RESEARCH REPORT

Medium Efficiency Filtration: Improved Filters for Residential Forced Air Furnaces

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/MEDIUM EFFICIENCY FILTRATION:/

IMPROVED FILTERS FOR

RESIDENTIAL FORCED AIR FURNACES

Prepared for

Project Implementation Division
Policy, Research and Program Sector
Canada Mortgage and Housing Corporation

by

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Ottawa, Ontario

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CMHC SUMMARY

Background:

The creation and maintenance of clean air environments with reduced levels of dust, mould and other pollutants is highly desirable in housing, especially for those homes where there are smokers or allergy sensitive individuals. In a forced air heating system, air stream filtration offers an opportunity to effectively reduce pollutant levels. However, typical throw-away or washable furnace filters are only 5% efficient in removing particulate matter, while electronic filters, which can be 70-90% efficient, have the disadvantages of high capital cost and possible ozone production. Medium efficiency filters with efficiencies in the range of 15-60% may represent a cost-effective alternative to upgrading the quality of residential ventilation.

Objectives:

To determine the cost effectiveness of medium efficiency filtration, in comparison with typical low and high efficiency filters, with respect to (a) reducing levels of dust, tobacco smoke and mould, and (b) impact on fan and furnace operation.

Methodology:

A representative selection of twelve filters were field tested at three typical furnace airflow rates. Static pressure drops, airflow rates and heat exchanger temperatures were measured. A particle counter was used to measure filter efficiencies in removing artificially introduced quantities of cigarette smoke and dust particulates. The potential for filtering at return air grilles and for installing filter clogging alarms was also investigated.

Conclusions:

Medium efficiency filters were found to be significantly more effective than low efficiency filters but less effective than high efficiency electronic filters in removing dust at low velocity ventilation rates. With respect to cigarette smoke, m.e.f.'s performed as effectively at low velocities as electronic filters; neither appeared to be effective at higher velocities. In most cases, the airflow reduction caused by medium efficiency filters was less than 20%, and could be accomodated through simple adjustments. The cost of retrofit procedures was nil for 25 mm filters and minimal for thicker media.

Recommendations:

Medium efficiency filtration would appear to be a cost effective method of improving air quality when installed with a low-velocity continuous ventilation system. It would not appear to be very effective with intermittent high-velocity systems. Increased use of two speed air handling systems is therefore recommended. Since the potential for filter clogging is much greater than for low efficiency filters, the consultant could not recommend that medium efficiency filters be considered appropriate for all retrofit situations, and recommended that retrofit test procedures be implemented to determine the suitability of specific furnace systems prior to the installation of medium efficiency filters.

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EXECUTIVE SUMMARY

This report details the results of a field investigation undertaken to compare the mechanical and filtration properties, in a residential furnace application, of eleven medium efficiency filters with respect to one standard low efficiency filter. The filtration properties investigated were the ability to remove dust and tobacco smoke from the airstream. The impact on airflow and external static pressure was also assessed.

The furnaces tested were determined to function properly with the medium efficiency filters in place, however, it is recommended that guidelines to determine the suitability for the widespread use of the filters should be developed.

A literature search provided both the mechanical compatibility of the furnace from an operational point of view, and a representative selection of filters from those available in the market.

Three forced air furnace airflow rates were selected for testing and the furnaces were retrofitted to accept the filters. Static pressure drops across the filters and the furnaces were measured. Airflow rates and heat exchanger temperatures were also recorded. Filter efficiency was measured using a particle counter. Testing was conducted during the week of March 24-28, 1986.

It was found that the dust removal of most of the medium efficiency filters was significantly higher than the low efficiency filter. The efficiencies of tobacco smoke removal were low, and only apparent under low air flowrates.

In an attempt to determine the presence of mold spores in the housing environment, preliminary sampling showed there was not a significant amount of spores present to make an effective measurement across the filters.

1.0 BACKGROUND

With the increased airtightness of residential dwelling units, improved indoor air quality has become a growing concern. Indoor air pollutants such as tobacco smoke, dust particles, lint, animal dander and cooking pollutants can exist in greater concentrations due to the reduced natural air exchange rates of these residential units. Residential furnace systems using forced air heating typically contain a low efficiency impingement type filter. This filter serves two purposes: one, to remove particles from the air and, two, as a result keep the furnace blower clean.

These low efficiency filters, approximately 10% efficient, principally filter out larger size particles in the 35 micron and greater range, without restricting the airflow. Replacement of this type of filter should be at least once a month. Based on the costs of this low efficiency ($4-$5/3 filters) this is a simple inexpensive maintenance cost related to the furnace system.

There are a wide variety of medium efficiency filters available, operating in the range of 30% to 50% efficient. The efficiency is usually defined as the ability to capture particles of varying sizes. A typical test standard is ASHRAE 52-76, although it is not the only one. Filters are usually tested for arrestance, dust spot, or particle count. The arrestance test is a measurement of the filter's ability to remove large particles. A dust spot test reveals the filter's effectiveness at removing dust that can stain, and is a valuable indicator to owners of large buildings where cleaning and maintenance costs can be high. Stain removal performance using atmosperic dust is called **efficiency**. Since the vast majority of dust particles are of the small, light-weight variety, a particle count will provide a realistic picture of a filter's effectiveness in removing these small particles from the air.

Generally, the medium efficiency impingement filters exhibit high efficiencies for the large particle sizes, such as lint, pollen and mold spores, (10-30 micron), at 85%. The efficiency of removal of tobacco smoke is usually much lower, at 5-15% (particle size .1 micron). Thus the average efficiency over the test range is calculated to be 30-50%, depending on the filter.

Since the filters are normally manufactured from a cotton or polyester mat, the denser the mat, the greater the chances for impingement of particles, and also the higher the pressure drop across the filter. The major concern to the implementation of medium efficiency filters in residential furnaces is the pressure drop. They normally operate at 75 Pa, whereas the low efficiency filter operates at 30 Pa.

Most residential forced air heating systems are designed such that the pressure drop through the return air ducting is between 12 and 20 Pa. The supply ducting pressure drop is 35 to 50 Pa. Thus, the furnace must deliver rated airflow at an External Static Pressure (ESP) of 47 to 70 Pa. Most furnaces are shipped from the factory with a motor and pulley arrangement designed to deliver rated airflow at 65 Pa ESP. A corresponding increase in pressure requirements decreases the delivered airflow. Since the ESP is measured with the low efficiency filter in place, a medium efficiency filter increases the pressure requirements by 75 Pa - 30 Pa = 45 Pa. It is clear that an airflow reduction will result. Moreover, the long term implications, when the filter becomes loaded with dust, may result in even greater airflow restrictions.

To overcome the airflow reductions, the furnaces can be retrofitted, either by the wholesaler or the homeowner, with a smaller diameter blower pulley. Most furnaces have dual pressure rating at design airflow, such as the most common rating of 65 Pa ESP with a 175 mm pulley, or 125 Pa ESP with a 150 mm pulley. The higher rating allows for additional pressure requirements when air conditioning coils are installed. Thus, in theory, most furnaces could be retrofitted with medium efficiency filters without suffering any loss in performance, but the ability to add air conditioning may be removed. However, with the higher operating pressures, filter clogging may cause a marked reduction in airflow. As the filter clogs with dust, the pressure drop increases and the airflow decreases. The furnace system eventually reaches a state where the motor overheats and trips its thermal overload, or the bonnet temperature increases beyond the high limit temperature setpoint and the heat source is de-energised. The amount of clogging required to initiate the shutdown is very much dependant on the total installation, and not only the filter.

2.0 OBJECTIVE AND SCOPE

The objective of the field investigation was to determine the operating characteristics of medium efficiency filters in residential forced air heating systems. Further, the impact on total system performance and air quality was to be assessed.

The work included the selection of three different forced air heating systems, and a representative sample of medium efficiency filters. The furnace systems were retrofitted to accommodate the filters and the monitoring equipment. The operating characteristics of each system was then monitored.

3.0 PROCEDURE

3.1 Manufacturer Search

A survey of existing forced air furnaces was undertaken to determine the typical operating pressure limitations. A representative sample of furnace capacities is included in Table 3.1 below.

Furnace	ESP, Pa
Duomatic Olsen, gas	125 w/150 mm pulley
Duomatic Olsen, oil	125 w/165 mm pulley
Chromalox, electric	125 w/150 mm pulley
Brock, gas	125 w/125 mm pulley
Lennox, electric	175 Direct Drive
Lennox, gas	200 Direct Drive
ICG, gas	125 w/150 mm pulley

Note: All ratings were obtained from manufacturer's published literature

Table 3.1: Typical Maximum External Static Pressures at Rated Airflow

As previously stated, the duct pressure losses are typically less than 70 Pa, thus most equipment does have the capacity to accept filters with higher pressure drop characteristics.

Twelve generic types of filters were selected based on the ratings in the manufacturers literature. Seven of the filters were standard commercial pleated impingement types, two were electronic, two were classified as electrostatic (self induced), and the last one was the standard low efficiency filter. In selecting the filters classified as medium efficiency, the ratings given can vary considerably depending on the test method referenced. A chart of the types of filters and their efficiencies is included in Table 3.2.

The impingement type works on the principle of the particles embedding themselves into the filter media. As the filter fills up the filter becomes more efficient. The electrostatic (self induced) operates on the principle that a polyethylene scrim becomes charged by the airflow across it. This in turn attracts the particles as they flow by the polyethylene. A glass fiber media also assists in the filtering of the particles that are not picked up by the polyethylene.

The two electronic filters were chosen to represent two different methods of operation. The elctrostatic filter is a plug-in model that has an ionizing section, where the airborne particles receive an electrical charge. These positively charged impurities then enter a collector section where they are drawn to negatively charged plates. The polarized media filter uses a high voltage screen in front of a glass fibre media to polarize the media. Neutral charged dust particles are attracted to either the positively or negatively charged faces of the polarized media.

