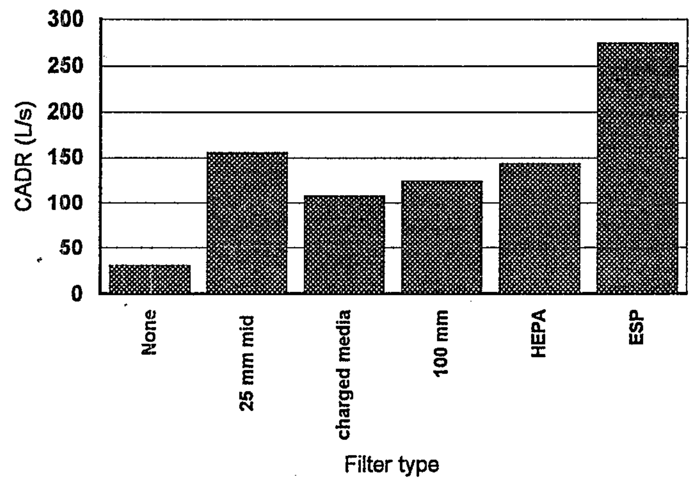


Figure 3: Mean Indoor PM10

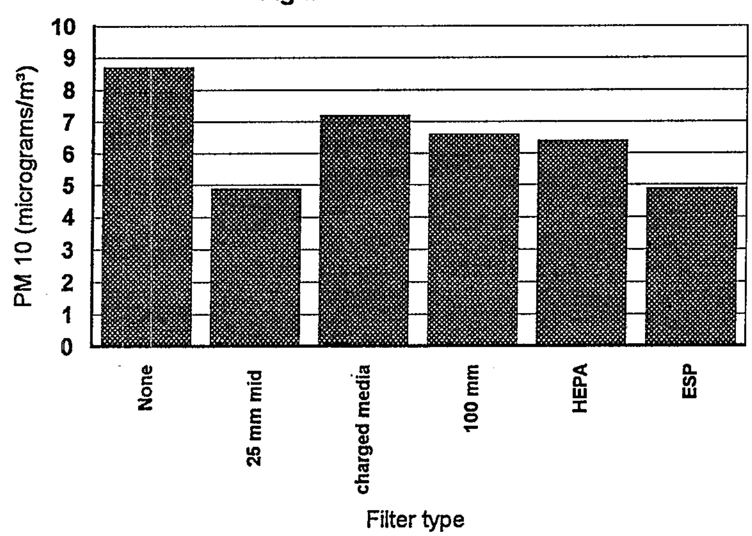


Figure 3 shows the cumulative indoor particulate concentrations in the six houses, which has been constructed from about 280 hours of data per filter. Again, there is a vague trend evident with the extremes represented by "no filter" and the ESP, however, the differences are not as marked as the differences in filter efficiencies. One factor may be the relatively short duration of the filter testing. If an efficient air filter actively cleans the entire house, then it may be that the data collection times were insufficient for these long term effects to take place. More importantly though, the dust production or source effects tend to overwhelm the dust reduction potential of the air filters. Figure 4 shows a typical 24 hour monitoring period in a house, with PM10 concentrations in a house with the ESP in operation. The concentrations are the average of the two interior collection sites, the bedroom and the living room. Note that during activity periods, concentrations go as high as 30 micrograms per cubic metre. PM1 has a lower amplitude but a similar pattern. The peaks shown emerge no matter what filter type was in use, and were observed as well with personal monitors. In essence, activity creates a dust cloud that overwhelms background concentrations and will determine the bulk of respiratory exposure. Note that during resting periods the PM1 concentrations drop to near zero in this house. In the same house with no filter in place, the patterns are similar but during the rest period, baseline concentrations are significantly above zero. It appears that a good filter will significantly reduce the house concentrations during rest periods. However, for most people in most houses, this rest period exposure will be only a small part of the total particulate exposure, dwarfed by particulate exposure during the activity periods.

