

RESIDENTIAL EXHAUST EQUIPMENT

A Research Report

Prepared for:

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EXECUTIVE SUMMARY

Canada Mortgage and Housing Corporation contracted HRAI/TSDI and ORF to conduct an investigation of residential exhaust fans. The intent was to discover how exhaust fan systems are being installed in Canadian houses, and how these systems could be improved. The contractors were to produce a builder's guide to exhaust equipment based on these findings.

The work commenced with an international equipment and literature search, to determine the practices in other countries and to find exhaust equipment that may be more effective than what is currently used. The search also uncovered the technical data (eg. flow characteristics) required for proper system design. Laboratory testing at ORF filled in the gaps of this technical data. Field testing, in four cities across Canada, established current fan system installation procedures and the resulting exhaust flow rates.

The literature search revealed that European and far Eastern exhaust systems differ from North America units. Central systems are prevalent in Europe while Japanese fans tend to be through-the-wall. For systems comparable to those used in North America, there was no apparent advantage to the off-shore products. Performance ratings based on different standards made meaningful comparison difficult. The one Japanese fan tested to the North American standards showed airflow rates significantly below manufacturer's ratings.

There is now adequate information available to design exhaust fan systems. Certified exhaust equipment provides performance specifications, and recent Ontario Hydro studies have shown the reliability of this data. Duct system component characteristics are available from organizations such as ASHRAE. The lab testing at ORF produced good flow vs. pressure curves for various wall and roof caps. The lab tests also showed how inappropriate ducting and terminations degraded the system flow rates by up to 55%. Duct taping test results were inconclusive.

The field surveys showed that many trades are currently involved in the installation of exhaust fan systems, including electricians, sheet metal workers, roofers or siders, and others. Very few of the 20 installations inspected showed any evidence of system design or post installation testing. Flexible ducting in bathroom fans was widespread. In both bathroom and kitchen systems, downsizing the ducting from manufacturer's specifications was common. The bathroom fan systems were measured at an average of 44% of their rated flow; the kitchen fans were at an average of 38% of their rated flow.

Field measurements of room sound levels during exhaust fan operation did not correlate to rated fan sound levels. Fan installation variability, room size and reverberation characteristics, as well as measurement uncertainties, appear to have masked differences in sound levels due to the fans themselves.

The builder guide highlighted the flow deficiencies, and made strong recommendations to use certified equipment installed to manufacturer's specifications. Disregarding these instructions may result in systems that do not meet design flow rates, leading to inadequate residential ventilation.

TABLE OF CONTENTS

		PG.#
	EXECUTIVE SUMMARY	i
1.	INTRODUCTION	1
2.	METHOD OF APPROACH	1
3.	PRESENTATION OF FINDINGS	2
3.1	State-of-the-Art and Practice - Exhaust Equipment	2
3.2	Field Observations and Testing	11
3.3	Laboratory Testing of Components and Systems	19
3.4	Simplified Builder Guidelines	32
4.	CONCLUSIONS AND RECOMMENDATIONS	32
5.	REFERENCES	33
	Appendix 1: Residential Exhaust Fans - Literature and Equipment Search	
	Appendix 2: Field Study and Field Testing of Residential Kitchen Range Hood and Bathroom Exhaust Systems	
	Appendix 3: Laboratory Evaluation of Range Hood and Bathroom Exhaust Components and Systems	
	Appendix 4: Draft Builder's Guide to Residential Exhaust Systems	

1. INTRODUCTION

This is a report of an investigation to identify or develop material for a simplified builder guide describing exhaust fan products and systems to achieve more effective and acceptable residential exhaust systems.

The scope of the investigation involved three elements, including a literature search and review of exhaust system practice and products, both here and abroad; field observations on and testing of field installed exhaust systems in four major centres across Canada and a laboratory testing phase to evaluate the airflow performance of both common components and systems.

These three work elements were seen as an appropriate means of identifying how the current exhaust systems practice, in Canada, could be modified to be more effective and useful to homeowners.

2. METHOD OF APPROACH

The review of the state-of-the-art and practice in exhaust equipment and systems involved on-line searches and reviews of published indices; contacts with individuals and organizations involved in research, testing and performance certification; contacts with trade associations, commissions and manufacturers, both North American and foreign.

The field observations and testing of residential exhaust systems involved regional members of HRAI visiting builder sites in Vancouver, Calgary, Quebec City and Halifax to gather information on equipment used and local installation practice. This was followed by spot measurements of airflow capability and sound levels of both bathroom and kitchen range hoods.

Finally, a laboratory testing phase was undertaken to fill the gap in existing knowledge of pressure loss characteristics of residential exhaust components and systems. These tests were to confirm manufacturer pressure drop data and to develop new pressure drop data on individual components and systems.

The review of the state-of-the-art and practice in exhaust equipment and systems was to identify what equipment was currently in use or under development. There was also a need to identify what work had already been done to minimize the requirement for further laboratory testing.

The field observations on systems across Canada were to identify not only what fans and components were currently in use, but, more importantly, how it was being installed. This information was to be used later to define the laboratory test program, particularly with what exhaust system configurations were to be tested to determine pressure loss characteristics.

3. PRESENTATION OF FINDINGS

3.1 State-of-the-Art and Practice - Exhaust Equipment

Current Practice

An extensive review of the literature, particularly of the Air Infiltration and Ventilation Centre [2], [3], [4], [5], [6], [7], [8], revealed the common practice in Europe was central exhaust systems, as opposed to the local exhaust practice in Canada [1]. The findings are summarized in Table 3.1.1. Occupant acceptance of exhaust systems in Europe seemed to be as low as that generally acknowledged by homeowners in Canada. The contrast in the climates in Europe and Canada was seen as the most important reason for concluding that central exhaust systems, as designed and installed in Europe, would not be accepted in Canada.

Current Equipment

Current trends in residential exhaust fans and controls were investigated through contacts with manufacturers, trade associations and commissions in North America, Europe and Japan. The American equipment is intended as local exhaust fans, controlled through the bathroom light switch or a simple on-off switch, installed in the ceiling or above the range, in the case of a range hood. Builder range hood models often use propeller fans, while upgrade models have twin centrifugal fans. In Japan, the bathroom fan designs are similar in appearance to North American units, but invariably incorporate centrifugal blower wheels. Japanese propeller

TABLE 3.1.1 CURRENT VENTILATION PRACTICE IN EUROPE

Country (Winter design temp.)	Exhaust System Type(s)	System Description / Operation	Occupant Acceptance	Ref.
Denmark (-7°C)	Central Mechanical	<ul style="list-style-type: none"> Continuous exhaust from kitchen, toilet & bath; make-up air through open windows, inlet valves, leakage. Recent regulation allows 40% of rated volume flow 12 hours each day. 	<ul style="list-style-type: none"> N/A 	2
France (-4°C)	Central Mechanical	<ul style="list-style-type: none"> Continuous exhaust from kitchen, toilet & bath; make-up air through slots near ceiling or upper part of window frame. Minimum continuous ventilation 90 m³ / hr. Speed control <u>only</u>. Air inlets, exhaust valves and fan sized to produce negative pressure ~10 Pa below atmospheric pressure. Doors undercut to allow free movement of ventilation air throughout house. 	<ul style="list-style-type: none"> Air inlets often blocked by occupant due to cold drafts or soiling on walls or to reduce noise from outside. Although designed to run continuous 25% of homes surveyed had fans disabled (fuses removed). 49% considered system noisy. Occupants wanted more control over system operation. 	3
Germany (-9°C)	Central Mechanical	<ul style="list-style-type: none"> Continuous exhaust from kitchen, toilet & bath; make-up air inlets at low level away from occupant spaces. Some exhaust only. Large cross-sectional area inlet to keep velocity low. Exhaust <u>only</u> not allowed where combustion appliance used / radon problem. 	<ul style="list-style-type: none"> N/A 	4
Netherlands (-5°C)	Central Mechanical	<ul style="list-style-type: none"> Continuous exhaust from kitchen, toilet & bath; make-up 'ventilation grids' installed above windows or a 'fanlight' (small openable window above main window) Dutch standard calls for 25m³ / hr per person. 	<ul style="list-style-type: none"> Complaints of drafts due to airflow through ventilation grids. 	5
Norway (-11°C)	Central Mechanical	<ul style="list-style-type: none"> Continuous exhaust from kitchen, toilet & bath; adjustable vents on outlets; make-up air through vents in upper frames of windows. Speed control <u>only</u>. 	<ul style="list-style-type: none"> Control defeated by occupant in many cases. Condensation not a problem. 	6
United Kingdom (-3°C)	'Passive' Central	<ul style="list-style-type: none"> Vertical outlet ducts from kitchen & bathroom; inlet vents in windows Driven by ΔT and / or ΔP. 	<ul style="list-style-type: none"> Inadequate in 'tight' construction leading to occupants opening windows. Condensation problems. 	7
	'Passive' Central	<ul style="list-style-type: none"> Vertical outlet ducts from kitchen & bathroom; simple rain cover on roof; ducts insulated in attic space; make-up air through inlets; total inlet area 1 / 3 of duct cross-sectional area. 	<ul style="list-style-type: none"> Some complaints of draft near windows in cold weather. Wind noise at roof cover during windy weather. Occupants said steam and smells from cooking cleared quickly. 	
	'Trickle Passive' Central	<ul style="list-style-type: none"> 'Trim' vents installed in windows without vertical duct. 350 mm² open area / window when fully open. Vents in window provide both 'exhaust' and 'make-up'. 	<ul style="list-style-type: none"> In retrofit cases marked reduction in condensation and mould growth. 	

fans, where used, have wider blades than is common in North American designs, possibly accounting for the lower sound levels claimed by manufacturers. Japanese range hoods all utilized centrifugal fans, and often incorporated such features as a protective splashguard for the range.