In addition to furnaces and filters, manufacturer's literature was searched for filter clogging alarms, and for mechanisms to attach the filters at the return air grilles, in place of retrofittings at the furnace. This option may be particularily attractive to retrofit older equipment.

Filter No.	Filter Type	Thickness (mm)	Published efficiency (%)	Test velocity (m/s)	Approx. Price Range
Baseline					
1	Low efficiency	25	8-10	---	$1-2
Pleated					
2	woven cotton and synthetic	100	30 ASHRAE 52-76	3.0	$23-27
3	non-woven, synthetic	100	30 ASHRAE 52-76	2.5	$23-27
4	non-woven, synthetic	100	60 ASHRAE 52-76		$23-27
5	woven cotton and synthetic	50	30 ASHRAE 52-76	2.5	$11-13
6	non-woven synthetic	50	30 ASHRAE 52-76	2.5	$11-13
7	non-woven synthetic	50	60 ASHRAE 52-76		$11-13
8	woven cotton and synthetic	25	30 ASHRAE 52-76	2.5	$8-11
Self Charging					
9	Polyethylene nylon		arrestance (AFI Dust Test)		
10	Polyethylene nylon	25	50, NBS Atmospheric dust spot rating	2.5	$25-30
Electronic					
11	Electronic	25	79	1.5	$160-170
12	Electrostatic	25	96 ASHRAE 52-76	1.5	$240-300

Table 3.2: Filter Selection for Test Program

3.2 Selection of Furnace and Retrofit

Since the manufacturer survey demonstrated that the pressure capacities of most furnaces were 125 Pa, the selection criteria narrowed to the air velocity across the filter frame. There is a significant variance between different manufacturers, as noted in Table 3.3.

Manufacturer	Model	Face Velocity across filter, m/s
Duomatic Olsen, gas	HCS 60	1.4
	HCS 70	1.6
	HCS 80	1.8
	HCS 90	2.1
Duomatic Olsen, oil	BCL 115	1.2
	BCL 125	2.2
Carrier, electric	40QB042	1.8 - 2.9
	40QB048	1.9 - 3.0
	40QB060	2.5 - 3.5
Chromalox, electric	HAF 310	1.5 - 2.1
	HAF 330	2.5 - 3.2
Brock, gas	HEUG 60	1.0
	HEUG 100	1.7
Brock, oil	.65 gph	1.2
	.85 gph	1.5
	1.10 gph	1.9
ICG, gas	HGD 60	0.9
	HGD 75	1.1
	HGD 90	1.4

Note: The information was obtained from the manufacturer's published data

Table 3.3: Typical Face Velocity across Furnace Filters

Based on this information, three representative installations, encompassing the velocity ranges listed in the table were chosen. **House 1**, was a high-boy gas furnace installation, with the air return plenum connecting to the side of the furnace, at floor level. The measured face velocity through the return air plenum was 4.0 m/s, with no filter in place, and 3.6 m/s with the standard configuration of low effiency filter. Two other velocities were chosen using a furnace with a dual speed blower. This arrangement typically allows continuous low speed fan operation to improve on the air distribution and air filtering, with high speed operation when there is a demand for space heating. The high speed face velocity is referred to as **House 2** at 2.8 m/s and the low speed as **House 3** at 1.2 m/s, measured with the standard filter in place. The furnace was a high-boy gas furnace, as shown in Figure. 3.1.

The furnaces were retrofitted with 100 mm deep filter frames as shown in Figure 3.1. In addition, sampling ports, both upstream and downstream of the filter frame were installed. The sampling ports were equipped with static pitot tubes to monitor pressure drop, and conical inlet sampling tubes to collect tobacco smoke counts.

3.3 Testing Procedures

The pressure drop across the varous filters, and the corresponding airflow was monitored for each filter installation.

The efficiencies of the filters in the removal of dust, cigarette smoke, and mold spores from the airstream were tested by measuring concentrations of each upstream and downstream of the filter. Tests were done on twelve (12) filter types in one housing unit. The materials and procedures for each test are described in the following sections.

3.3.1 Pressure Drop and Airflow

At the sampling ports upstream and downstream of the filter, the static pressure drop across each filter was measured using a Dwyer Magnehelix Guage (0 - 1 inch w.g.)

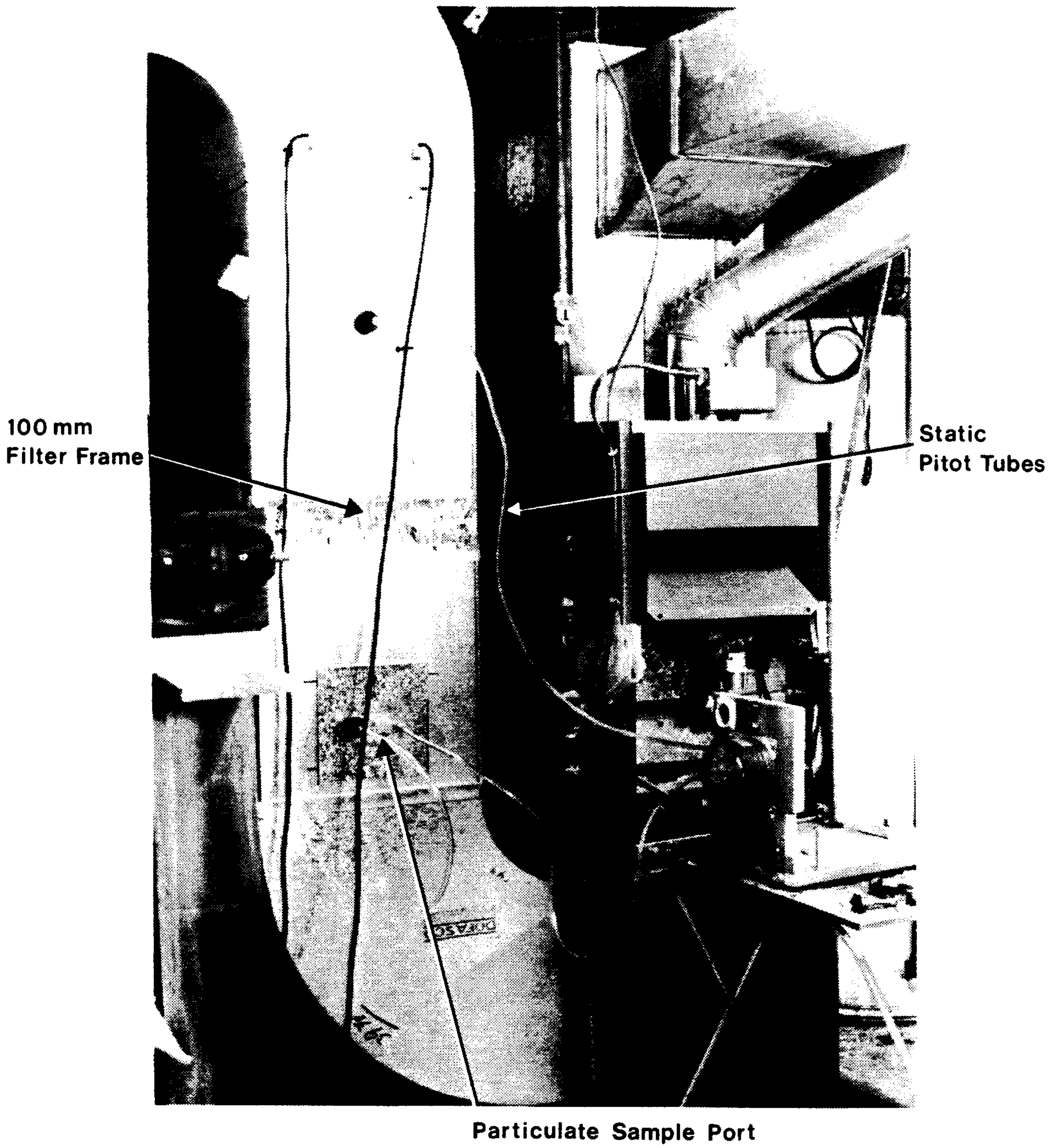


Figure 3.1: Furnace 2, Instrumented

The output temperature of the furnace was recorded at the bonnet directly above the heat exchanger. The temperatures were measured using a digital thermometer with a K-type thermocouple probe.

The airflow rates were measured approximately 400 mm above each filter. A velocity profile across the duct was recorded for each filter and the average of nine points was used as the face velocity on the filter. An Airflow Development Hot Wire Anemometer, Model TA6000, was used for the measurement of the airflow rates.

In addition, each furnace air return system was progressively restricted to determine the system fan curve.

3.3.2 Removal of Cigarette Smoke

Cigarette smoke in the airstream was measured using a particle counter (MDA Digital Dust Indicator, P-5H). The particle counter determines relative dust concentrations by measuring the intensity of light scattered by the dust passing through an illuminator chamber. The greater the intensity of scattered light, the higher the concentration of dust. The particle counter was the method of choice, because:

1. Its detection limit of 1 ug/m^3 during real time sampling is superior to the detection limit of the standard filter sampling method (5 ug/m^3 based on a 1000 L air sample).

2. Since the particle counter is calibrated with an aerosol using a particle size of 0.3 mm, it is most sensitive to particle sizes in the micron and sub-micron range. (The size range of cigarette smoke particulates). Particles larger than 10 microns are excluded by a double impactor separator.

3. The particle counters' sensitivity (ability to detect change in concentrations) is 1 ug/m^3, lower than that of the filter sampling method (based on a 1000 L air sample).

4. The particle counters accuracy averages $\pm$ 10% over its measuring range of 1 ug/m^3 to 10 ug/m^3.

5. The particle counter gives direct readout of results, enabling on-site assessment of test protocols and conditions (such as adequacy of smoke sources).

6. Since large sample volumes (1000 L) and long sampling times are not required, it is more adaptable to in-duct sampling during typical furnace operating conditions.

7. The results, expressed in counts per minute (CPM), are directly related to the concentration of that dust and comparable to any other result for the same dust.

