RESEARCH REPORT

The Canadian Residential Duct and Chimney Survey

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FINAL REPORT

THE CANADIAN RESIDENTIAL DUCT AND CHIMNEY SURVEY

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D I S C L A I M E R

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1. INTRODUCTION

The installed flow and thermal performance of ducts and chimneys in housing is not well known. However, recent field surveys funded by the Canada Mortgage and Housing Corporation (CMHC) have revealed that many fans, furnaces, and fireplaces are not working as intended. Fans have exhibited poor air flow (Ref 1). Combustion appliances are susceptible to pressure-induced spillage, or to draft problems caused by poor design and maintenance of the venting systems (Ref 2). Also site-built systems, such as furnace ducting or masonry chimneys, differ widely from the theoretical designs that are used to determine appliance specifications (Ref 3). Often there has been no attention given to system design or to commissioning of new venting and ventilation systems in Canadian houses.

This report describes the results of a project funded by CMHC, with the intent of achieving a better understanding of the nature and extent of such problems. The project commenced in September, 1988. The overall objective was to provide research organizations and policy groups with a detailed and accurate description of the current condition of ventilation systems, ducts and chimneys, in all types of Canadian houses, from coast to coast.

Properly organized and analyzed, this kind of information should help to achieve a number of more specific objectives, including:

*improved installation and equipment codes;

*techniques for problem recognition and avoidance (particularly with chimney performance);

*better retrofit procedures (and better appreciation of when a specific retrofit is warranted); and,

*refinement of research tools, performance tests, and methods of evaluating installed systems in houses.

Prior to undertaking work on a survey of ventilation systems, CMHC recognized the need for a new device which could allow rapid and accurate testing of the flow and thermal performance of ducts and chimneys. This device is referred to as a Duct Test Rig (DTR), and its use was critical to the successful and extensive data collection work described in this report.

The DTR is an ingenious device for measuring air flows and heat losses in ducts and chimneys. It has a powerful fan and an adjustable orifice mounted in a portable flow chamber. By means of multiple attachments, the flow chamber can be easily fitted to varying types of ventilation supply and exhaust openings, allowing the Duct Test Rig to be used for a multitude of test purposes.

The design and development of a DTR was completed for CMHC by Sheltair Scientific Ltd., as part of an earlier project. For details, refer to the Design and Development of a Device for Testing Residential Ducts, Fans and Chimneys (Ref 4).

The remainder of this report is divided into four major parts:

Survey Design;
Test Protocol Design;
Test Results; and
Appendices.

Because of the breadth and scale of the Duct and Chimney Survey, each of these sections contains substantial information which may be of use to readers interested in interpreting test results, or to researchers conducting similar survey work.

The essence of the project was the creation of a computer data base. This data base has been called the DTR Base. It contains all of the test results on a computer file, and is intended to accompany this report.

2. SURVEY DESIGN AND SELECTION OF HOUSES

2.1 Selection of Houses and Communities

To obtain a representative sample of houses across Canada, it was decided to test houses in the five major populated regions of the country. Within each region two communities were selected. One community was heavily populated. The second community was chosen to represent the greatest difference from the first in terms of climate, style of house and fuel types.

Vancouver was paired with Kelowna. These two communities are in very different climatic regions. Also, the Okanagan is the second largest congregation of population in British Columbia, next to the Lower Mainland and Vancouver Island. It was expected that Kelowna houses would be similar to much of the interior of B.C., and the northern prairies.

Winnipeg was paired with Calgary. Calgary is the largest population base in the prairies, next to Edmonton and Winnipeg. However, its climatic conditions are significantly different than Winnipeg and Edmonton, because it is located in the foothills. It also seemed worthwhile selecting a community in Alberta, since Alberta has more houses than all of Atlantic Canada.

London was paired with Toronto. London is away from the lakes, and is significantly colder than Toronto. London is representative of many large communities in southern Ontario. It is also within easy driving distance of the Toronto area.

Montreal was paired with Quebec City. Montreal was thought to be representative of the largest population base in Quebec, and contains some unique types of older houses and chimneys. Quebec is a smaller centre than Montreal. It has more diversity of housing types and is the major centre in French speaking Canada.