Local bathroom fans and range hoods, in the United Kingdom, are not as common, with central systems being more common. However, units for ducted application are available and resemble current practice elsewhere. Range or cooker hoods, uncommon in the U.K., feature centrifugal fans only, with round rather than rectangular duct connections, as found in North American designs.

In Europe, single location exhaust fans are not as common either. The exhaust fans reviewed had centrifugal fan wheels, with some equipped with permanent split capacitance unit bearing motors capable of full speed variation. The unit bearing motor, a desirable feature, is unavailable in North America.

Fans intended for electronic cooling application were also reviewed for possible use in residential exhaust systems. The tube axial (propeller) designs were not considered to be suitable because of limited static pressure capability, while the centrifugal fans were judged to more than meet the requirements for exhaust fan application.

The findings on exhaust equipment are summarized in Table 3.1.2.

Table 3.1.2 Comparison of Bathroom Exhaust Fans and Range Hoods

Country and Make	Type	Model	Capacity L/s @ 24.9 Pa	Power Consumption Watts	Noise Level phons	Noise Level Sones	Sound Level dBA	Flow Efficiency L/s/watt	Approx. Price \$ Cdn
Bathroom Fans									
North America									
Broan	Std Washroom	650	25	N/A		3.0		N/A	34.15
Broan	Deluxe Washroom	360	50	40(est)		1.5		1.25	179.00
Nutone	Std Washroom	663LC	25	N/A		2.5		N/A	43.15
Nuton	Deluxe Washroom	QT-110	53	37(est)		2.5		1.43	147.19
Reversomatic	Std Washroom	EB50	28	46(est)		1.5		1.20	53.45
Reversomatic	Deluxe Washroom	QB-80	35	20(est)		N/A		1.75	128.16
Japan									
Mitsubishi	Std Washroom	V-10Z8	15	19	30.0	0.5		0.79	105.70
Mitsubishi	Deluxe Washroom	V-20ZSB	105	51	40.0	1.5		2.09	274.29
Mitsubishi	Axial Spot Fan	V-12ZPA2	23	23	44.0	1.4		1.00	88.57
Mitsubishi	Axial Inline	V-12ZM4	26	19	43.5	1.3		1.37	137.14
Toshiba	Std Washroom	DVF-14JX	32	16	26.0	0.4		2.00	142.86
Toshiba	Deluxe Washroom	DVF-20M	114	49	37.5	0.8		2.33	183.81
Toshiba	Axial Spot Fan	VFP-12HB	24	25	38.5	0.9		0.96	88.57
United Kingdom									
Xpelair	Std Washroom	DX200	23	25		N/A		0.92	N/A
Xpelair	Deluxe Washroom	DX400	72	110		N/A		0.65	N/A
Vent-Axia	Std Washroom	T-6W	75	56		N/A		1.33	N/A
Vent-Axia	Deluxe Washroom	T-9W	143	92		N/A		1.55	N/A
Range Hoods									
North America									
Broan	Standard	4824	76	N/A		5.5		N/A	74.30
Broan	Deluxe	5824	85	N/A		5.5		N/A	133.90
Nutone	Standard	LL6124	85	N/A		7.5		N/A	89.75
Nutone	Deluxe	NN8130	94	N/A		5.5		N/A	251.45
Japan									
Mitsubishi	Standard	V256H3	143	68	50.5	2.1		2.10	282.85
Mitsubishi	Deluxe	V317HD	163	80	51.5	2.2		2.03	509.52
Mitsubishi	In-Cupboard	V604HMBL	163	139	46.0	1.5		1.17	373.93
United Kingdom									
Xpelair	Standard	NKH55	71	120		N/A		0.59	N/A
Xpelair	Deluxe	XTH100	132	300		N/A		0.44	N/A
Xpelair	In-Cupboard	HU55	92	120		N/A		0.77	N/A
Electronic Fans									
Howard	Tubeaxial	3-15-44'	43	17		2.5	53	2.53	N/A
Howard	Centrifugal	3-90-8607'	25	19		1.6	47	1.32	N/A

Laboratory and Field Testing of Components and Systems

Here an attempt was made to identify whether previous work had been undertaken to measure pressure/flow characteristics of residential exhaust system components. C.S.A. Standard C260.1 [9] contains graphs of pressure drop versus flow rate for several common exhaust system components. The data was developed from measurements by Ontario Hydro Research Division. Pressure drop versus volume flow rate data, obtained in tests on an airflow measurement chamber built to A.M.C.A. requirements, was provided to the project team by a major exhaust fan manufacturer. The components appeared to be the same as those pictured in C.S.A. Standard C260.1-1975, however, the results exhibited major differences.

Ontario Research Foundation [10] measured the airflow capability of nine range hoods and nine bathroom fans and compared the results to the manufacturer claimed performance. The measured air delivery of five of the range hoods and six of the bathroom fans was less than 90 percent of the manufacturer's marked rating. The more expensive models were found to be within the airflow tolerance allowed.

Figures 1 and 2 present the actual pressure versus airflow characteristics for the range hoods and bathroom exhaust fans as determined by ORF [10]. The propeller fan equipped exhaust products exhibit a relatively flat pressure/airflow characteristic, with a relatively low static pressure capability. The centrifugal blower equipped units, on the other hand, exhibit a steep characteristic with a much higher static pressure capability. The latter would be less sensitive to additional external static pressure imposed by a poorly designed or installed exhaust distribution system.

Ontario Hydro Research Division [11] conducted measurements on exhaust fans in 12 residences in Southern Ontario. Fan volume flow rate and noise were measured. The results of this investigation are summarized in Tables 3.1.3, 3.1.4 and 3.1.5. While there were significant differences between the rated flow rate and actual flow rate observed, the procedure for airflow measurement is considered inaccurate. The average noise increase resulting from fan use was measured to be 19 and 24 dBA for kitchen and bathroom fans respectively.

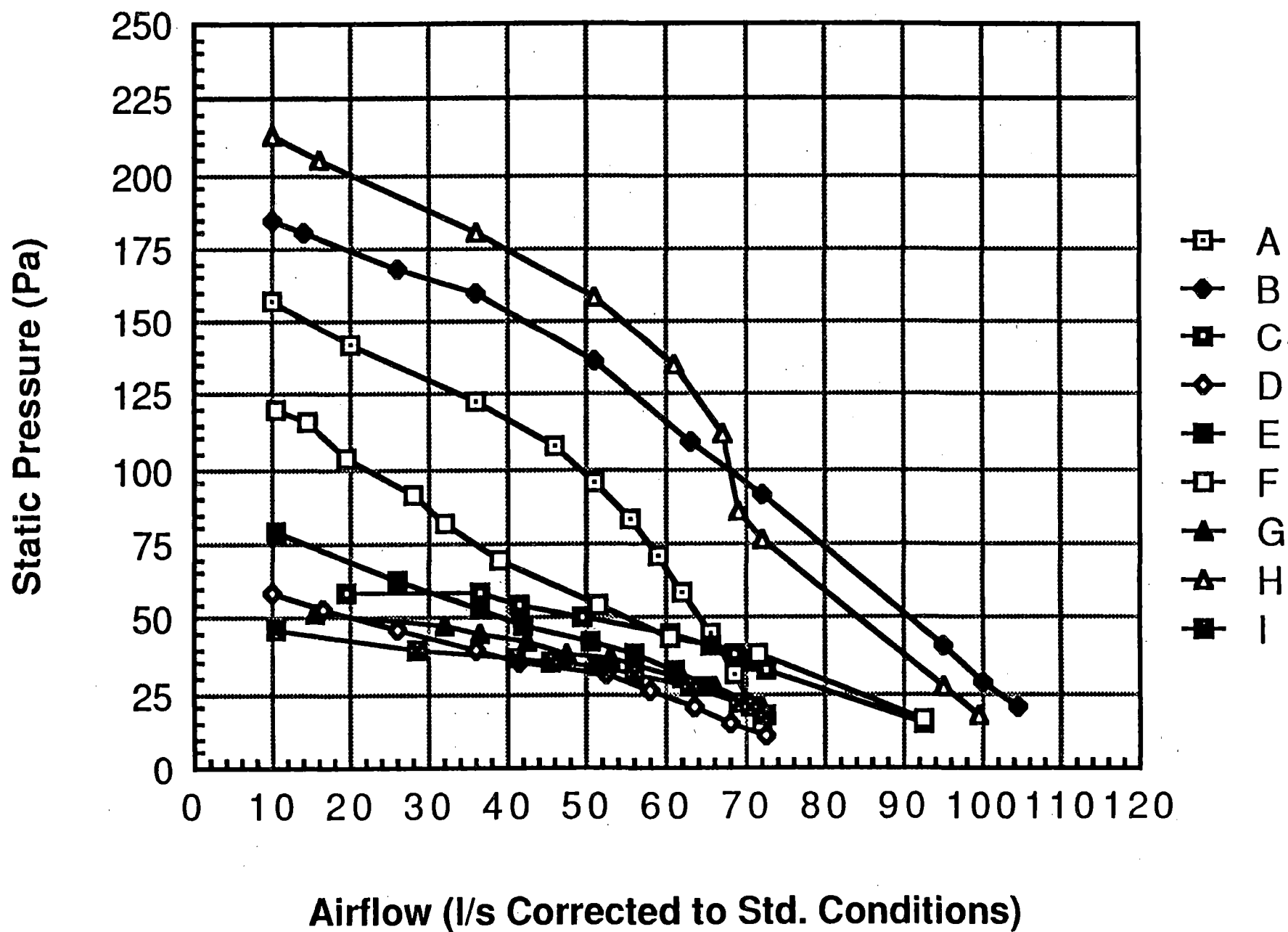
Figure 1: Rangehood Performance [10]