In order to sample in the duct, sampling probes were made which, at the intake end, consisted of a funnel (5.5cm long, 3.7cm I.D. at intake), connected to copper tubing (7mm I.D.). Approximately 10 cm from the funnel edge was a 90° bend in the copper tubing, to enable sampling into the direction of airflow in the duct. The probes extended 25 cm into the duct, so that the intakes were placed in zones of approximately equal air velocity (as determined previously by velocity measurements). The copper tubing was connected to the particle counter by Tygon tubing (7mm I.D., 45cm in lenth) and a brass tubing adapter machined for the particle counter. The installation is shown schematically in Figure 3.2.

The particle counter has an internal fan which draws air through a double impaction separater, to remove, by impaction, the larger non-respirable particles from the airstream. When operating under normal conditions, that is, when drawing air indirectly rather than through sampling probes, the particle counter does not count particles larger than 10 microns in diameter. The separation characteristics of the counter are different if the air velocity at entry to the counter is different. This was most likely the case when sampling probes were connected to the counter. The theorectical results of a lower entry velocity would be increased penetration of larger particles, resulting in higher counts. This effect would be offset by particulate loss in the sampling probe, through deposition or impaction. These factors, which theoretically affect the number of particles which remain airborne were not considered to be significant, however, the effects were likely similar for all measurements made.

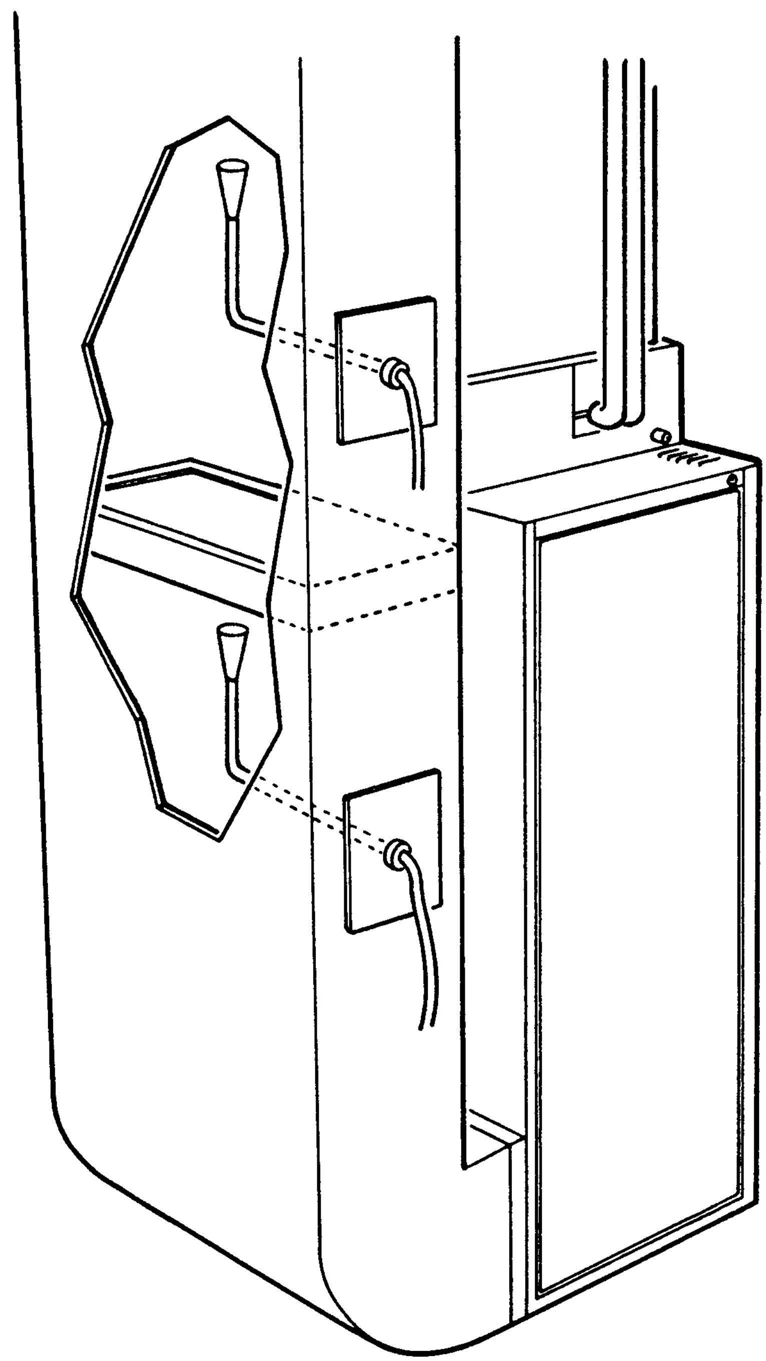


Figure 3.2: Cigarette Smoke Sampling Tube Installation

The cigarette smoke source used for all test runs was five cigarettes, lit simultaneously and left to burn down at the return air grille. The grille was located on the main level of the house, approximately 600 mm laterally from the furnace air return. Since the air intake at this grille was significant, the cigarettes burned evenly and completely in approximately ten minutes, and the smoke generated was entrained in the return air was noted to be consistant for all tests.

The sampling protocol consisted of independent particle counts over one minute intervals, alternating above and below the filter. The sampling line was disconnected at the adapter to the particle monitor. In this way, the volume of air flowing through the particle counter from the previous sampling location was minimized.

The sampling protocol commenced with House 2 with no filter in place. It was then repeated with a test filter in place, with one complete cigarette burn per filter. Approximately seven pairs of sequential one minute counts were taken for each filter. Typically, the level of smoke generations was an order of magnitude higher than the background particulate counts, and thus background effects were considered minimal.

3.3.3 Removal of House Dust

House dust is a generic term intended to describe particulate of a broad particle size range which may become airborne in a housing unit. In order to increase the concentrations of airborne dust in the airstream, a fine talcum powder (Desitin Baby Powder) was puffed manually into the return air grille. House dust (from a vaccuum cleaner bag) and flour were also tried, but were not so effective in providing a well-distributed airborne particulate in the return air. The particle size range of the powder was estimated, using optical microscopic techniques to be predominantly 3.8 to 7.1 microns.
This range of particle size encompasses the smaller particles that normally would not be effectively arrested by a low efficiency filter. For comparison purposes, Table 3.4 summarizes typical contaminants and their sizes:

Description	Particle Size, Micron
Lint	30
Pollen	30 - 20
Mold Spores	19
Soot	3
Animal Dander	3
Insecticides, Bacteria, Dust	1 - 10
Fumes	1
Tobacco Smoke	.5

Table 3.4: Size Range of Typical Airborne Contaminants

Dust in the airstream before and after the furnace filter was measured using the same particle counter described in the previous section. The sampling probes and lines were shortened considerably, to minimize the deposition of larger particulates in the sampling tubes.

The sampling protocol consisted of one three minute particle count both before and after each filter, in House 3. Longer sampling intervals were selected to average out the variations in powder source strength.

3.3.4 Removal of Fungal Spores

Airborne fungal spores are generally in extremely low concentrations in homes with low relative humidity, such as that which is common in Ottawa homes in winter. Therefore, preliminary testing was done to determine the presence of spores in the airstream before testing individual filters.

Twenty microscope slides were coated with a glycerine jelly (195g glycerine, 5g gelatin, 4g phenol, 40 ml water). Ten slides were laid across and at right angles to each of two support tubes. The slides were held in position by plasticene. Each support tube was then placed across the duct diameter, one before the filter and one after the filter. The support tubes were secured at each end so that the coated surfaces of the slides faced into the airflow. These were left in place for 66 hours, in House 3. They were subsequently removed and randomly numbered. The slides were stained with lactophenol blue and analyzed for fungal spores using an optical microscope. Thirty to fifty microscopic fields were examined in the centre of each slide.

4.0 RESULTS AND DISCUSSION

4.1 Pressure Drop and Airflow

The face velocity traverse data from each house, for each filter, was averaged and is presented in Table 4.1. The baseline data point for the calculation of reduction in airflow was the air delivery with the standard low efficiency filter (1) in place. For comparison purposes from house to house, the percent reductions in airflow data is presented in the form of a bar chart in Figure 4.1.

It is observed that in most cases the reduction in airflow caused by the medium efficiency filter is below 20%. This reduction could easily be overcome by adjusting the pitch diameter of the adjustable motor pulley or by downsizing the blower pulley. The pitch diameter

	Filter No.	Velocity (m/s)	Static Pressure Drop Across Filter (Pa)	Static Pressure Drop Across Furnace (Pa)	% Reduction in Airflow from Nomina
House 1					
	No filter	4.0	0.0	59.8	N/A
	Baseline	3.6	12.5	69.7	0
	Pleated	2.9	32.4	82.2	19
		3.2	37.4	82.2	11
		3.5	29.9	77.2	3
		3.3	39.8	84.7	8
		2.7	57.3	94.6	25
		3.2	44.8	89.6	11
		3.1	49.8	94.6	16
	Self Charging	3.4	29.9	82.2	5
		3.1	49.8	94.6	14
House 2					
	No filter	3.1	0.0	54.8	N/A
	Baseline	2.8	29.9	64.7	0
	Pleated	2.5	64.7	89.6	11
		2.2	72.2	97.1	21
		2.5	59.8	87.1	11
		2.4	59.8	89.6	14
		1.8	99.6	119.5	35
		2.2	64.7	89.6	21
		2.3	67.2	89.6	18
	Self Charging	2.4	59.8	87.1	14
		2.2	79.7	99.6	21
	Electronic	2.2	67.2	92.1	21
		2.8	67.2	92.1	0
House 3					
	No filter	1.3	0.0	12.5	N/A
	Baseline	1.2	10.0	17.4	0
	Pleated	1.2	14.9	24.9	0
		.9	24.9	29.9	25
		1.2	14.9	24.9	0
		1.1	19.9	24.9	8
		.7	29.9	34.9	41
		1.0	19.9	24.9	17
		1.0	19.9	24.9	17
	Self Charging	1.1	17.4	24.9	8
		.9	19.9	27.4	25
	Electronic	1.1	17.4	24.9	8
		1.1	14.9	24.9	8