Halifax was paired with Fredericton. Fredericton is the next largest community in Atlantic Canada. It is an interior community, away from the ocean, and experiences significantly different climatic conditions than Halifax. Also, Fredericton has been on the natural gas line for some years, and contains many older, converted heating systems.

Twenty houses were tested in (or around) each of the 10 communities. Details on the regions, communities, and housing stock are presented in Table 2. In addition to these 200 houses, another five houses were selected for testing in Ottawa, Ontario. This allowed for inclusion of housing types more representative of Northeast Ontario, and allowed for involvement of staff in CMHC's national office in some of the testing.

Table 1: REGIONS, COMMUNITIES, AND HOUSING STOCK

Region	# of Test Houses	% Canadian Houses in this Region*	Local Community (# of House holds)	Remote Community and Size (# of House holds)
B.C.	40	12	Vancouver (477,000)	Kelowna (24,000)
Prairies	40	18	Winnipeg (217,000)	Calgary (211,000)
Ontario	45	35	Toronto (1,190,000)	London (106,000)
Quebec	40	26	Ottawa/ Hull (256,000)	Quebec City (195,000)
Atlantic Canada	40	8	Halifax (94,000)	Fredericton (17,000)

*Census of Canada, 1981

To find houses for inclusion in the study, a number of methods were used, including:

* placing advertisements in community newspapers or, where no community newspaper existed, placing advertisements in the classified section of major newspapers;
* sending press releases to community newspapers, major newspapers and real estate weeklies for editorial coverage; and
* contacting CMHC regional offices to solicit houses of staff interested in participating in the project.

CMHC offices were only contacted in locations where sufficient number of houses could not be found through our initial advertising (Calgary, London, Toronto, Montreal, Quebec City, Halifax).

Advertisements and press releases were written in both French and English, and generally produced an excellent response. Press releases to community papers were particularily effective, often receiving front page coverage.

A toll free phone line was installed in Sheltair's Vancouver office, and was staffed full-time for a period of five weeks by a bilingual receptionist. As each homeowner called to register his or her house, they were asked a number of questions regarding heating and ventilation equipment, and whether other data pertinent to house selection. Homeowners were also queried about their availability at different times during the week. (See Appendix 1 for a sample questionnaire.)

Completed questionnaires were entered into a customized data base program for registered houses. A program was also prepared to print out individual house descriptions based on the dBase records. (Appendix 1 also contains a sample House Description Form). These single page printouts were sent to the regions for screening prior to final house selection.

The Table below lists the number of registered houses from which test houses were selected for the study in each location. Because only five houses were needed for testing in Ottawa, that city was not included in the advertising campaign. The total registered houses in each community was restricted to approximately 50, although in three communities many more people responded to the advertising campaign.

TABLE 2 NO. OF HOUSES REGISTERED

Total # of Registered	
Location	Houses
Vancouver	54
Kelowna	36
Calgary	37
Winnipeg	54
Toronto	39
London	16
Montreal	33
Quebec City	22
Halifax	18
Fredericton	50
TOTAL	**359**

In 6 out of 10 cities included in our survey, we were unable to register enough houses to ensure a representative sample.

In these cities, we contacted a CMHC representative and asked that he or she assist us in soliciting volunteer CMHC staff so that we could include their houses in our registered data base.

All of the data collected on each of the registered houses was entered into a survey data base that was provided to each of the field crews on a lap-top computer. Prior to entering any of the test data for a particular house, the housing sample data base was accessed by the computer and the user was able to review all details collected during the phone interview. This data base of registered houses became a foundation from which all the subsequent data bases on different devices were built.

For each region, a statistical profile of housing types was completed that described housing by year of construction, number of stories, fuel type, and so on. Statistics were collected from Regional project managers, from Statistics Canada and from existing data bases. In most cases an effort was also made to obtain "best guess" estimates from regional CMHC staff.

Statistical profiles of typical house characteristics are included in Appendix 1. In part, the statistics were used to assist in the house selection procedure. Each regional supervisor was provided with these summaries, along with other information necessary for selecting representative houses. This was used only to establish priorities amongst registered houses in each community. A separate procedure was developed for determining what devices should be tested in each house, and what type of test to use on each device.