Figure 2: Bathroom Fan Performance [10]

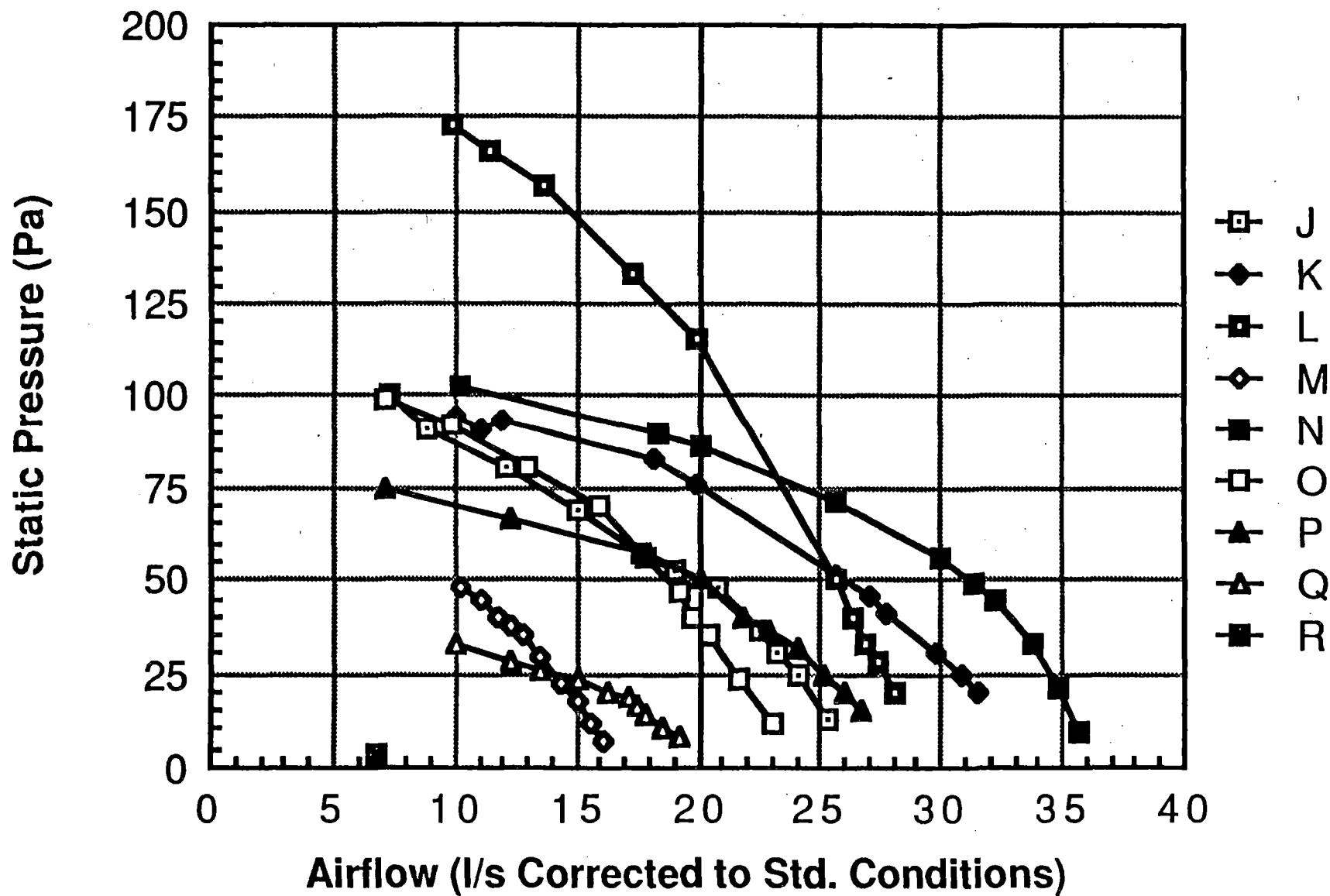


Table 3.1.3 Air Flow Capacity of Residential Exhaust Fans [11]

Home No.	Kitchen Fan				Bathroom Fan			
	Rating		Measured		Rating		Measured	
	Vol. Flow L/s	Static Press. (Pa)	Vol. Flow L/s	Static Press. (Pa)	Vol. Flow L/s	Static Press. (Pa)	Vol. Flow L/s	Static Press. (Pa)
1	83	25	77	NM	26	NA	NM	NM
2	NA	NA	15	NM	26	NA	15	NM
5	NA	NA	22	NM	NA	NA	9, 7	NM
6	NA	NA	74	NM	26	NA	17	NM
7	NA	NA	51	29	NA	NA	19	NM
8	118	NA	76	25	NA	NA	56	NM
14	NA	NA	31	20	NA	NA	19	NM
15	66	NA	45	NM	38	NA	26	NM
16	NA	NA	25	NM	-	-	-	NM
17	160	NA	51	NM	NA	NA	23	NM
19	NA	NA	29	NM	NA	NA	28	NM
20	295	25	127	NM (57)*	NA	NA	16	NM

Note: NA Not available from fan label and fan manufacturer

NM Not measured

* Obtained from manufacturers' rating curve.

Table 3.1.4 Measured Noise Levels of Residential Exhaust Fans [11]

Home No.	Kitchen Fan		Bathroom Fan	
	Ambient (dBA)	Increase Due to Fan (dBA)	Ambient (dBA)	Increase Due to Fan (dBA)
1	42	16	-	-
2	42	19	32	22
5	40	22	36	24
6	42	15	32	29
7	60	4	35	19
8	38	29	36	27
14	44	16	35	21
15	48	14	48	18
16	35	27	-	-
17	38	28	38	26
19	42	20	29	36
20	46	10	41	24
Range	(35-60)	(4-29)	(29-48)	(18-36)
Average	43	18	36	25

Table 3.1.5 Summary of Exhaust Fan Capacity and Usage [11]

Home No.	Total Exhaust Capacity (L/s)	Fan Usage minutes/day	Cap X Use (L/day)	Comments
1	103	4	7	
2	29	0	0	
5	39	131	85	prone to odour problems
6	90	21	32	prone to odour problems
7	70	8	9	
8	132	11	24	
14	51	2	2	prone to odour problems
15	70	27	32	prone to odour problems
16	25	30	13	prone to odour problems
17	74	73	90	
19	57	8	8	prone to odour problems
20	142	34	80	

One investigation [12] involved measuring ventilation rates and operating time in exhaust systems installed in townhouses. The kitchen and bathroom were exhausted simultaneously by the same fan. The total flow rates were found to range between 63 L/s and 88 L/s, with an average of 75 L/s.

Exhaust Fan Usage

Although both [11] and [12] involved exhaust fan usage monitoring, the most definitive study was that undertaken by GEOMET [14]. A questionnaire was sent to 3,000 members of Market Facts Incorporated "Consumer Mail Panel". The survey findings relate frequency of use and reasons for non-use to type of range fan (by fuel type). The findings are summarized in Table 3.1.6.

A recent project, undertaken in Winnipeg to investigate indoor air quality, airtightness, and air infiltration rates of a random sample of houses [14], contains some data on exhaust fan usage patterns, and reasons cited to explain the fan usage patterns. This information is extracted as follows:

Fan Usage Patterns - How Long Per Day Do You Use Your Fan?

	Never	Less than 1/2 hr.	1/2 hr. to 2 hrs.	More than 2 hrs.
No. of Responses	16	52	38	6

Stated Reason for Not Using Fan Regularly

	Inadequate for Purpose	Too Noisy	Broken	Other
No. of Responses	3	11	1	13

How Disturbing Do You Find The Fan Noise In The Room It Is Located In?

	Not at All	Mildly Disturbing	Moderately Disturbing	Very Disturbing
No. of Responses	35	36	15	24

The above answers were obtained from a sample of 59 houses which contained exhaust fans. Some houses contained more than one exhaust fan.

Current Research and Future Developments

Contacts with individuals involved in research were intended to identify whether there was a breakthrough in exhaust equipment, which could impact on future phases of this project. The University of Minnesota [15] was evaluating the effect of airflow patterns caused by range hoods, with emphasis on their ability to control emission of gases and vapours from a localized source. This work was not seen as relevant to the scope of the current investigation.

Similarly, another investigation [16] was leading to the development of an improved gas range with higher capture efficiency to overcome problems relating to nitrogen oxides and water vapour emission. This work, although of interest, was not seen to impact on the subsequent phases of this investigation.

3.2 Field Observations and Testing

Following the state-of-the-art and practice review, a field survey of residential exhaust system practice, in the different regions of Canada, was planned and undertaken. Four major centres represented by Vancouver, Calgary, Quebec City and Halifax were targeted by the project team. The same approach employed by Bach [1] in the Toronto area was communicated to the HRAI contacts in the other cities.

The contacts were to visit a number of different building sites, at the rough-in stage, to observe details of the installation of the bathroom and kitchen exhaust fans, record model numbers of equipment and to provide in the different centres. A second phase was to involve measurement of airflow and sound, using equipment and procedures developed by Ontario Research specifically for the project.