Table 4.1: Pressure Drop and Airflow Data from the Test Houses

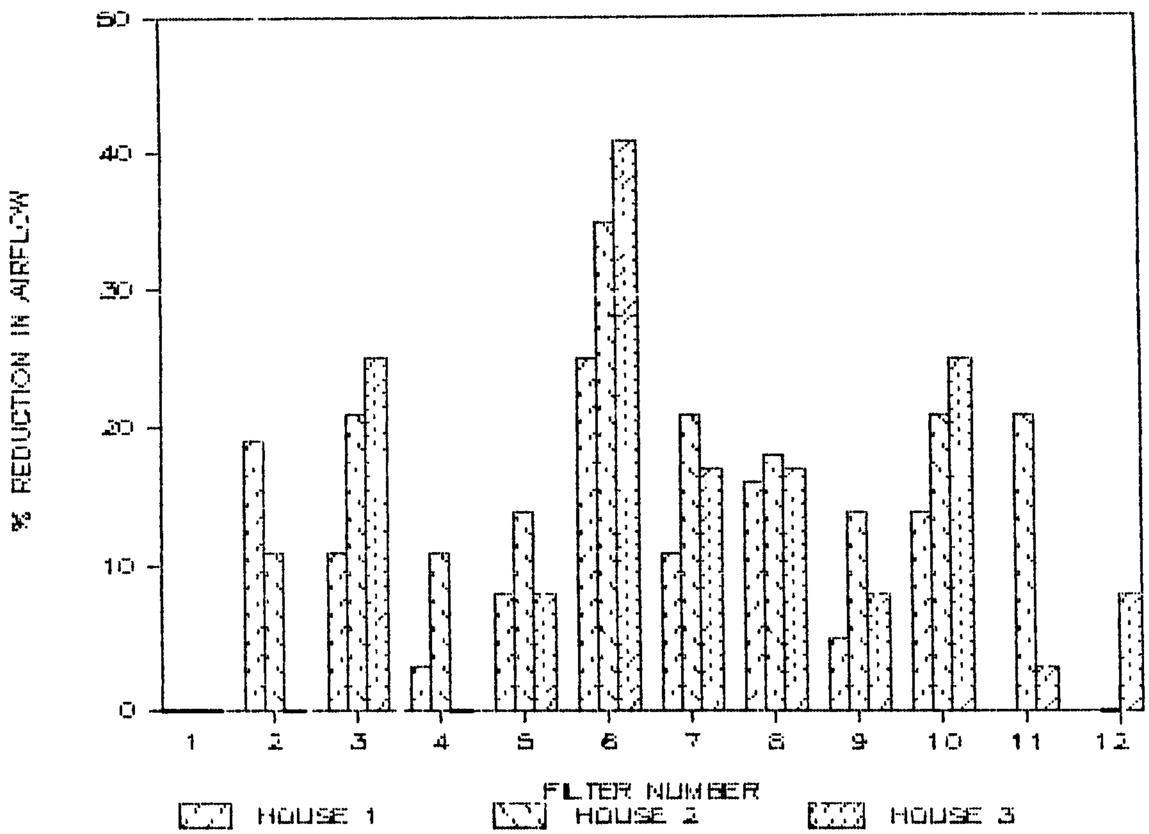


Figure 4.1: Reduction in Airflow Caused by Medium Efficiency Filters

can easily be adjusted by, removing the fan belt, loosening a set screw on the pulley and screwing one pulley face towards the other. A new pulley would cost $10 - $15.

The data was also plotted in the form of fan curves for the three furnaces. This information is included in Figures 4.2 to 4.4. The baseline data point is the operating point of the furnace with the low efficiency filter in place.

The reduction in airflow caused an increase in the temperature of the air leaving the furnace (bonnet temperatures). The lower the airflow, the greater the bonnet temperature. For the two houses monitored for bonnet temperature, the baseline temperature for House 1 was measured to be 70°C, and 55°C for House 2. Baseline was with filter 1 in place. The maximum increase in bonnet temperature was measured to be 7°C in House 1, and 8°C in House 2. Thus the range of bonnet temperatures was 70 - 77°C in House 1, and 55 - 63°C in House 2.

The data is presented graphically in Figure 4.5. The measured values can be compared to a sample of manufacturer's ratings that ranged from 22 - 39°C rise for electric furnaces to 47°C rise for gas and oil furnaces. With an air inlet temperature of 21°C, the output temperatures would be 43-60°C and 68°C, respectively. These ratings are catalogued at a nominal airflow, which is usually at the average of the high and low airflow ratings of the furnace. The catalogued airflow range for the furnaces vary by ± 15% of the nominal, and thus, the bonnet temperature rise would vary from the nominal with a change in airflow. A furnace rated at a 47°C temperature rise is designed to operate at 54°C rise or 75°C output air temperature, maximum, with a clear filter. A reduction in airflow due to filter clogging (either with the low or medium efficiency filter) may cause overheating of the furnace, and tripping of the high limit temperature control. The high limit control is installed to ensure furnace shut-down in the event of loss of airflow, and is normally set at 95°C.