Through discussions with CMHC staff, a "quota system" was developed for guiding field crews in the selection of devices. This quota system and the device selection procedure, were described in the Field Manual used by the test crews. The Quota Tables are presented in Appendix 2 of this report, including quotas for chimneys, heating systems, passive ducts, and exhaust fans, summarized for the entire housing sample, and for each community in the sample.

In general, the selection of houses made available for testing in this project was extremely diverse, and permitted the data base to be representative of houses in communities across Canada. For several communities, in fact, the age and style communities across Canada. For several communities, in fact, the age and style of houses, and types of heating systems, for the housing in the sample, closely mirrored the statistical profile.

In only two communities was the response to the advertising campaign so weak as to create problems with providing a representative selection of houses. These communities were Quebec City, and London. In Quebec City, the poor response was difficult to explain and was compounded by an unusually high number of electrically-heated houses in the sample, plus a very scattered distribution throughout the city. In both communities, part of the problem was the absence of any small community papers in which to place advertisements. Despite large and expensive display ads on repeated occasions in the major dailies, it seemed impossible to overcome natural suspicion when advertising in a mass-circulation medium. In retrospect, the use of radio ads or leaflets may have been warranted in those communities where smaller weekly papers were absent.

2.2 Organization of the Research Team

In order to accomplish an intensive survey of devices, in a large number of houses over a single heating season, it was necessary to establish a team of building scientists, engineers, and experienced technologists, located in regions across the country.

The survey work could then be conducted by field crews working out of five regional offices. Each region had a consulting firm with local offices and support personnel, and with a senior consultant designated to manage field testing and respond to unforeseen problems.

The consulting firm used an experienced technologist to conduct tests on 20 houses in each of two communities in their region. In each community, a local heating contractor was asked to provide an experienced (provincially certified) heating tradesperson to assist the technologist for a two week period. The tradesperson provided trade skills, tools, a truck and ladder, muscle, knowledge of local geography, and experience with local appliances.

An outline of the regions where survey work was conducted, the regional firms, project managers and the designated building technologists is presented below:

TABLE 3 REGIONAL BREAKDOWN OF CONSULTANTS AND COMMUNITIES

Region	Consulting Firm	Manager	Technolgist
B.C.	Sheltair	S. Moffatt	B. Sikorski
Prairies	Unies	G. Proskiw	M. Gleadhill
Ontario	Scanada (Oakville)	E. Bonnyman	A. Cameron
Quebec	Scanada (Ottawa)	B. Platts	K. Ruest
Maritimes	Pearson	R. Lund	R. Lund

The field crews were trained and supervised by a field research manager: Peter Moffatt, who travelled to at least 8 test houses in each region.

3. DESIGN OF TEST PROTOCOL

The design of a field test protocol occupied several weeks of testing, and involved data collection on five pilot test houses in Vancouver. The object of this design stage was to produce a procedure that allowed 2 persons to test most devices in a house in a period of approximately 2.5 hours.

For each ventilation device in a house three key questions needed to be addressed:

1. What characteristics of the device should be measured, and in what priority?
2. What is the best method for using the DTR to obtain these measurements?
3. What additional data or information may be required to properly interpret the results of the measurements?

Pilot testing was conducted in the Vancouver area to explore each of these issues and refine a test procedure for each of 10 different ventilation devices.

A complete summary of procedures for the field visits was compiled in a Field Manual. The Field Manual presents the Test Protocol in a step-by-step fashion. A brief outline of the contents of the Field Manual is presented below in Table 4. Because the Manual was used as a complement to on-site training, it is written as a reference manual rather than a beginner's guide. Sections of this Field Manual are included in Appendix 3.

TABLE 4 LIST OF FIELD MANUAL CONTENTS

1. Summary of Procedures for Field Visits

   Step by step description of procedures for field technician and heating tradesman, including a tool checklist

2. List of Registered Houses

   A list of houses that have been registered in each community

3. House Description Addendum

   Additional house information is required on this form.

4. Device Selection Procedure

   An explanation of quotas, and a procedure for determining which device to test and how to test it.