TABLE 3.1.6 Range Hood Fan Usage - GEOMET [13]**Type of Range Fan as a Function of the Type of Cooking Fuel**

	Residences without Fans (%)	Residences Recirculating Hood Fans (%)	Residences with Vented Hood Fans (%)	Residences with Ceiling or Wall Fans (%)
Gas	42	12	31	14
Electricity	26	20	39	12

Frequency of Use of Range Hood Fans

	Residences with Gas Ranges (%)	Residences with Electric Ranges (%)
Dinner	44	37
Lunch	14	12
Breakfast	21	16

Frequency of Use at the Dinner Meal as a Function of Fan Type and Building Type

Type of Fan	Respondents Using a Fan Always or Often (%)
Unvented Hood	33
Vented Hood	42
Ceiling or Wall Fan	34
Type of Building	
Mobile Home	52
One-Family Detached	40
One-Family Attached	39
Buildings for 2-4 Families	25
Buildings for 5+ Families	33

Reasons for Using or Not Using Fans	(%)
Remove Smoke or Steam	87
Remove Odors	56
Remove Heat	28
Improve Indoor Air Quality	19
Not Using Fans Due to Noise	39

Field Observations

Vancouver: Bathroom exhaust fans were installed with 76 or 100 mm sheet metal or flexible duct. Because of the new Building Code in B.C., the exhaust fan is installed in a box with the joints caulked or sealed to prevent air leakage. Electricians often install the fans. Most systems are controlled by on/off switches with the occasional use of a timer in the bathroom. Dehumidistat control was seldom used. Range hood fans were installed with 125 mm diameter sheet metal duct. Finally, the fans installed were national brands, available throughout Canada.

Calgary: Bathroom exhaust ductwork, in the new homes surveyed, was found to be: 76 mm diameter in either galvanized sheet metal or plastic, or a combination of both types. Only two of the seven homes had ducted range hoods installed; the remainder were equipped with recirculating range hoods. Wall and/or roof termination devices had been installed on only two of the homes at the time of the survey. One house had the fan manufacturer's wall and roof cap terminations installed, while the other had the common plastic dryer vent wall cap as a bathroom exhaust duct termination. Apparently, in Calgary, the sheet metal contractor supplies all exterior termination devices to the roofers and brick layers. As in other regions, the electrician supplies and installs the fans.

Quebec City: Bathroom exhaust fans were installed with a combination of either 76 or 100 mm diameter rigid sheet metal and flexible duct. Occasionally, 125 mm flexible duct was observed on bathroom fan installations. Range hood ducting was almost exclusively that recommended by the manufacturer (85 mm x 255 mm) and this was the only observed location in Canada where the rectangular ducting was used. In addition, the wall, roof and eave caps and fittings were those supplied by the exhaust fan manufacturers, a practice not observed in the other major cities. As with the other markets, the bathroom and kitchen fans were from the major Canadian suppliers.

Halifax: Bathroom exhaust ductwork was observed in each case to be 76 or 100 mm diameter flexible vinyl duct. Control was by separate on/off switch. The only range hood observed was a recirculating unit. Halifax was the only city where a

rough-in for a central ventilation system was observed. Fresh air supply to the bedrooms, living and family rooms was to be provided, together with high wall exhaust from the kitchen, laundry and upstairs bathrooms. Electricians select and install the fans in many cases, with other trades installing insulation and terminations. The regional contact concluded that fewer than 5 percent of the installations in this area were inspected for compliance to good building practice.

Field Testing

Ontario Research Foundation prepared equipment and procedures for airflow and sound measurements to be made in each of the 4 cities by the same contacts. Instructions on how to use the equipment were prepared and issued to the regional contacts, together with a data sheet to be used for each installation.

Field Airflow Measurements

Flow hoods equipped with static pressure taps, a balancing fan, a commercially available airflow sensor, an AIR Ltd. electronic manometer, together with ductwork and ancillary equipment, were supplied to the regional contacts to enable measurement of airflow through both kitchen and bathroom exhaust systems.

The field test equipment is illustrated in Figures A and B of Appendix 2. The flow sensors used were 100 mm and 150 mm flow grids manufactured by Conservation Energy Systems of Saskatoon, Saskatchewan, and the pressures were measured using an Air Measurements Ltd. electronic digital micromanometer model MP6KD, with a full scale range of ± 1.999 " W.C., resolution of .001" W.C. and accuracy specification of 1% of reading ± 1 count. We are confident that the equipment, used by an experienced operator, would produce measured airflows within 10% of the actual airflows.

The regional technicians were provided with detailed instructions on how to set-up, carry out the measurements, record the readings and estimate the airflow rate. Data sheets were provided, to be completed, for each fan evaluated in the field. The data

sheets returned by the regional contacts were analyzed and the airflow results are presented in Tables 3.2.1 and 3.2.2.

Bathroom Exhaust Fans: The bathroom fans, as installed in the field, delivered, on average, only about 45 percent of their advertised airflow. The most common fan, covered by the field survey, was rated at 25 L/s and at 25 Pa static pressure by the manufacturer. The average flow rate measured on this fan in the field was 12 L/s. Further investigation revealed that this same fan had been flow tested by ORF [10] and found to deliver only 60 percent of the rated flow at 25 Pa, or 15 L/s. The poor fan performance which was originally thought to be caused by excessive duct resistance in the field installations, may have been simply a case of a bathroom exhaust fan with an optimistic airflow rating delivering its actual airflow capacity at 25 Pa.

Range Hoods: The range hood airflows, measured in the same houses, were found, on average, to deliver only 34 percent of the manufacturer's rated airflow. Nine of the fourteen range hoods evaluated in the field measurement phase were representative of units originally tested at Ontario Research [10]. The original laboratory data revealed that these fans delivered anywhere from 80 to 100 percent of the manufacturer's claimed airflow. One could therefore generally conclude that the disappointing performance of the range hoods was largely due to excessive static pressure resulting from poor duct system design. Unfortunately, no detail of the duct system designs was available to quantify the static pressures.

The same range hood was employed in houses 11A, 14A, 15Q and 16Q in Table 3.2.2. This range hood had been evaluated at ORF [10], and is fan G in Figure 1. Note in Table 3.2.2 that in house 11A an airflow rate of 55 L/s was measured, whereas in house 16Q an airflow rate of only 17 L/s was measured. While this represents a 70 percent reduction in airflow rate from Figure 1, it can be determined that the increase in static pressure associated with this change in flow rate is only 30 percent. This example simply illustrates the low static pressure capability of a propeller fan equipped range hood. If fan B in Figure 1 (equipped with twin centrifugal blowers) had been installed and subjected to the same relative increase in

TABLE 3.2.1: Field Airflow Measurements - Bathroom Exhaust Fans

<u>House No.</u>	<u>Fan Model</u>	<u>Manufacturer's Rated Airflow (L/s @ 25 Pa) (1)</u>	<u>Field Measured Airflow (L/s)</u>	<u>Percent of Rated Airflow (%)</u>
1B	A1	24	9	37
1B	A1	24	5	23
2B	A1	24	13	54
2B	A1	24	14	59
3B	A1	24	14	57
3B	A1	24	9	37
10A	A1	24	14	59
10A	A1	24	14	59
11A	NR	NA	11	NA
11A	NR	NA	12	NA
12A	A1	24	12	53
12A	A1	24	NR	NA
13A	A1	24	15	64
13A	A1	24	NR	NA
14A	A1	24	12	53
14A	A1	24	NR	NA
15Q	A1	24	5	23
16Q	B1	24	6	26
17Q	B2	38	13	34
18Q	A2	28	6	22
19Q	B1	24	11	46
20Q	B1	24	10	42
21Q	NR	NA	4	NA
22N	E1	24	4	19
23N	A1	24	16	70
24N	NR	NA	7	NA

Note:

NA - not available

NR - not recorded

(1) - Ratings are converted from information published by manufacturers in cfm.
Conversions to L/s are not exact in the above table.

B - Vancouver, B.C.; A - Calgary, Alberta; Q - Quebec, P.Q.; N - Halifax, N.S.

TABLE 3.2.2: Field Airflow Measurements - Kitchen Range Hoods

<u>House No.</u>	<u>Fan Model</u>	<u>Manufacturer's Rated Airflow (L/s @ 25 Pa) (1)</u>	<u>Field Measured Airflow (L/s)</u>	<u>Percent of Rated Airflow (%)</u>
1B	B10	85	12	14
2B	B10	85	50	59
3B	A11	85	78	92
11A	A10	75	52	69
12A	C10 (Recirc)	75	23	31
13A	C10	75	37	50
14A	A10	75	34	45
15Q	A10	75	17	23
16Q	A10	75	16	21
17Q	A12	140	30	22
18Q	A12	140	32	23
19Q	D10	NA	17	NA
20Q	B11	65	24	37
21Q	B10	85	23	27
22N	F10	75	24	32
23N	A12	140	27	19
24N	A10	75	27	36

Note:

NA - not available

(1) - Ratings are converted from manufacturers' published information for vertically discharged range hoods. Information is published in cfm, and conversions to L/s are not exact.

B - Vancouver, B.C.; A - Calgary, Alberta; Q - Québec, P.Q.; N - Halifax, N.S.

static pressure as the propeller fan in the previous example, one can see, with reference to Figure 1, that a much smaller reduction in airflow would result because of the centrifugal fan's steeper pressure versus airflow characteristic.

Field Sound Level Measurements

The regional technicians were also provided with a Bruel and Kjaer Model 2409 sound level meter to enable measurement of A-weighted sound levels in the houses, both with and without the fans in operation.