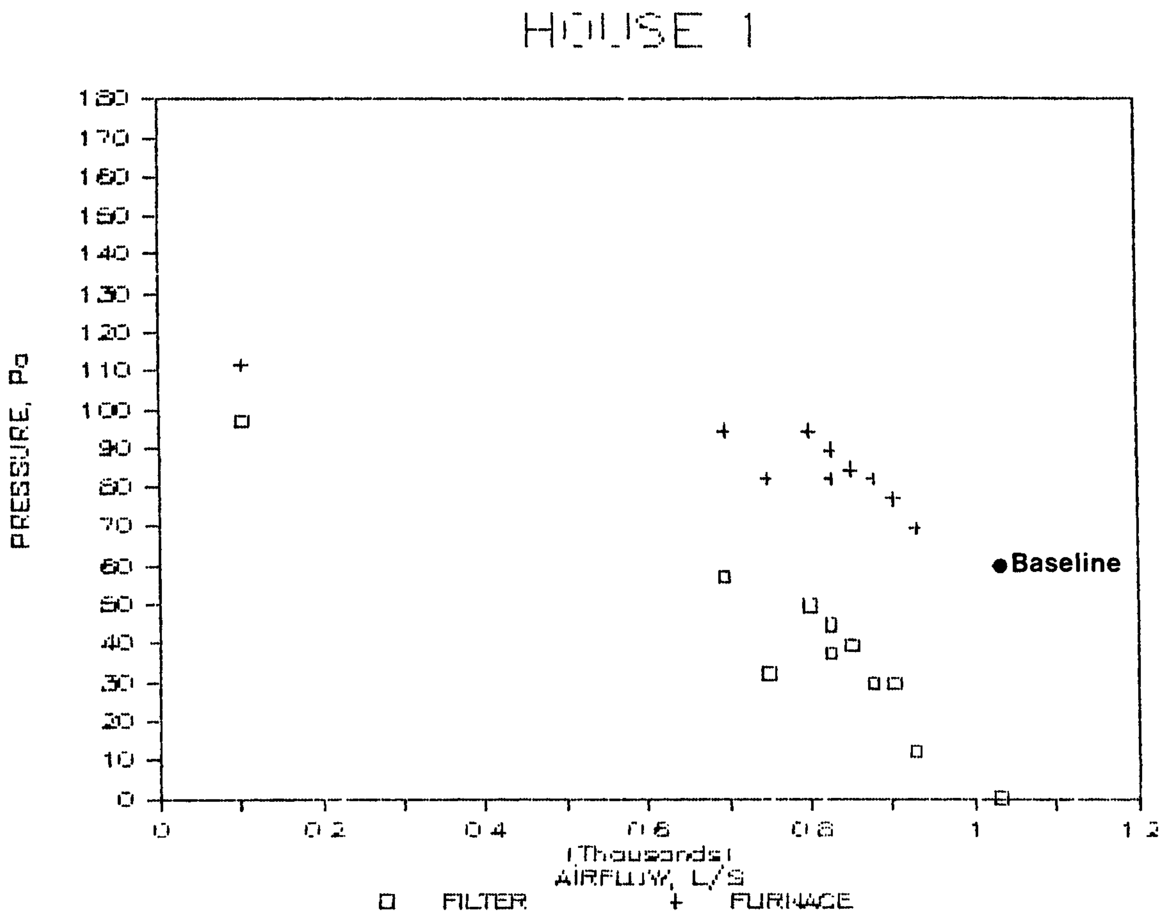


Figure 4.2: House 1 Fan Curve

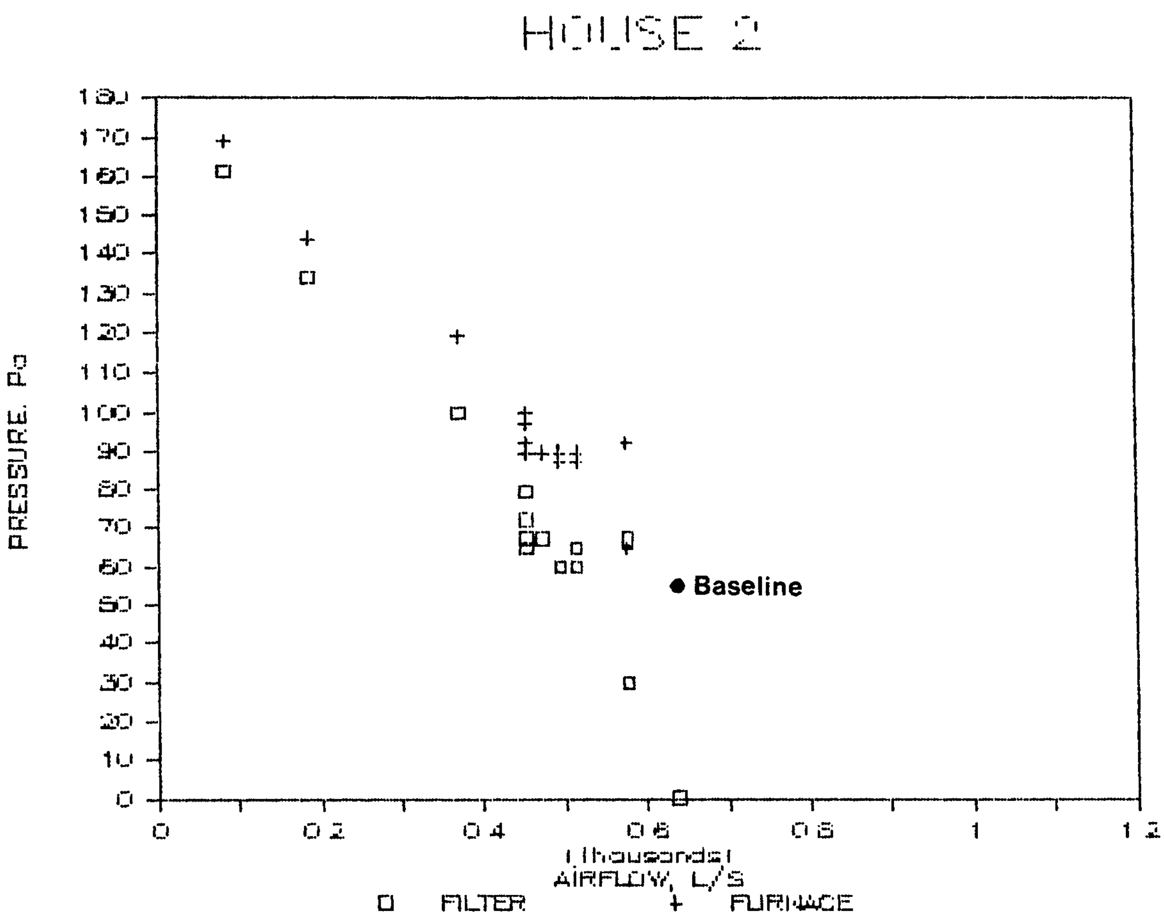


Figure 4.3: House 2 Fan Curve

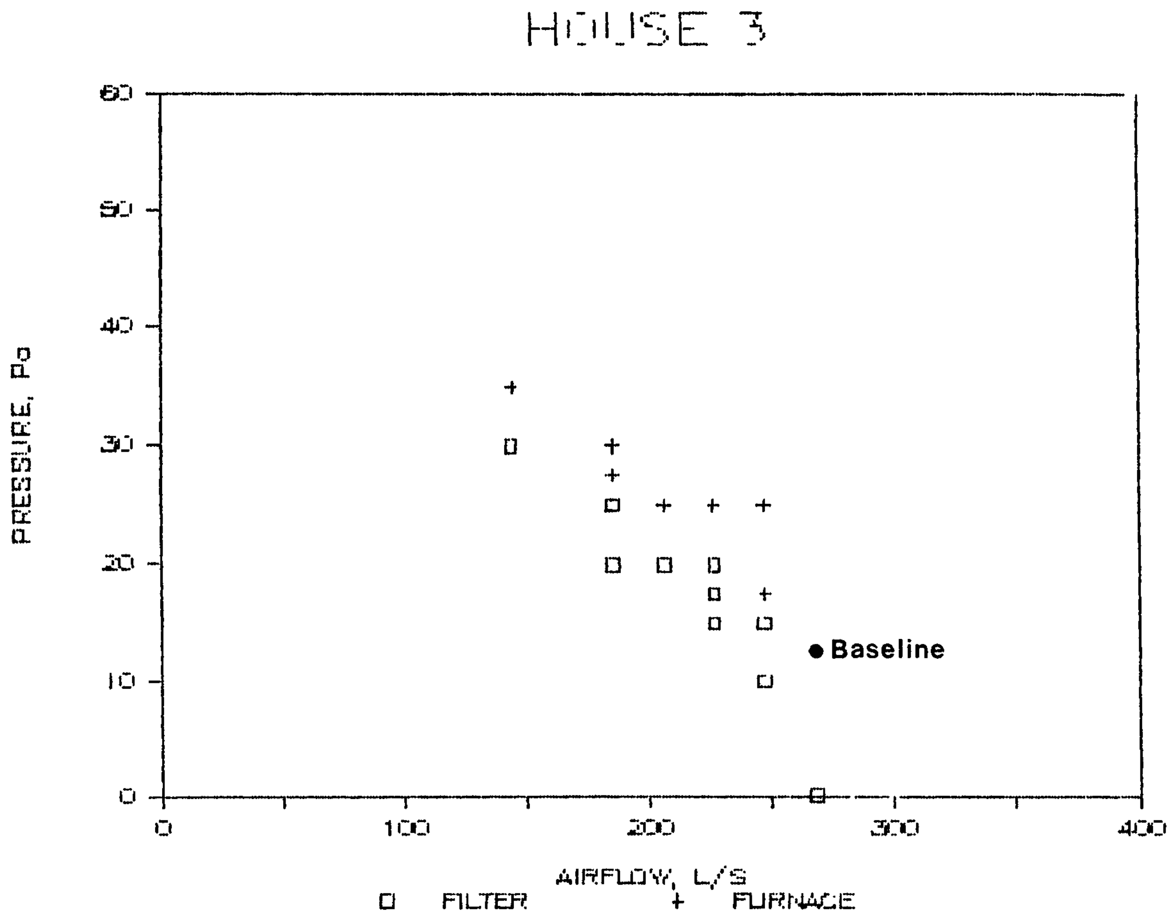


Figure 4.4: House 3 Fan Curve

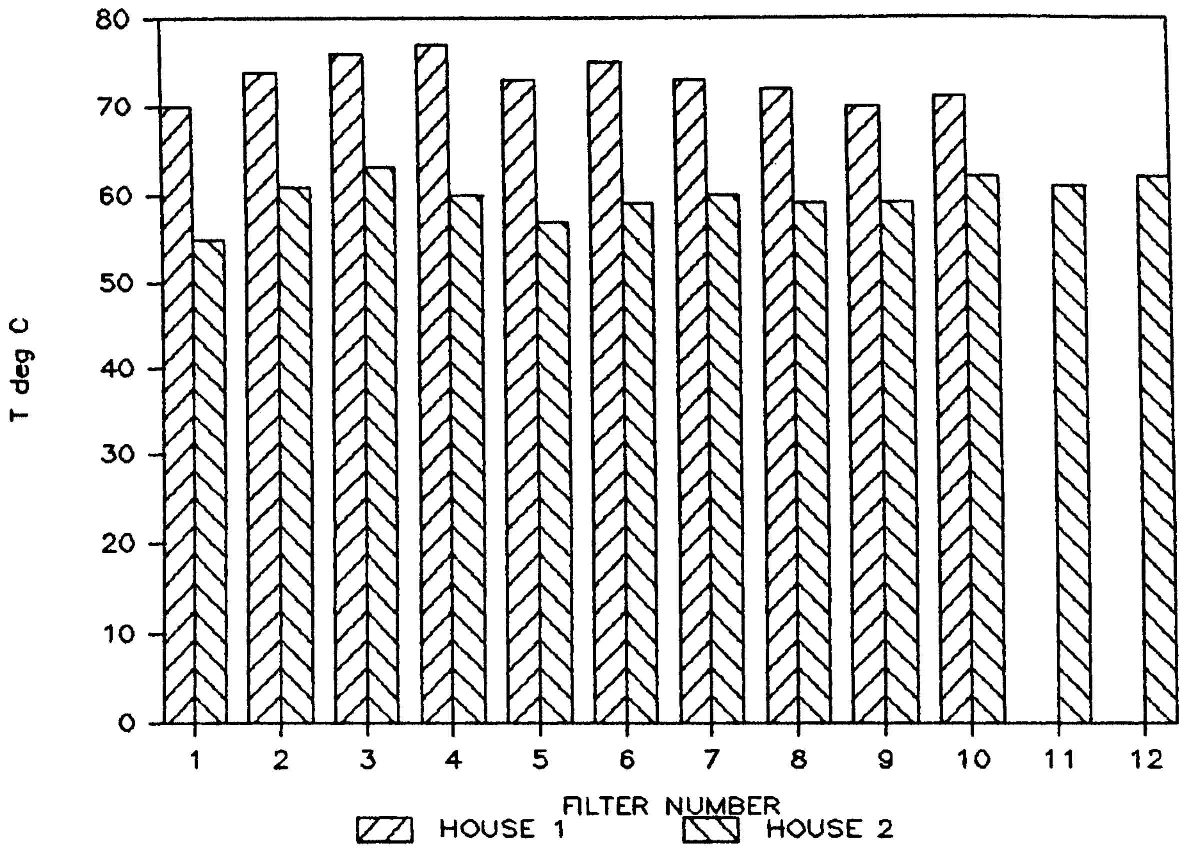


Figure 4.5: Measures Furnace Bonnet Temperatures with Various Efficiency Filters

4.2 Removal of Cigarette Smoke

The seven one-minute particle counts taken alternately before and after each filter during a cigarette burn (House 2) were averaged and have been summarized in Table 4.2. In every test run the average particle count at the measurement point after the filter was slightly higher than that at the measurement point before the filter. This would imply that all filters tested had negligible impact on the removal of cigarette smoke. The increase is most probably due to the sampling protocol. The before and after counts were taken sequentially, and the background level of smoke in the house air was constantly increasing. Thus all subsequent counts were higher than previous counts.