5. List of Photographs

   A form to list photos taken by roll (typically, 1 of the house and 1 of the heating appliance under test)

6. Computer Operation

   How to operate the computer program, & back-up data

7. Hard Copy Instruction and Data Forms for Each Device

   Data input forms and sketches of typical set-ups are provide for each device, by sub-sections:

A Furnace	D Heating System	G Bath Fan	J Vacuum
B Fireplace	E Heating Duct	H Kitchen Fan	
C Wood Stove	F Passive Duct	I Clothes Dryer	

8. Inspection Forms

   Forms to be used on various tests. Included are: chimney and fan checklists; a combustion safety checklist; and a commentary form for unusual situations.

9. Householder Information

   A letter to hand out upon arrival, and a guide to final conversations with the householder.

10. Duct Test Rig Manual

   A thorough manual describing operation and maintenance of the DTR

11. Sample Forms Completed on a Typical House

   A completed sample package of forms on a single house.

A considerable amount of thought and discussion was required to finalize the Test Protocol for testing each device in the house. Much of the conceptual work is too detailed and lengthy to document, although some of the more interesting conclusions are mentioned as part of the test summaries provided below. For an estimate of the time required for a two-man crew to complete each test, refer to the Quota Tables in Appendix 2. For a more detailed and illustrated description of test protocols, refer to the Field Manual (Appendix 3).

3.1 Procedures for Testing Exhaust Fans

Exhaust fans tested in the survey included four basic types: BATH, KITCHEN, CLOTHES DRYER AND VACUUM. Each of these devices required a different approach and warranted a separate data base and data form.

The object in measuring exhaust fans in the field was to provide a clear indication of how performance is influenced by fan age, accumulations of dust, grease, bugs, etc., installation practices, etc. (The fans flows themselves can more easily be determined through lab testing.)

In approximate order of priority, the following characteristics of exhaust fans were tested:

1. Air flows at inlet under standard operating conditions (i.e. zero pressure):

This is a standard test procedure when using the DTR, and involves mating the flow chamber to the exhaust fan inlet (or outlet) and matching the air flows using the DTR's fan in series with the exhaust fan.

In general it was felt preferable to measure air flow at the exhaust outlet as opposed to the inlet, since it is the air flow that leaves the house that impacts most on ventilation rates and house depressurization. However measuring at the exhaust air inlet is most practical for wall and ceiling fans and vacuum cleaners.

A wide range of techniques and attachments were used to connect the DTR to each type of exhaust fan. Measuring the air flows of range hoods required either moving the stove, or using a 90° elbow. Different field crews used different approaches.

Whole house vacuum cleaners were tested only if they truly exhausted air out of the house, as opposed to into a basement. The DTR was typically fitted to the vacuum outlet, and occasionally to the intake hose, using a transition.

2. Air flows at a range of negative pressures:

The ventilation "compliance" of a house is directly related to the flow versus pressure characteristics of exhaust systems. Testing this characteristic with the DTR involved adjusting the fan speed to create a negative pressure in the hood relative to the surrounding room, and recording the reduced flow rate. Typically the flows were recorded for a pressure differential of 5 Pascals, and at 10, 15, and 20, as long as the fan continued to exhaust air.

3. Air flow at varying amounts of positive pressure:

The exhaust systems may function as exfiltration routes and have impact on energy efficiency, ventilation rates, icing problems, etc. To test this characteristic, flows were measured at positive pressures in a similar way to negative pressures.

4. Air flow at the exhaust fan outlet under standard operating conditions.

Measuring at the exhaust air outlet is more practical for clothes dryers, and sometimes also for range hoods. Because of the cold weather testing, clothes dryers outlets were measured more often from inside the house than outside, using a surrogate outlet hood on the disconnected hose.

Air flow measured at the inlet of an exhaust fan will seldom match air flow at the outlet. The differences are due to leakage from the pressurized duct system. Ideally, the flow was to be measured at both the inlet and outlet, since this provides an accurate and interesting measurement of the air leakage through the duct system. Unfortunately this was rarely possible.

To assist in the interpretation of data, additional information on exhaust fans was collected, including:

- -system configuration (inlet type, outlet type, locations);
- -manufacturer and model of fan; and
- -duct sizing, length, and type.

The inspection forms are also included in the Field Manual.