Figure 4: 24 Hour Monitoring Period in House 3

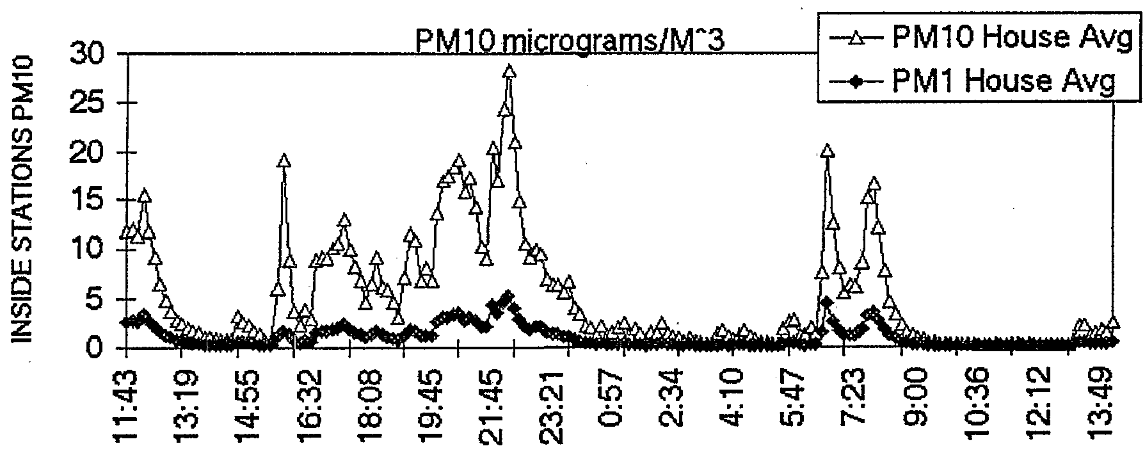
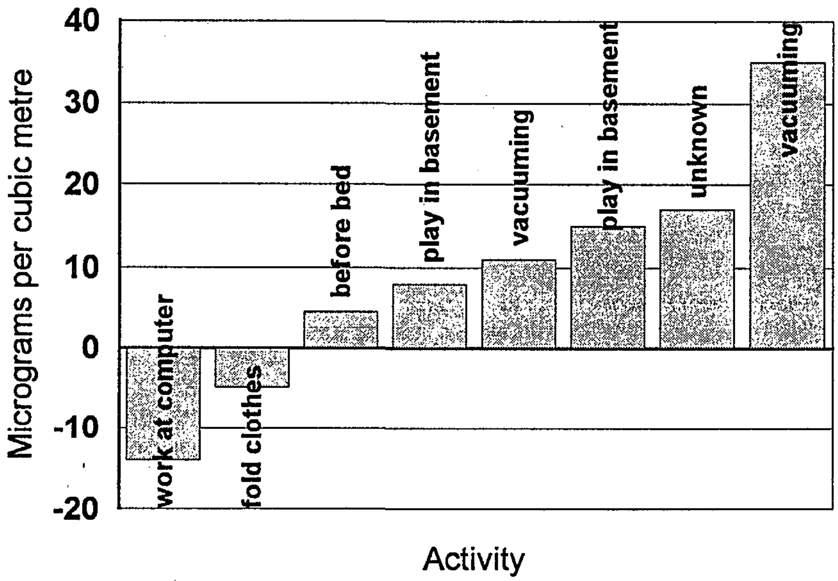


Figure 5 provides a comparison of personal exposure results and station monitoring, with the subject being a 12 year old boy in House 3. As can be seen in the graph, for some activities such as vacuuming, the personal exposure was significantly higher than a station monitor nearby. For other activities, including rest periods, the station monitor would slightly overstate particulate exposure.

The ozone testing on fifteen houses where ESPs were in operation showed that all but one produced measurable amounts of additional ozone. The ozone increase in the duct airstream, before and after the ESP, averaged 9 parts per billion (ppb) with a range of -2 to 22 ppb. The ESPs were tested for ozone as found and after cleaning, and there was no consistent improvement to lower ozone production after cleaning. The increase in ozone levels in the

Figure 5: Excess of Personal Exposure Over House Average



indoor air was always less than the increase seen in the ducts. Measured inside levels of ozone never exceeded 20 ppb, less than the Canadian one-hour, residential guideline of 120 ppb [4]. Outdoor ozone levels were significantly higher than those measured indoors.

DISCUSSION

This research showed that upgraded filters installed in a forced-air furnace circulation system reduce the amount of particulate in the duct system, roughly in proportion to their measured effectiveness. The results also show that this will not necessarily result in a significantly reduced particulate exposure, due to the particulate source terms that overwhelm this removal mechanism. Household particulate can be reduced through standard approaches such as removing footwear on entry; keeping major dust generators (e.g. smoking, pets) out of the house; reducing dust collecting surfaces (open shelves, carpets, upholstered furniture, etc.); diligent and frequent vacuuming with an efficient vacuum cleaner; and reducing the entry of particulate-laden outdoor air, by closing windows, improving house airtightness, and installing a intake filter on the air supply. If these improvements are made, then the installation of an efficient furnace filter, with the furnace fan operating continuously, would probably make a significant reduction on the remaining, minimal particulate exposure.

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