Sound level measurements were taken with the microphone positioned as follows:

- for range hoods, 1.5 meters above the floor, .3 meters centrally located in front of the range;
- for bathroom exhaust fans, .75 meters above the toilet seat, .6 meters out from the wall behind the toilet.

The original intent of these sound level measurements was to determine whether field measured sound levels (dBA) showed the same trends as manufacturers' certified sound ratings. That is, units with higher sone ratings would exhibit higher A-weighted sound levels. An alternative approach available to the project team was to measure individual frequency sound levels (i.e. broad-band measurement) and estimate the sone levels by calculation. It was decided that additional training of the regional contacts would be required to undertake this type of measurement. As the complexity and resulting errors of measurement increased with the number of individual measurements required, it was decided to simply measure the A-weighted output of the range hood and bathroom fans.

The sound level measurement results are presented in Table 3.2.3. The manufacturer's rated sound level in sones is presented, together with the A-weighted sound levels measured in the homes, with fans both 'on' and 'off'.

Examination of the data in Table 3.2.3 does not appear to yield any strong trends of increasing field 'Measured Sound Level' with increasing 'Rated Sound Level'.

One must realize that conditions, (eg. wall construction, external static pressures), operating voltages and installation techniques used in the field may be considerably different than what would be encountered in the certification laboratory. The sound level measurement procedures also vary considerably. For these reasons, the measured sound levels in the houses cannot be used to develop a correlation with fan certified sound level ratings.

3.3 Laboratory Testing of Components and Systems

Proper design of residential exhaust systems depends on the availability of accurate information on exhaust fan flow and system component pressure drop characteristics. While pressure drop characteristics through exhaust system components have been well documented by ASHRAE and others, there was little information on pressure drop through wall and roof caps. In addition, little information was available on the flow rates through typical residential exhaust systems or how poor design or sloppy installation practice could impact on exhaust system performance. A series of laboratory tests were needed to address these two areas and to ultimately provide better empirical data for design of exhaust systems.

The components and complete exhaust systems selected for laboratory evaluation were chosen from observations during the field surveys.

Component Tests

The following components were selected for the laboratory evaluation:

- A commercially available, sheet metal bathroom exhaust wall cap, manufactured by a major supplier of residential exhaust equipment. It joins to a 100 mm duct directly or to a 75 mm duct through a transition. The damper is spring loaded.
- A commercially available, sheet metal range hood exhaust wall cap, from the same supplier as above. It connects directly to an 85 x 255 mm rectangular duct and has a spring loaded damper.
- A plastic, clothes dryer vent wall cap, with a 100 mm round damper. It is designed to fit a 100 mm round duct. The damper is gravity operated. This cap is commonly used on both bathroom and kitchen exhaust systems in central Canada.

TABLE 3.2.3: Field Sound Level Measurements

House No.	Manufacturer (Model)		Rated Sound Level (Sones)	Measured Sound Level	
	Bathroom	Range Hood		Fan 'On" (dBA)	Fan 'Off" (dBA)
1B	A1		3.0	72	44
	A1		3.0	80	44
		B10	7.0	71	23
2B	A1		3.0	60	54
	A1		3.0	62	54
		B10	7.0	66	54
3B	A1		3.0	62	23
	A1		3.0	62	23
		A11	5.5	71	24
10A	A1		3.0	50	46
	A1		3.0	50	48
11A	NR		NA	50	43
	NR		NA	52	45
		A10	6.5	62	42
12A	A1		3.0	44	38
	A1		3.0	52	39
		C10 (Recirc)	NL	62	42
13A	A1		3.0	52	44
	A1		3.0	48	42
		C10	NL	65	43
14A	A1		3.0	53	38
	A1		3.0	44	37
		A10	6.5	66	35
15Q	A1		3.0	46	20
		A10	6.5	64	24
16Q	B1		4.0	61	20
		A10	6.5	68	20
17Q	B2		3.5	54	26
		A12	4.5	65	20
18Q	A2		3.0	57	20
		A12	4.5	65	34
19Q	B1		4.0	58	24
		D10	NA	63	31
20Q	B1		4.0	57	27
		B11	5.0	64	27
21Q	NR		NA	50	22
		B10	7.0	65	22
22N	E1		NR	58	35
		F10	NL	71	36
23N	A1		3.0	49	32
		A12	4.5	69	34
24N	NR		NA	51	34
		A10	6.5	66	33

- Two sheet metal roof caps, one for bathroom exhaust systems (76 or 100 mm duct), the other for range hood installations (85 x 255 mm duct). The bathroom roof cap had a gravity loaded damper, the range hood both a gravity and spring loaded damper.
- A bathroom exhaust fan, imported from Japan, with a rated airflow rate of 25 L/s at zero external static pressure. The rationale, here, was to compare airflow capabilities and efficiency with the North American units tested and reported on earlier [10].

System Tests

In the case of both bathroom and range hood exhaust systems, the layout of the ductwork and the selection of components was based on field observations. In each case, through the introduction of substandard components, the performance of the system was degraded from "good to poor". The systems as tested are shown in Figure 3.

Test Results

Figures 4, 5, 6, 7 and 8 present the pressure drop versus volume flow rate as determined in the ORF Airflow Test Facility, Figure 9, for the wall and roof caps. Comparisons with data from [9] and unpublished data from the equipment supplier are shown where available.

Tables 3.3.1 and 3.3.2 summarize the pressure drop versus volume flow rate results determined on the bathroom and kitchen exhaust system tests.

The component pressure drops, measured by ORF, Figures 4 through 8, are in close agreement with the data from [9], but considerably lower than those reported by the manufacturer. The large differences existing between the two sets of data cannot be explained. The manufacturer's data was originally developed over fifteen years ago. The current contact with the company knew nothing about the test program. The data was never officially published, which makes it even more difficult to explain the discrepancies.

The bathroom exhaust system tests, Table 3.3.1, show a significant reduction when