3.2 Procedures for Testing Furnace and Wood Stove Chimneys

Chimneys included site-built masonry units, prefabricated B-vents, and insulated metal chimneys. Masonry chimneys were further categorized as metal lined, tile lined and no liner. An effort was also made to differentiate between standard metal insulated chimneys and high temperature varieties, although this sometimes proved difficult in the field.

In preparation for chimney testing, the appliance was disconnected from the vent. The DTR was then connected to the vent in place of the appliance, using a transition hood, with reducers of varying sizes to match the diameter of the vent.

Openings in the flue for a shared appliance were temporarily blocked for these tests, so as to gain a better measurement of basic chimney performance. The impact of the shared vent was felt to be amenable to computer modelling, and leaving it open would only complicate the field test results, obscuring the impact of restrictions or leaks in the vertical chimney, and adding an unknown quantity of additional heat.

If a barometric damper was present, it was held shut (with tape) but not sealed, so as to simulate low draft operating conditions.

Information collected on the chimneys included a visual inspection for safety problems or code violations, and a complete dimensioning of the system using forms and terminology originally developed for the FLUESIM computer model (Ref.5). These forms are included in the Field Manual (Appendix 3).

3.2.1 Flow vs. pressure tests on chimneys

This test was designed to measure the restriction (or free area) of the venting system, including both the vent connector and the vertical chimney. By adjusting the speed of the DTR fan, the flows through the chimney system were recorded for the conditions at the time of the test, and for positive hood pressures of 10, 20, 30, 40 and 50 Pascals. The actual flows were then used to calculate the "free area" of the vent. This free area was compared against the total physical area of the vent opening, and a percentage reduction in area (due to chimney restrictions) was calculated. If reductions were greater than 50%, the field crew was asked to investigate and explain the nature of the restriction. Sometimes the calculated free area of the vent would actually exceed the physical area, due to smooth surfaces and numerous air leaks in the vent.

The "free area" of a chimney was calculated as follows:

Flow (L/s) @ 10 Pascals * 4 = Free Area (cm^2)

This equation is a rule of thumb that is roughly equivalent to the CGSB Standard 149.10 M86 for calculating ELA values.

Draft Correction

Initially some difficulties were encountered with measuring flow vs. pressure in chimneys, because the DTR hood pressure was referenced to the furnace room. This produced flow exponents that were far too low, and produced poor correlations. It was later recognized that a correction was necessary to account for the stack pressure (or chimney draft). A regression analysis was done on the flows recorded at the 5 pressures. A variable for draft was introduced to explain why the slope of the regression fit did not equal the expected 0.5 exponent value for a sharp edged orifice. By assuming a square root relationship and inserting the draft variable into the flow equation as an initial hood pressure, the data base was recalculated (this will be covered in more detail in a later section). The results were much improved. As we would expect, the flow up the chimney, caused by the calculated draft, often matched the flows that were later measured in the chimney, before heat was added during the characteristic length test. This confirmed the accuracy of the approach.

Winds also complicated this test. It was necessary to obtain wind speeds for each of these tests, by reviewing Environment Canada meteorological summaries for test days in each community. Wind speeds at chimney height in a residential subdivision are usually less than what is recorded at airport stations. Wind fluctuations were obvious to field crews during the tests. The crews were been instructed to take readings only when values were at their lowest point and when they were relatively stable. Crews were also instructed to use the smallest orifice setting possible for tests in windy conditions so that the DTR would restrict flow in the chimney during heavy gusts and thereby smooth out fluctuations.

3.2.2 Thermal characteristics

To measure the thermal characteristics of a chimney, the DTR was fitted with a hood containing a 1 kW duct heater. This hood was placed in-line with the vent. Hood pressures were maintained at zero throughout the test, so that restrictions from the hood did not influence chimney flows. The 1 kW heater was operated for a 5 minute period, while continuously recording flows and temperatures at the vent connection, vent to chimney junction, and chimney exit. Voltage and amperage draw of the DTR fan and heater are used to calculate the heat input. Recording voltage was considered important because of the wide range of voltages discovered in houses which would effect the actual wattage output of an electric resistance heater.