Test runs taken in House 3 (three one-minute counts average) are also summarized in Table 4.2. In every test run the average particle count at the measurement point downstream of the filter was lower than that at the measurement point upstream of the filter. The ratios of particle counts downstream/upstream have been expressed as a percentage, describing filter breakthrough of cigarette smoke. The lowest normalized breakthrough was 36% (Filter 6). All other breakthrough values compared to the low efficiency filter at over 100% (no removal), ranged from 50 to 66%.

Although the differences between the lowest and highest breakthrough values are likely indicative of significant differences in cigarette smoke removal efficiencies, the differences within each group of filters are not considered significant.

It is noticed from the table that the low efficiency filter (Filter 1) does not retain the small diameter smoke particles. At low velocities, the medium efficiency filters did remove from 11 to 51% more smoke than Filter 1. The low velocity (House 3) test is representative of the continuous low speed circulation of air in a two speed system and demonstrates the desired benefits from this operation.

Filter	Velocity m/s	House No. 2 After:Before[1]
No Filter	3.1	59:58
Baseline	2.8	88:85
Pleated	2.5	74:71
	2.2	75:68
	2.5	78:73
	2.4	49:43
	1.8	55:49
	2.2	79:74
Self Charging	2.3	103:98
	2.4	88:84
	2.2	96:91
Electronic	2.2	66:62
	2.8	92:88

Filter	Velocity m/s	House No. 3 After:Before[2]	Filter Breakthrough, % Normalized to Baseline
Baseline	1.2	133:98 [3]	100
Pleated	1.2	141:159	66
	0.9	113:167	51
	1.2	123:149	62
	1.1	100:126	60
	0.7	115:232[3]	36
	1.0	105:133	59
Self Charging	1.1	53:78	51
	0.9	78:116	50
Electronic	1.1	71:91	59
	1.1	30:41	54

1. Average of 7 one-minute particle counts
2. Average of 3 one-minute particle counts
3. Average of 2 three-minute particle counts
4. Background levels continually increased during testing

Table 4.2 Filter Breakthrough - Cigarette Smoke

4.3 Removal of Dust Particulate

The three-minute particle counts taken alternately before and after each filter in House 3 are summarized in Table 4.3. In every test run, the particle count at the measurement point downstream of the filter was significantly lower than that at the measurement point upstream of the filter. The ratios of particle counts have been expressed as a percentage, describing filter breakthrough of particulate. Breakthrough ranged from 19% (Filter 4) to 84% (Filter 9). Breakthrough values for nine of the twelve filters tested were less than 50%, with the baseline low efficiency filter at 51%. Although differences between filters with similar breakthrough values (e.g. Filter 12 at 32%, Filter 6 at 36%) are not significant, the range of breakthrough values is so broad that it is indicative of real differences within the group for filters tested.

It is noted that in this test, with respect to the larger dust particles, some medium efficiency media filters performed as well as the electronic devices.

4.4 Breakthrough of Fungal Spores

The twenty microscope slides were examined for evidence of spores or other identifiable structures of fungi. Only one (1) spore was observed (ALTERNARIA), on a slide which was placed in the duct after the filter. No other fungal spores were observed on any of the 19 other slides.

Because there were so few fungal spores in the mainstream, no other sampling was done.

4.5 Filtering of Return Air Grilles

Return air grilles in most new housing are pressed steel construction, with designs for both floor and wallmounting. In older homes, the grilles range from wood or cast iron floor grilles to pressed steel wall grilles.

Although the types are highly variable, the sizes usually do fall within a standard range. The most common sizes are 355 x 200, 600 x 200 and 760 x 200 mm. In some installations, where medium efficiency filters are desired but cannot be mounted at the furnace, the alternative would be to mount the filters at the grilles.

Filter	**House No. 3 Downstream:Upstream**	**Velocity m/s**	**Filter Breakthrough %**
Baseline	117:230	1.2	51
Pleated	159:394[2]	1.2	40
	110:467	0.9	24
	86:443	1.2	19
	134:342	1.1	39
	153:421	0.7	36
	127:440	1.0	29
	215:309	1.0	70
Self Charging	168:199	1.1	84
	127:311	0.9	41
Electronic	107:285	1.1	38
	84:266	1.1	32

1. One three-minute particle count
2. One five-minute particle count

Table 4.3 - Filter Breakthrough - Dust Particulate

To accomplish this, the return air grille must be replaced with a grille designed to retain a filter. Although this is not a common practice in residential installations, suitable grilles are available through most manufacturers of commercial grilles and registers. Typically, the manufacturer can supply a grille to any specified size. These grilles are generally constructed from aluminum, and come in a variety of designs. A 760 x 200 mm grille would cost approximately $40.00. Typical arrangements are included in Figure 4.6. The information was compended from Hart & Cooley, and E.H. Price product literature.

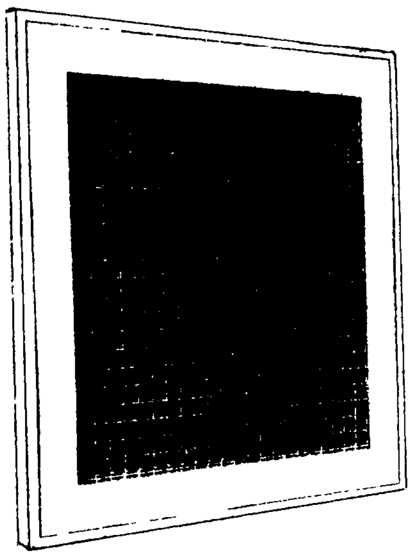
4.6 Retrofit

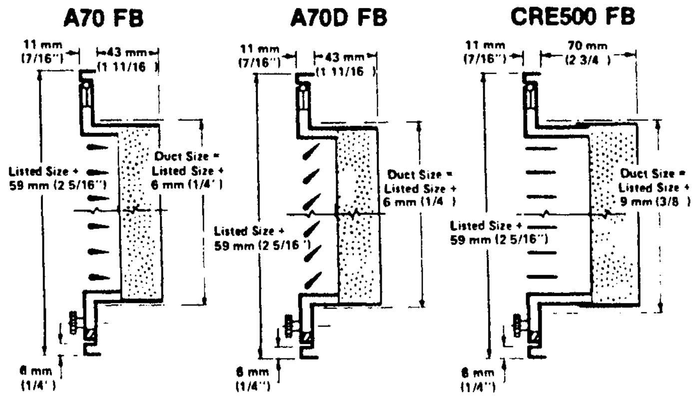
The retrofit of a medium efficiency filter into the residential furnace system must consider both the mechanical installation of the filter, the adjustment of the furnace pulleys, and possibly the change of blower motor. The mechanical considerations are straightforward and are presented below. The change of pulley and motor is discussed in Section 4.7.

The medium efficiency filters are typically available in depths of 25, 50, 100 and 150 mm. Generally, the thicker the filter, the greater the number of pleats, and hence the larger the surface area of media exposed to the airstream. The large surface area lowers the velocity across the media, which may improve the filter's ability to remove small particles, and lower the pressure drop across the filter. The extended surface area filters also take longer to clog than the 25 mm filters.

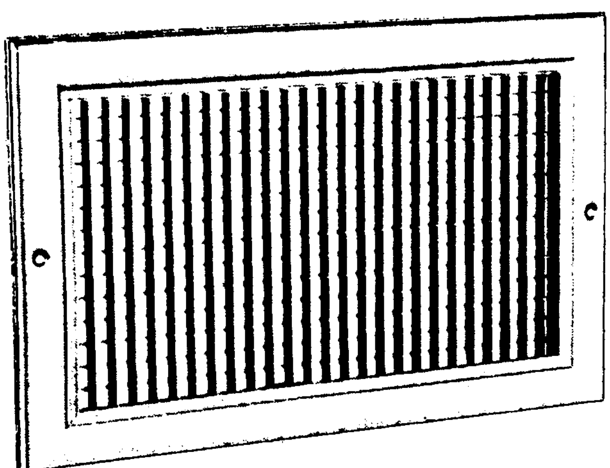
Any 25 mm depth medium efficiency filter can be retrofitted in a furnace that is equipped with a low efficiency filter frame, at no other cost than the cost of the filter. In some low-boy furnaces, in which the filter rests on tilted support in the air return plenum, a thicker medium efficiency filter can be installed with no modifications. If it is desired to install an extended surface area filter, then the ductwork must be modified. The easiest modification is to remove a section of one side of the duct, as shown in Figure 4.7. The depth must be sufficient to install the desired filter, and a new filter frame or retaining screw must be added. With the thicker filter, it is advisable than an approved heating contractor be retained to perform the modifications, and re-balance the system. The cost of the work for a typical high-boy installation should be under $75.00.