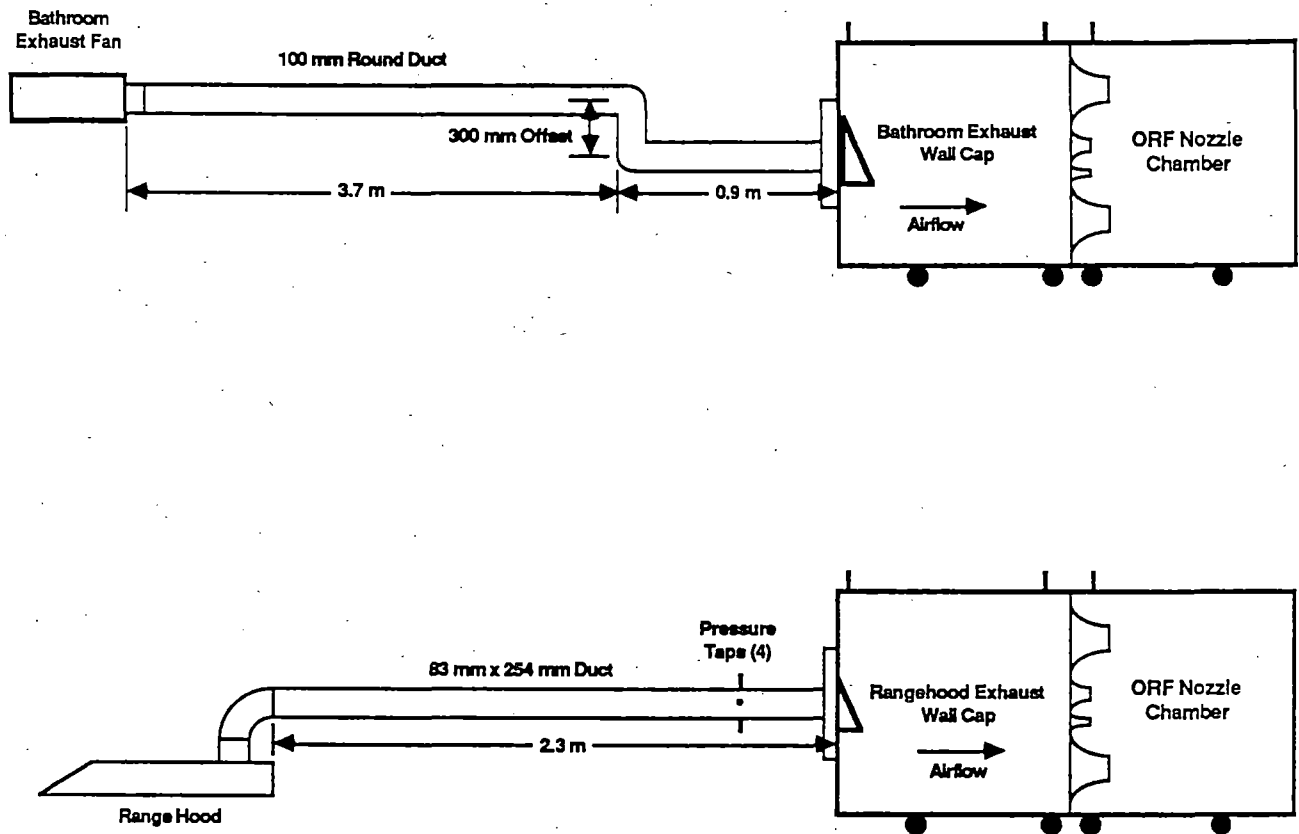


Figure 3: Bathroom and Range Hood Exhaust System Layout

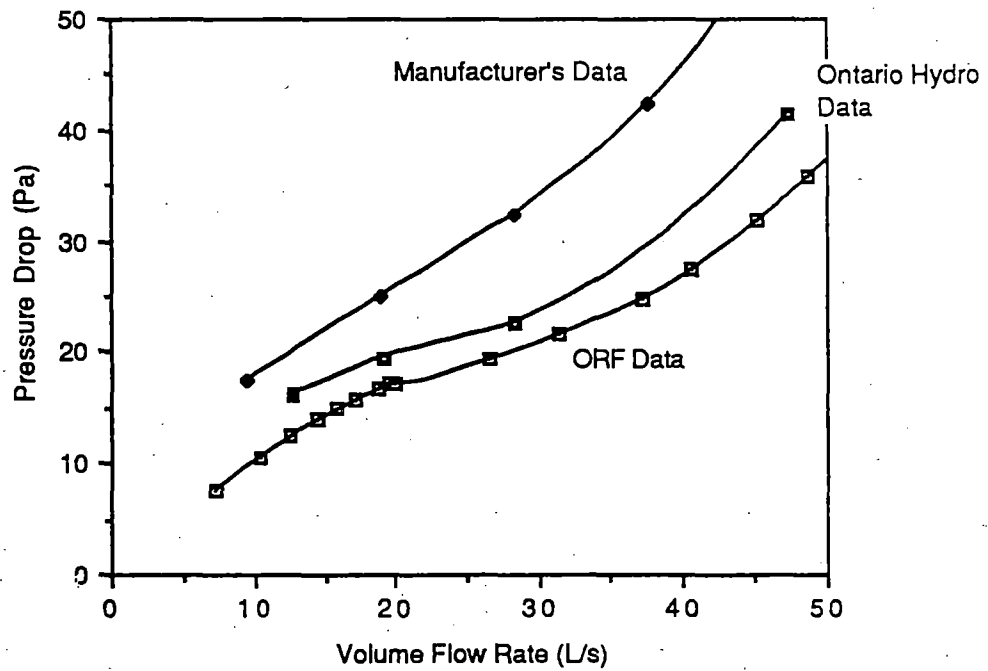
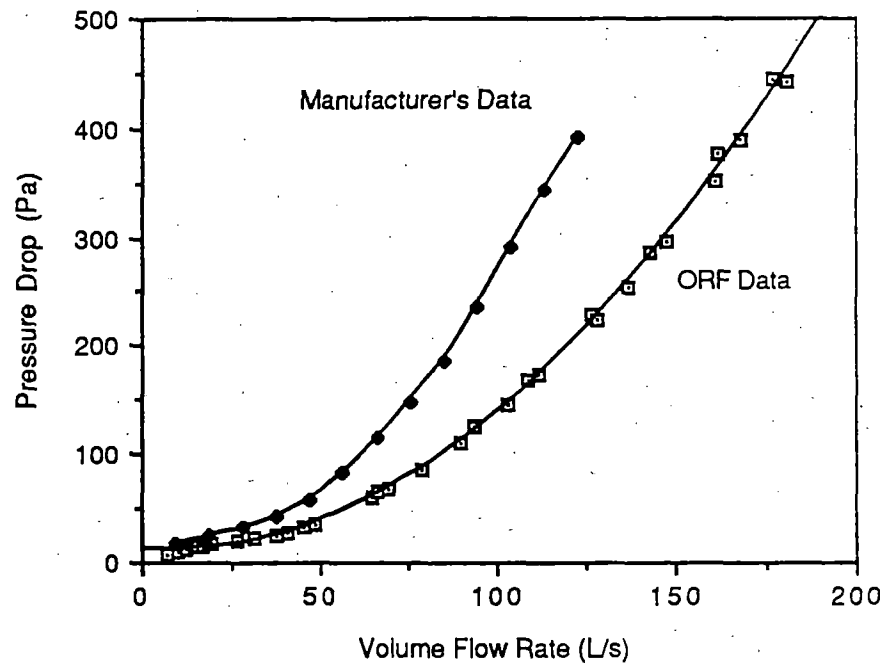
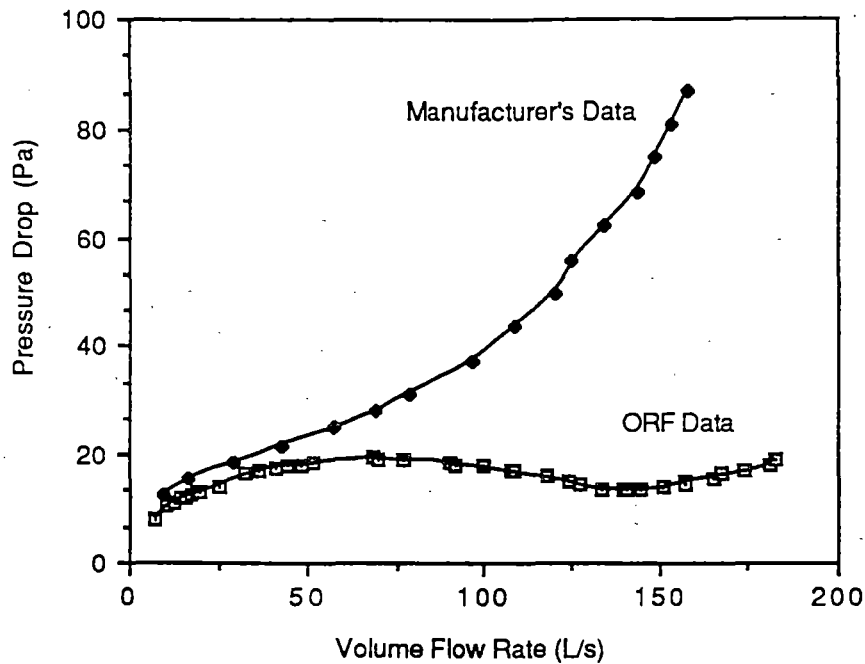
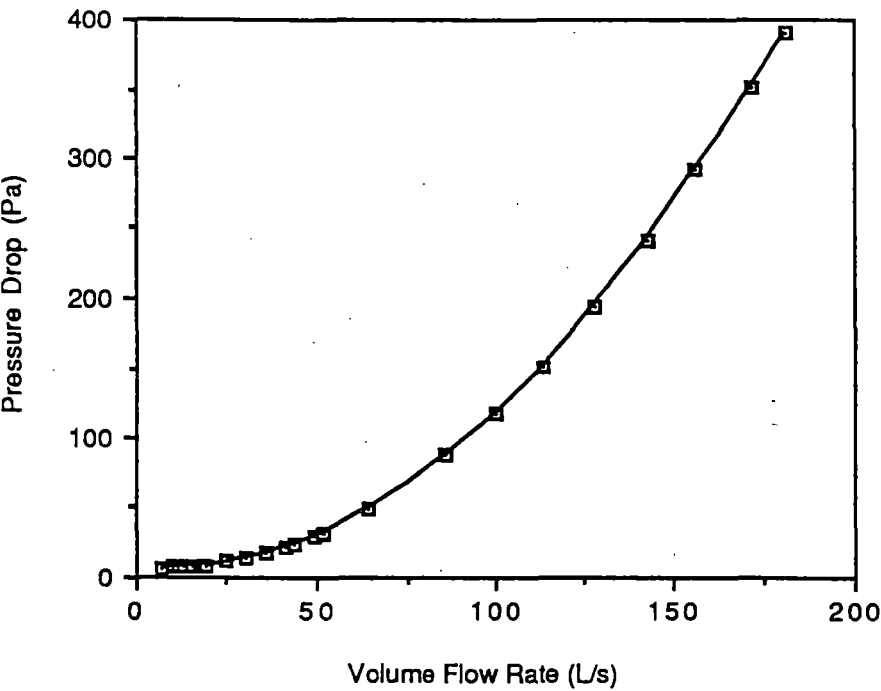