Temperatures at the chimney top are measured using an AD590 IC (integrated circuit) thermometer inside a whisk located approximately 450mm below the chimney cap. The thermometer/whisk assembly was inserted up the chimney using an electricians tape. Both the tape and the thermometer wire were carried on spools. This approach worked very well. Occasionally, offset chimney configurations would make insertion impossible, and the technician would have to climb the roof to place the thermometer.

Initially it was thought preferable to hold air flows constant during the thermal test, but this was found to be impractical due to the rapid flow fluctuations and high capacity of some chimneys. Instead the flow was allowed to increase normally, while maintaining a constant heat input. This also proved easier to interpret, since the five minute mark provides a convenient time period for averaging flows and is about the same length as a furnace cycle.

Initially it was also thought that more heat input than 1 kilowatt may be required for massive masonry flues in order to register significant temperature changes at the chimney top over the brief time period of testing. This was later shown to be incorrect, by means of both FLUESIM modelling and field experience. Even massive chimneys would experience a rise of at least five degrees Celsius. The accurate, fast-response I.C. thermometers were usually capable of tracking flue gas temperatures.

A more serious problem was trying to test masonry chimneys that had recently been operated. The DTR was used to purge the flue for extended periods, to reduce the cooling time. Otherwise, the chimney top temperature would actually drop during the thermal test. A related problem was the heat transfer from adjoining flues in masonry chimneys. For example, an operating furnace could interfere with the fireplace, if flues for both appliances were within the masonry enclosure.

Some difficulty was also encountered with measuring the vent connection temperature due to very poor mixing of heated air exiting from the DTR. Consequently temperature rise in this location became a calculated value, based on furnace room temperature, air flow and heat input. This was found to produce very reliable air temperature predictions and was far more convenient than a traverse of temperature measurements so close to the DTR.

Data collected as part of the thermal test was recorded directly on the data base. It was also used to calculate the "characteristic length" of each chimney. This is a property of a chimney related to its thermal losses at steady-state conditions. The characteristic length is defined mathematically as:

Tc = H / ln [(Te - Tamb) / (Tm - Tamb)]

Where:

Tc = Characteristic length of chimney in meters

H = Chimney height in meters

(includes the run of the flue connector and the vertical chimney)

Te = Air temperature at the exit of the chimney in degrees Celsius

(@ time = 300 seconds)

Tamb = Ambient temperature in degrees Celsius

For outside portion of chimney Tamb = Temperature Outdoors

For inside portion of chimney Tamb = Temperature Indoors

Tm = Mixed air temperature in flue connector after duct heater

Calculated using the following formula

(Heat / Flow * Constant) + Tbsmt

where:

Heat = Induced heat of duct heater in Kilowatts

Flow = Flow in litres per second up the chimney

(@ time = 300 seconds)

Constant = 0.0012

(a conversion factor for determining temperature rise)

Tbsmt = Temperature of air in basement in degrees Celsius

Some of the calculated characteristic length values, especially for flue connectors, are not realistic (ie. negative values). This was because of compounded errors in

Some of the calculated characteristic length values, especially for flue connectors, are not realistic (ie. negative values). This was because of compounded errors in both calculation, and field measurement. Because heat input was a calculated value, slight discrepencies are unavoidable. And accuracy of the chimney base temperature data was limited by use of single spot measurements; - a grid of thermometers would have been preferable since air flows in a chimney at the base are not well mixed. The smaller the drop in temperature between the DTR and the point of measurement, the greater the possibility for error in calculating characteristic lengths.

3.2.3 Leakage of the vent connector

To measure the air flow lost through leakage in the vent connector, the vent connector was disconnected from the vertical chimney and plugged. Air flow was then measured at a hood pressure of 50 Pascals. The higher pressure of 50 Pa was preferable because of the difficulty of accurately measuring very low flows, and because of the potential error due to the unavoidable loss in static pressures (and corresponding flows) at leakage locations further away from the DTR.

3.2.4 Leakage of the vertical chimney

A similar process to leakage measurements in vent connectors was used to measure leakage in a vertical chimney. The chimney top was bagged, while the DTR measured airflow at the base. In some cases this test was deemed impractical due to the hazards of climbing roofs. As well, homeowners were concerned about the potential for broken shingles. Even still, a surprisingly large number of chimneys were tested for leakage.