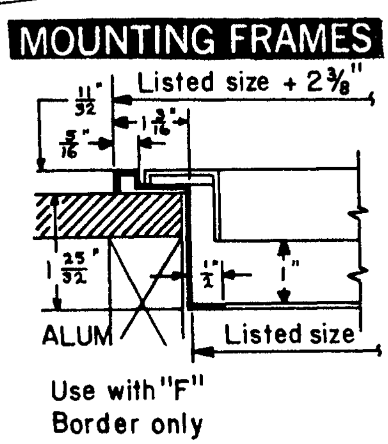
FILTER BACK RETURN GRILLES





RETURN GRILLES & REGISTERS





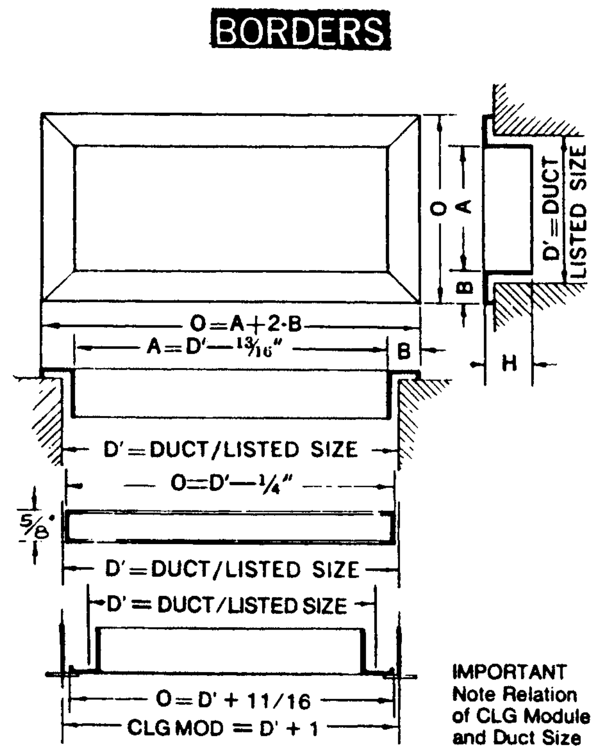


Figure 4.6: Return Air Grilles with Filter Frames

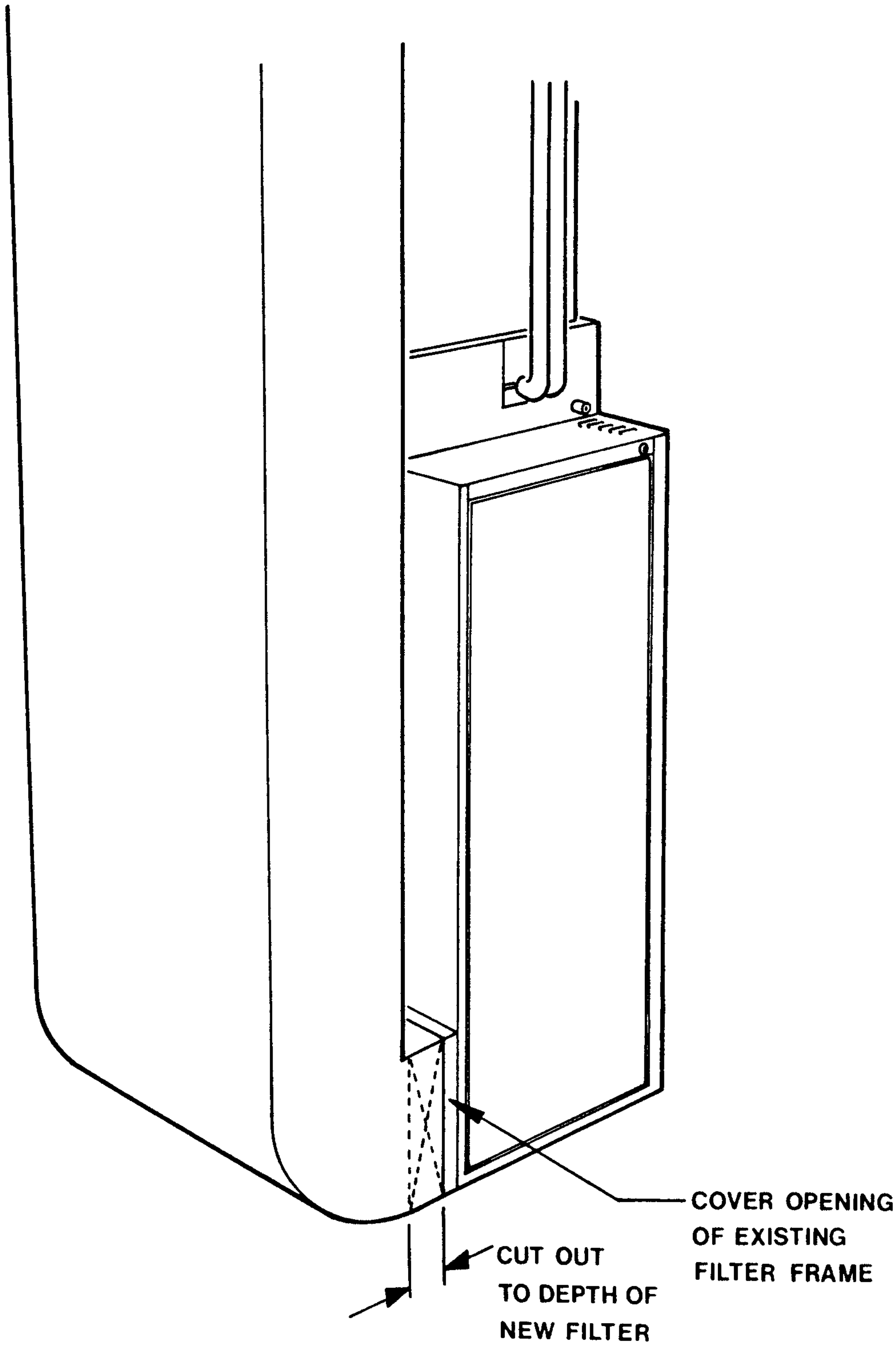


Figure 4.7: Furnace Filter Retrofit

4.7 Filter Clogging Alarms

As the efficiency of the filter increases, so does its ability to capture smaller particles, and its ability to clog, more than lower efficiency filters, is increased. A medium efficiency filter can capture smaller particles than a low efficiency filter and become much more restrictive to airflow. However, as the depth of a pleated filter increases, its surface area increases, and for the same elapsed time lifespan of a low efficiency filter, the medium efficiency filter will generally not reduce the airflow or increase in pressure drop more than the low efficiency filter. In other words, properly maintained systems do not require alarms. Based on the testing performed, it is projected that the filters could have a one year lifespan in a residential application if vacuumed clean every 2-3 months. The requirement for cleaning is evident upon visual inspection.

Consider the performance of House 1, as demonstrated by the following discussion, and Figure 4.8. The design operation of the furnace with a low efficiency filter is shown as Point A. The system operates at 60 Pa pressure drop. With proper maintenance and filter changes at maximum pressure increase of 20 Pa, the furnace operation moves to Point B, and the airflow reduces to approximately 82% of the design. Replacing the filter moves the performance back to Point A.

Consider the replacement of the low efficiency filter with a medium efficiency filter, changing the system operation to Point B. Based on the performance of the filters tested in this study, Point B is representative of real performance. It can be seen that if the filter clogs more than 20 Pa, the operation moves to the left of Point C, and system performance is dramatically reduced. Since the recommended increase in pressure gradient before replacement of a medium efficiency filter is in the order of 125 - 250 Pa, the useful life of the filter has been severely shortened. However, at this time, the filter could be cleaned (vacuumed) and re-installed. This example does demonstrate the dramatic negative potential of these filters on the system performance, if not properly maintained.

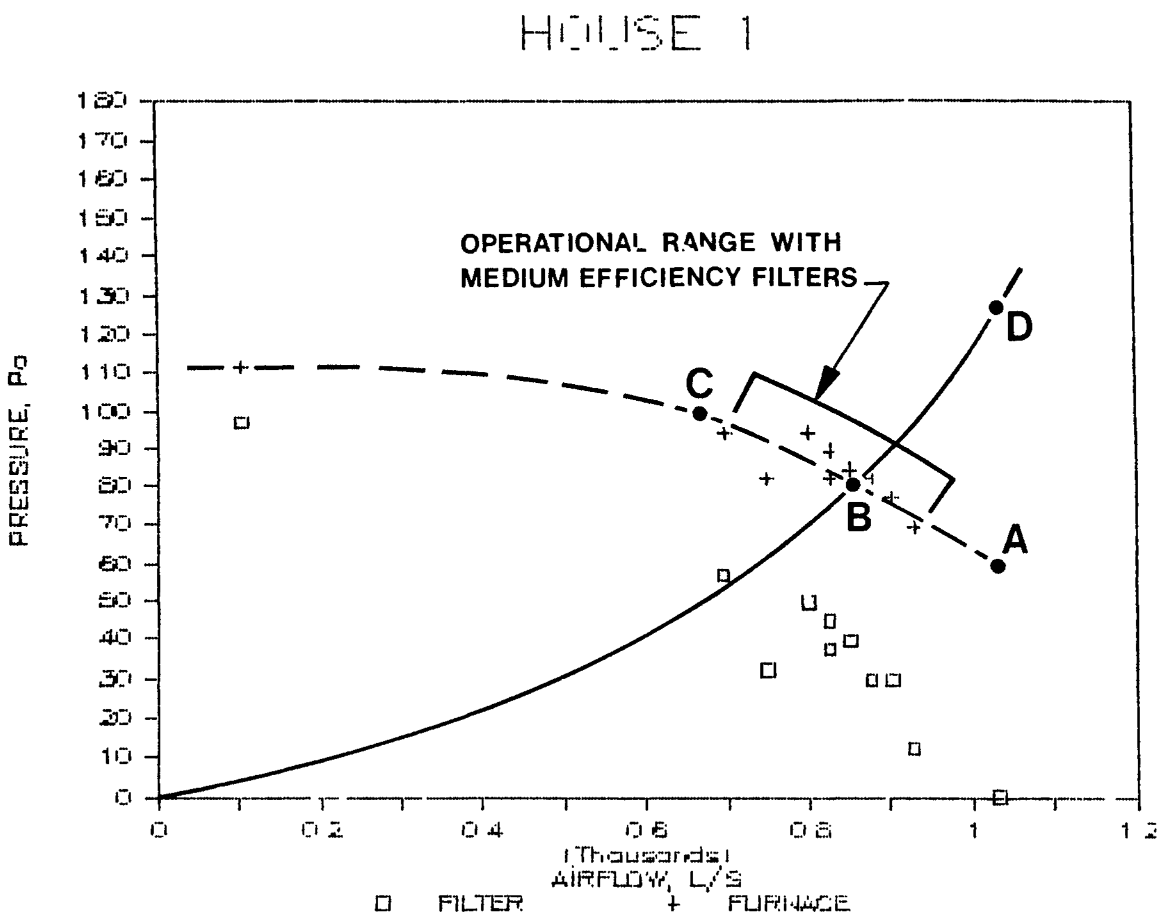


Figure 4.8: House 1 System Curve

Another alternative is to adjust the speed of the furnace blower to deliver desired airflow (airflow at Point A) at the new system performance of Point B. The fan laws govern the increase in flowrate from Point B back to Point A as:

$$\frac{\text{New Pressure}}{\text{Pressure}} = \left| \frac{\text{New Airflow}}{\text{Airflow}} \right|^2$$

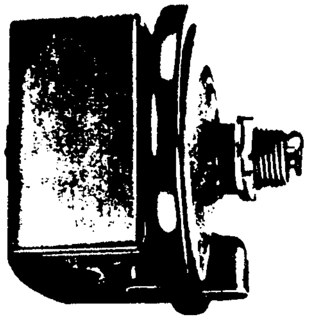
Thus to increase the airflow from 850 L/s back to 1040 L/s, the resultant system pressure is 127 Pa, shown as Point D. The system has no excess capacity to allow for contaminent removal by the filters. A compromise in airflow along curve BD lowers the system operating pressure, while allowing up to 25 Pa for filter operation.