Figure 4: Bathroom Wall Cap (Sheet-Metal)
Pressure Drop Characteristic



**Figure 5: Range Hood Wall Cap (Sheet-Metal)
Pressure Drop Characteristic**



**Figure 6: Plastic Dryer Vent Wall Cap
Pressure Drop Characteristic**

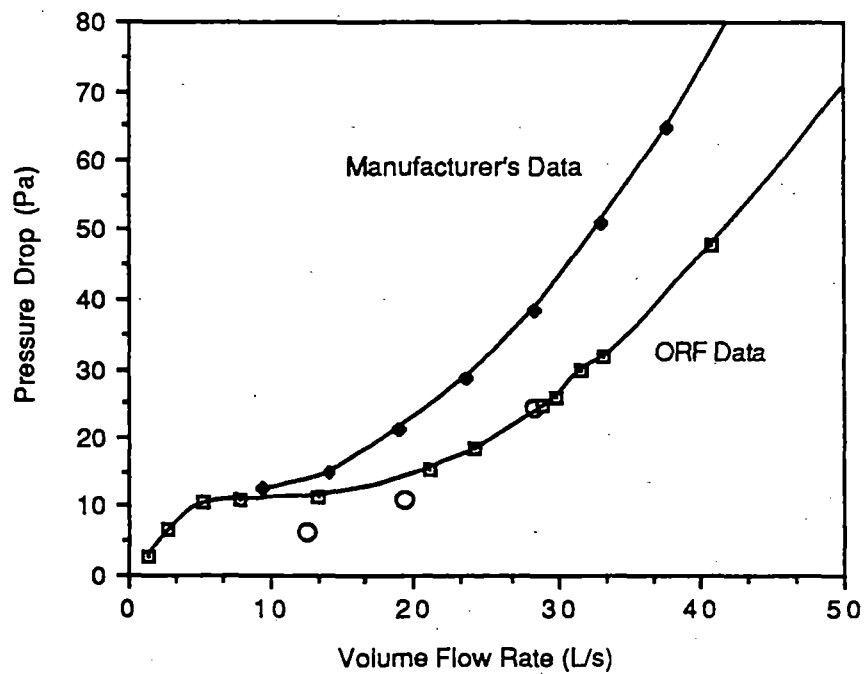
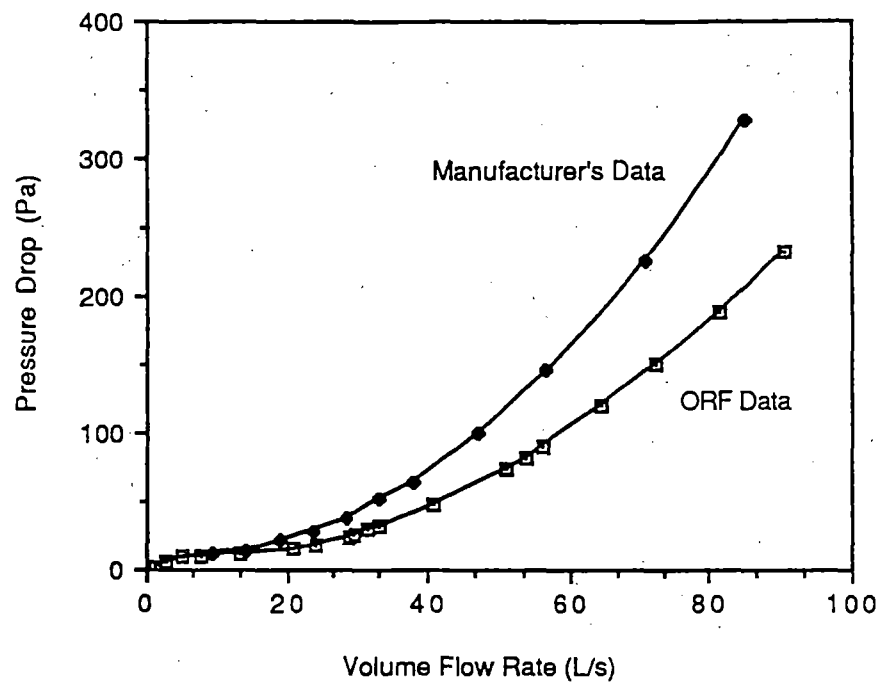


Figure 7: Bathroom Roof Cap
Pressure Drop Characteristic

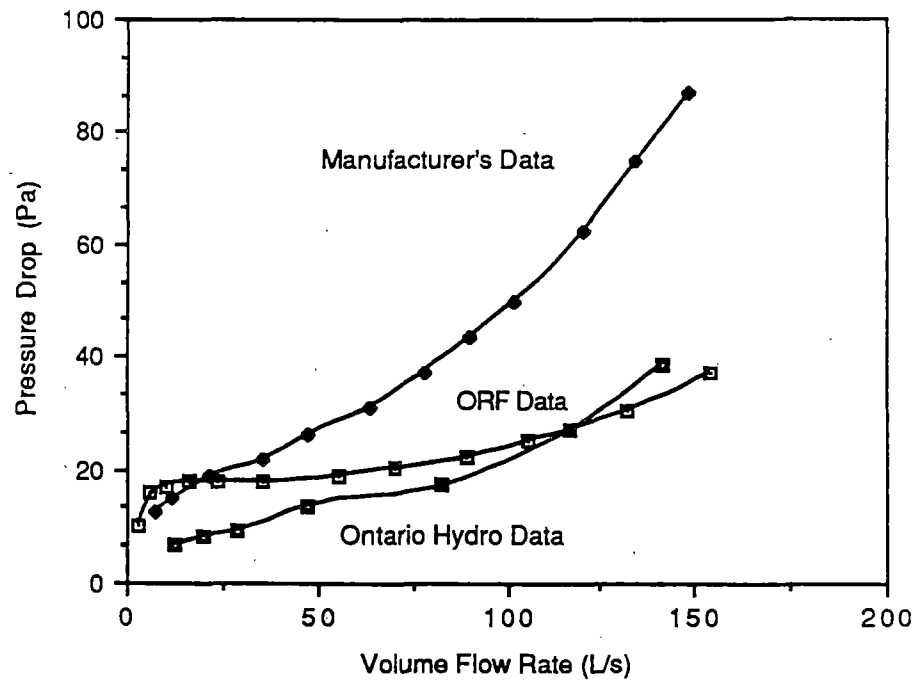


Figure 8: Range Hood Roof Cap Pressure Drop Characteristic

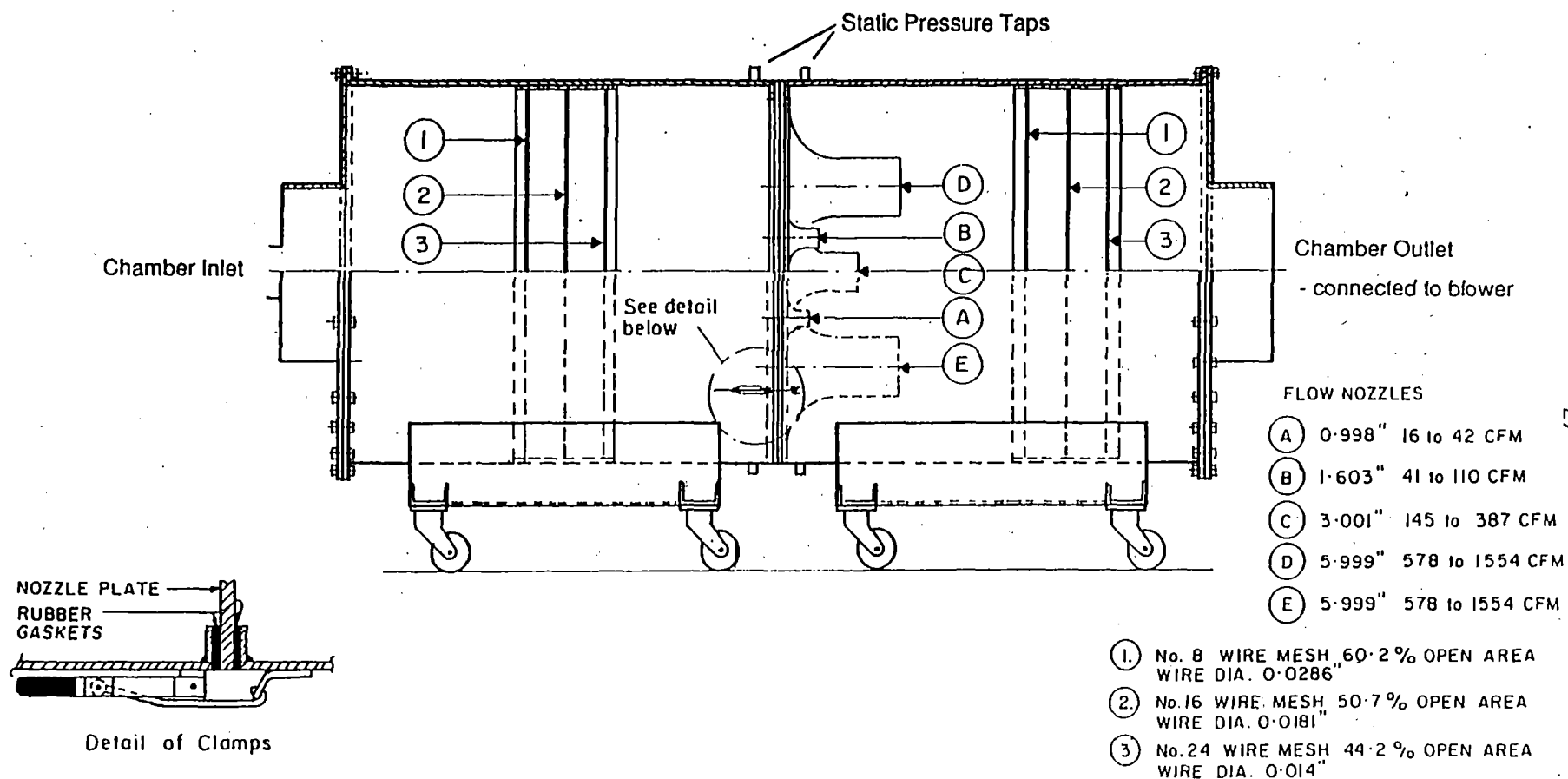


Figure 9: ORF Airflow Test Nozzle Chamber

TABLE 3.3.1: VOLUME FLOW RATES AND PRESSURE DROPS THROUGH BATHROOM EXHAUST SYSTEMS

Wall Cap	Duct Size	Comments	Volume Flow Rate Exiting From Cap			Pressure Rise at Fan (obtained from fan speed)			Volume Flow Rate Leaving Fan (obtained from fan speed)			Estimated Leakage		
			L/s			Pa			L/s			L/s		
Installation in Accordance with Manufacturer's Instructions														
Manufacturer's Bathroom Exhaust Wall Cap	100 mm	Joints Untaped	28.8	±	0.5	NA			NA			NA		
Manufacturer's Bathroom Exhaust Wall Cap	100 mm	Joints Taped	31.0	±	0.5	NA			NA			NA		
Typical Installation #1														
100 mm Dryer Vent Multi-Damper	75 mm	Joints Untaped	21.3	±	0.5	62	±	1.0	28.7	±	0.2	7.4	±	0.7
100 mm Dryer Vent Multi-Damper	75 mm	Joints Taped	23.2	±	0.5	74	±	1.0	24.7	±	0.4	1.5	±	0.9
Typical Installation #2														
75 mm Dryer Vent Single Damper	75 mm	Joints Untaped	20.7	±	0.5	NA			NA			NA		
75 mm Dryer Vent Single Damper	75 mm	Joints Taped	22.0	±	0.5	73	±	1.0	25.1	±	0.3	3.1	±	0.8
Typical Installation #3														
75 mm Dryer Vent Single Damper	5.5 m of 75 mm Flex Tube	Stretched to 5.1 m	16.0	±	0.5	91	±	1.0	18	±	0.5	1.6	±	1.0
75 mm Dryer Vent Single Damper	7 m of 75 mm Flex Tube	Stretched to 5.7 m	13.7	±	1.0	96	±	1.0	15	±	0.6	1.2	±	1.6