If a flue connector existed, then leakage was recorded for the total chimney, including the flue connector and vertical chimney. The leakage area of the vertical chimney was calculated by subtracting the flue connector leakage from the total chimney leakage.

Wood stove chimneys were difficult and messy to disconnect. Consequently, leakage was typically measured for the combined vent connector and vertical chimney, rather than testing each part separately.

3.3 Procedures for Testing Fireplaces

Fireplaces chimneys were categorized into three types: factory built metal, masonry unlined, and masonry with tile liner. The test procedure was the same as for furnace and wood stove chimneys, with several exceptions.

Because fireplaces have no vent connector, a large fireplace hood was attached to the DTR and fitted to the masonry surrounding the firebox opening. This approach required use of poly and duct tape and urethane rope to obtain a tight seal. An effort was also made to eliminate, as much as possible, the air leakage within the base of the firebox, including the ash clean out. Despite these efforts, some degree of air leakage inevitably occurred around the hood and through the firebox, and adds a degree of error to fireplace test results.

The use of the fireplace hood prevented the use of a duct heater for the thermal characteristics test and, instead, a 1.5 kW hair blower was used to generate heat at the log grate inside the firebox. This approach worked well and allowed for additional heat input and the higher airflow that was sometimes necessary for large fireplaces. The actual heat input was calculated by measuring the volts and amperage draw of the hair dryer during each test. This heat input was later used to derive the characteristic length of the chimney. The temperature at the throat of the chimney was also measured and either it, or the heat input, can be used in a later analysis of the thermal properties of the chimney.

3.4 Procedures for Testing Heating Systems

Three tests were conducted on forced air heating systems, in addition to separate tests of the heating ducts (described later).

3.4.1 Air flow and temperature at the supply registers

To determine the overall efficiency of the heating supply system, this test required that the field crew carefully measure the total air flow and temperature at every supply register in the house. This was a tedious and complicated test, that was continuously being improved and revised during the survey.

All measurements were taken after at least 5 minutes of furnace operation. Field crews would monitor plenum temperatures and start testing when trunk temperatures stabilized. Hand-held digital thermometers were used to record outlet temperatures. By putting the thermometers in place, in advance, accurate readings could be taken concurrently with the DTR air flow measurements.

Furniture was moved away from the registers to permit installation of the DTR, but otherwise the system was tested "as found". Initially it was thought preferable to test these systems with their registers fully opened, so as to standardize the tests between houses, and avoid occupancy variables. However, in practice it is very difficult to adjust and re-adjust registers in houses, particularly because many registers may be screwed or taped in position, or otherwise stuck as they are.

Other problems with this test procedure included keeping the furnace from shutting off on its high limit, and keeping the house from over-heating during the 30 minutes or more of continuous furnace operation. Windows in the house were opened and continuously adjusted to keep the indoor temperatures within 2 to 3 degrees of the starting temperature. Basement temperatures were sometimes difficult to control, and affected heat transfer from ducts.

3.4.2 Steady-state efficiency

An electronic combustion efficiency meter was used to determine the heat output from the furnace.

3.4.3 Trunk temperatures and return air flows

Air flow through the return air grilles was measured in a similar manner to the supply registers.

An effort was also made to measure temperatures at the furnace and at the end of the trunk, so as to determine the effect of the trunks on the heat flows. This proved difficult however, because the trunks were not often accessible, and because their dimensions changed frequently with distance from the furnace.

3.5 Procedures for Testing Heating Ducts and Passive Fresh Air Ducts

Four tests were conducted on heating ducts and fresh air supply ducts. Only one heating duct was tested in a house, and only if it was convenient to disconnect the duct from its trunk, and attach it to the DTR. Consequently, this was not a frequently-used test.

Because passive fresh air supply ducts were seldom present in the older houses, which comprised a large share of the test houses, these ducts were not frequently tested. Initially it was decided not to include fresh air ducts that are connected to the return air plenum of the furnace, since these are more properly included as part of the return air flows described above. However, in an attempt to achieve quotas on fresh air supply ducts, and to obtain more relevant information for the data base, a number of these "active" fresh air ducts were tested, including tests of air flow when connected to an operational return air system, and tests of air flow and thermal losses when disconnected and operating as passive ducts.