In both of the above examples, the operating range of the filter was determined to be limited to 20-25 Pa, demonstrating the requirement for proper regular maintenance.

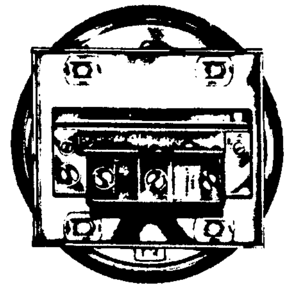
Since a medium efficiency filter has the capability of severely restricing airflow, over its operating pressure range, most commercial installations have sensors installed across the filter bank to monitor pressure drop. Two methods can be considered. Either a sail switch can be installed to sence absence of airflow, or a differential pressure switch can be installed across the filter. Both devices can be connected to an audible alarm, or light. The sail switch is best suited to applications where the requirement is to sense ON or OFF airflow, and although it can be used in this application, turbulance in the duct can hamper its performance. The differential pressure switch is the preferred solution.

The switches are available from many control manufacturer's, such as, Dwyer, Honeywell, Johnson Controls, and White-Rodgers. The differential set point is usually adjustable. The retail cost for the devices begin at $62.00, and installed costs could be $150-$250. A sample data sheet is included in Figure 4.9.

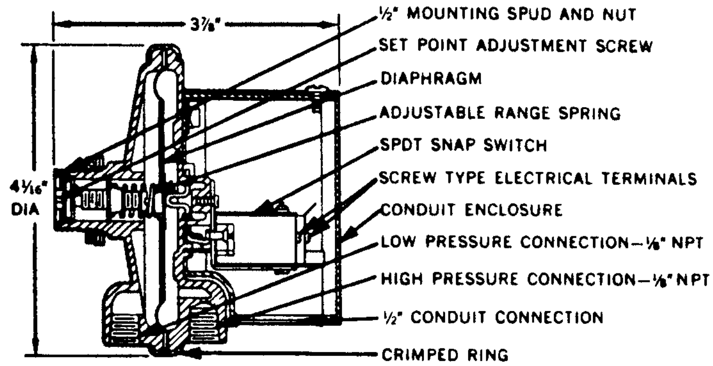
Current clamps used to monitor the power supplied to the furnace blower motor were also considered, however, it was found that the current supplied to the blower motor did not change significantly from the nominal full load rating of the motor, in any of the three houses, with any filter in place.



Model 1823 pressure switch U.L and C S A listed, F M approved



Series 1823 pressure switch Conduit enclosure removed to show electric switch



Construction and dimensions Series 1823 pressure switches

SERIES 1800

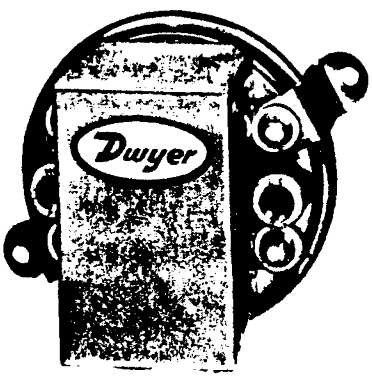
PHYSICAL DATA

Temperature limits: −30°F for dry air or gas to 180°F
Maximum surge pressure: 25 psig
Rated pressure: 10 psig
Pressure connections: ⅛" NPT
Electrical rating: 15 amps, 120 480 volts, 60 Hz A.C Resistive ⅛ H P. @ 125 volts, ¼ H P. @ 250 volts, 60 Hz A C. Derate to 10 amps for operation above 130°F or at high cycle rates
Wiring connections: 3 screw type, common, normally open and normally closed
Set point adjustment: Screw type inside mounting spud
Housing: Aluminum die casting Steel fittings zinc plated, dichromate dipped for 200 hour salt spray test
Diaphragm: Silicone rubber on dacron with aluminum support plate
Calibration Spring: Stainless steel
Mounting spud: ½" pipe thread
Weight: 1 lb , 5 oz
Installation: Diaphragm vertical

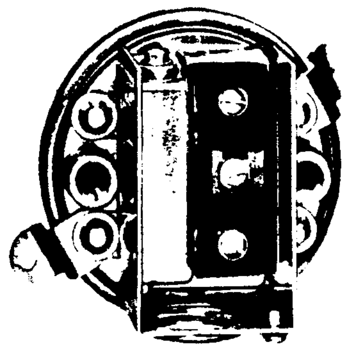
CAUTION: FOR USE ONLY WITH AIR OR COMPATIBLE GASES

MODEL 1823 SWITCHES: OPERATING RANGES AND DEAD BANDS.

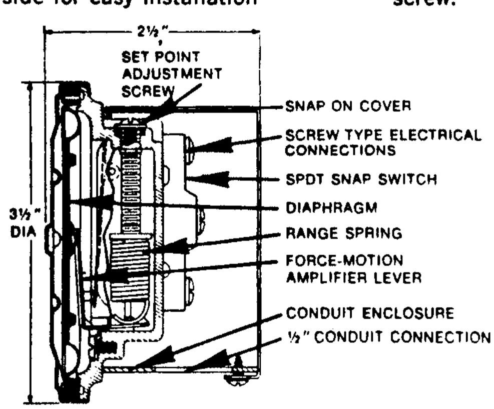
Model Number	Operating Range Inches, W.C	Approximate Dead Band At Min Set Point	Approximate Dead Band At Max. Set Point
1823-0	0 15 to 0 5	0 06	0 06
1823-1	0 3 to 1 0	0 08	0 08
1823-2	0 5 to 2 0	0 10	0 12
1823-5	1.5 to 5 0	0 14	0.28
1823-10	2 0 to 10	0 18	0 45
1823-20	3 to 22	0 35	0 70
1823-40	5 to 44	0 56	1 1
1823-80	9 to 85	1 3	3 0



Series 1910 pressure switch All pressure and electrical connections and set point adjustments are on one side for easy installation



Series 1910 switch with conduit enclosure off. Shows electric switch and set point adjustment screw.



The Dwyer-engineered force-motion amplifier increases the leverage of diaphragm movement and results in a switch with excellent sensitivity and repeatability.

SERIES 1900

PHYSICAL DATA

Temperature limits: −30°F for dry air or gas to 180°F
Maximum surge pressure: 10 psig
Rated pressure: 45' H_2O
Pressure connections: ⅛" NPT
Electrical rating: 15 amps, 120 480 volts, 60 Hz A.C Resistive ⅛ H P. @ 125 volts, ¼ H P. @ 250 volts, 60 Hz A C Derate to 10 amps for operation above 130°F or at high cycle rates
Wiring connections: 3 screw type common, normally open and normally closed
Set point adjustment: Screw type inside conduit enclosure
Housing: Zinc die casting and steel stamping Zinc plated for 200 hour salt spray resistance
Diaphragm: Molded Silicone rubber
Calibration spring: Stainless steel
Weight: 1 lb
Installation: Diaphragm vertical

CAUTION: FOR USE ONLY WITH AIR OR COMPATIBLE GASES

MODEL 1910 SWITCHES: OPERATING RANGES AND DEAD BANDS.

To order specify Model Number	Operating Range Inches, W C	Approximate Dead Band At Min. Set Point	Approximate Dead Band At Max Set Point
1910-00	0 07 to 0 15	04	05
1910-0	0 15 to 0 5	0 10	0 15
1910-1	0 4 to 1 6	0 15	0.20
1910-5	1 4 to 5 5	0 3	0 4
1910-10	3 0 to 11 0	0 4	0 5
1910-20	4 0 to 20 0	0 4	0 6

PRESSURE SWITCHES

Figure 4.9: Filter Clogging Alarms

5.0 CONCLUSIONS AND RECOMMENDATIONS

The study indicates a great variance in performance of the medium efficiency filters tested. The potential for contaminent reduction, particularly when installed in a continuous low speed fan operation was determined to be greater than that of the low efficiency filter. The cost of furnace retrofit is nil for the direct installation of a 25 mm medium efficiency filter, and deemed minimal for thicker filters. The initial pressure drop across the filters is generally lower with increasing filter thickness, and hence, a 100 mm filter with the lowest pressure drop is preferred.

In general, to ensure the successful integration of a medium efficiency filter into an existing system, pressure and airflow measurements are recommended. For the longer term integration of medium efficiency filters into residential applications, standards for the maximum allowable new filter pressure drop should be investigated.

The potential for reduced airflow caused by filter clogging is greater with the filters than with the low efficiency filter and proper consideration must be taken in the maintenance of retrofitted systems. It is not considered appropriate to generalize that medium efficiency filters can be retrofitted into residential systems without affecting system performance. Based on the information presented, a wide range of filter performance and system performance, is expected, and not all filters can be installed in any application.

It is recommended that retrofit test procedures be established to determine the suitability of each furnace system to accept a medium efficiency filter. The test procedure should be designed to obtain the portion of the fan curve identified as AC in Figure 4.8, as well as Points B and D. This data will allow the designer to determine if blower pulley changes and increased motor horsepower are required for the installation. From the tests conducted, no appreciable differences in performance between the electronic and medium efficiency filters were noted, however, economic considerations were not investigated.