TABLE 3.3.2: VOLUME FLOW RATES AND PRESSURE DROPS THROUGH RANGEHOOD EXHAUST SYSTEMS

Wall Cap	Duct Size	Comments	Volume Flow Rate Exiting From Cap			Pressure Rise at Fan (obtained from fan speed)			Volume Flow Rate Leaving Fan (obtained from fan speed)			Estimated Leakage		
			L/s			Pa			L/s			L/s		
Installation in Accordance with Manufacturer's Instructions														
Manufacturer's Rangehood Exhaust Wall Cap	83 x 255 mm	Joints Taped	86	±	1.5	50	±	4	90	±	1.9	4	±	3.4
Typical Installation														
100 mm Dryer Vent Single Damper	100 mm	Joints Untaped	52	±	1.0	133	±	5	52	±	2.8	0	±	3.8
100 mm Dryer Vent Single Damper	100 mm	Joints Taped	52	±	1.0	137	±	5	50	±	3.0	-2	±	4.0

the exhaust system is not designed or installed in accordance with manufacturer's instructions. The volume flow rate drops by about 30 percent in going from 100 mm duct to 75 mm duct, but is not affected significantly by the selection of the wall cap. Use of flexible duct of 75 mm diameter leads to a further reduction of 30 percent.

For the range hood system tests, Table 3.3.2, a reduction of 40 percent in volume flow rate was observed when the 85 x 255 mm ducts were replaced by the 100 mm diameter duct (common practice in Southern Ontario).

The effect on system airflow resulting from taping sheet metal duct joints is also shown in Tables 3.3.1 and 3.3.2. The most significant finding is the 20% reduction in leakage in Installation #1.

Japanese Exhaust Fan Testing

In addition to the exhaust system termination and duct work component laboratory evaluations, one off-shore exhaust fan was selected and subjected to the same airflow delivery measurement procedure as the fans in Reference [10]. This evaluation was undertaken because catalogue ratings could not be counted on, simply because the standards used for testing and rating exhaust fans were not the same in Japan and North America.

A bathroom fan manufactured and distributed in Japan was selected from a catalogue. An order was placed with a contact in Japan, who procured the unit from a local supplier. The unit was packaged and shipped to Ontario Research for airflow testing.

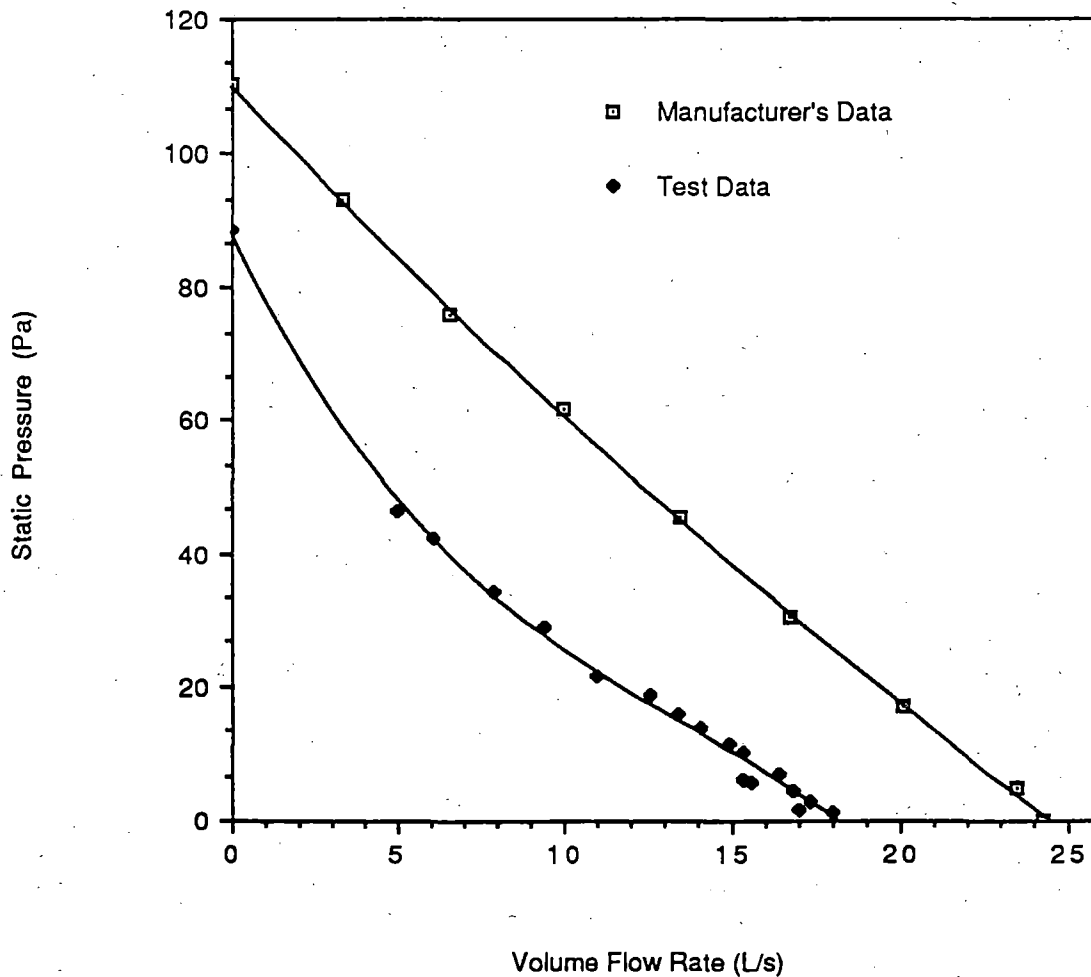
The bathroom fan was equipped with a 140 mm diameter fan. The motor was rated for either 50 or 60 Hertz application at 100 volts. The manufacturer's rated airflow was 24.5 litres per second at 'free delivery' conditions, at 60 Hertz. The manufacturer's catalogue provided a complete static pressure/airflow characteristic for the fan.

The unit was installed in the ORF Airflow Test Facility and tested in general accordance with AMCA 210-1985 "Laboratory Methods of Testing Fans for Rating Purposes". The test results are presented in Figure 10, together with data reproduced from the manufacturer's product catalogue.

The rather large discrepancy, between the ORF and Japanese manufacturer's data, cannot be explained by test procedural differences.

Rather, the fan's airflow capability appears to have been overrated.

Figure 10: Japanese Fan Performance



3.4 Simplified Builder Guidelines

A draft builder guide was prepared as part of this research study. This is included as Appendix 4 of this report.

4. CONCLUSIONS AND RECOMMENDATIONS

There is sufficient data on typical exhaust system components and fans to design effective residential exhaust systems where warranted. However, poor installation practice is, no doubt, largely responsible for homeowner dissatisfaction with local exhaust systems.

The builder guidelines must emphasize, above all else, that the manufacturer's installation instructions be followed. This simple point alone will ensure that most residential exhaust systems work as intended. For those systems requiring considerably more ductwork, there may be a need to emphasize the importance of using a bathroom or range hood equipped with a centrifugal rather than a propeller fan. The former design is less sensitive to external pressure and thus has a broader operating range.

Inspection authorities across Canada must also be made aware of the importance of ensuring that local exhaust systems are properly sized and installed. While inspection authorities generally ensure that exhaust fans are installed as required by local codes, they do not appear to check whether the fan has sufficient airflow capacity or whether the ductwork is in accordance with manufacturer's instructions. The responsibility for a properly installed local exhaust fan system should not rest entirely with the builder.

The use of flexible duct, in bathroom exhaust systems, should be subject to careful installation practice and, perhaps, limited to very short runs, or, alternatively, only permitted where a larger diameter duct will be installed than would be called for when using conventional sheet metal duct. For example, use 125 mm flexible vinyl duct where 100 mm galvanized round duct is adequate.

The plastic dryer vent type wall cap would appear to be as acceptable, with regard to pressure drop, in a bathroom fan application, as the manufacturer-supplied sheet metal wall cap.

However, for range hood application only, the wall cap supplied by the fan manufacturer should be used, together with the 85 mm x 255 mm duct normally specified.

Taping of joints, on galvanized round duct, resulted in reductions in leakage, from 25 percent without tape to 6 percent with tape (Installation #1, Bathroom Exhaust Systems). In the typical range hood installation, however, no leakage reduction was evident following the taping of the duct joints. This can be largely explained by the much larger number of joints in the bathroom system compared to those in the range hood system. The most significant leakage is probably at the adjustable elbows, each of which have 5 circumferential joints as well as 2 transverse joints. The bathroom system tested had two elbows, while the range hood system had only one.

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