The tests on heating ducts were similar in name and procedure to those described for chimneys, with the exception of the thermal test. Because a constant temperature difference already existed for these ducts as they are operated, there was no need for using a duct heater. Fresh air ducts were tested on the basis of the temperature drop between outdoors and indoors at the time of testing. Heating ducts were tested by measuring temperatures at the take-off from the trunk.

3.6 Test Equipment and Accessories

The DTR comprised the central piece of test equipment for the field survey. Two complete DTRs were fabricated, to expedite testing.

As expected, some refinements and modifications were required to the Duct Test Rig and associated equipment, in order to facilitate the new test procedures. Changes to equipment included:

- marking of the electricians' tape for easy determination of the height;
- development of a spool for wrapping wire from the AD590 thermometer when feeding out and reeling in the electricians' tape;
- purchase of additional AD590's for field replacement, if necessary, and packaging of these in the accessories box;
- purchase of a third carrying case for DTR accessories, due to the large number of specialized hand tools that were needed during test procedures;

- purchase of a lap-top computer and a separate aluminum carrying case for the computer accessories and supplies;
- provision for extra foam for customizing gaskets on site;
- provision of hair blow dryers for supplemental heat when testing large masonry chimneys;
- provision of digital, stand-alone thermometers for inserting in registers to speed up the Heating Systems Test;
- retrofitting the hood for chimney testing to permit measurements of static pressure downstream of the heating element, for improved accuracy;
- recalibration of the DTR to permit testing with the orifice completely closed;
- preparation of minimum and maximum flows for each orifice setting, based on allowable air calculations;
- retrofitting of a supporting strut around the adjustable orifice, to prevent the two portions of the orifice from separating when the DTR is held upside down;
- fabrication of a new, tighter foam gaskets;
- retrofitting of the pressure and temperature probes in the DTR, to permit these probes to be removed from the DTR on site and inserted into other locations, as appropriate;
- fabrication of a specialized probe for inserting in chimneys, to monitor centre-stream temperatures;
- fabrication of a specialized hood adapter, for connecting the DTR to chimneys, in tight locations where insufficient room exists for the use of a duct heater connection;
- re-soldering of the circuit boards for the DTR control unit and an addition of capacitors to the board to provide a more secure fitting and more stable readings; and

- provision of a portable ammeter, to measure current draw by the DTR and its duct heater during the thermal tests (voltage varied from house to house, and wattage had to be calculated for each duct and chimney thermal test).

The DTR flow equations were checked twice during the survey. Minor revisions were made on each occasion. At the beginning of the survey, the DTR was calibrated for very low flow conditions, with all of its orifice closed. At the completion of the survey, the flow calibration was redone, due to some small difficulties achieving good overlapping measurements with different orifice at very low flows. The final flow equations for the DTR equipment, as used in producing the database, are presented in Figure 1.

The two DTR units were named FLO and EDDY and were allocated to the following communities:

FLO	EDDY
Vancouver	Kelowna
Toronto	Calgary
London	Winnipeg
Montreal	Halifax
Quebec City	Fredericton
Ottawa	

FIGURE 1 DUCT TEST RIG RECALIBRATION, JANUARY, 1989

Summary of Corrected DTR Flow Equation Constants and Flow Ranges

A = variable orifice plate removed
B = maximum opening of variable orifice plate (VOP)
C = next largest opening of VOP
D = third largest opening of VOP
E = second smallest opening of VOP
F = smallest opening of VOP
G = VOP closed

DTR	Setting (orifice)	Flow Range (L/sec)	(Pascals)	Equation $Q=C*\Delta P^n$
FLO (#1)	A	165 → 390	20→110	$37,32 * \sqrt{\Delta P}$
	B	100 → 250	30→170	$18.91 * \sqrt{\Delta P}$
	C	40 → 120	25→190	$8.483 * \sqrt{\Delta P}$
	D	20 → 65	25→220	$4.350 * \sqrt{\Delta P}$
	E	12 → 33	35→220	$2.105 * \sqrt{\Delta P}$
	F	6 → 18	35→220	$0.9587 * \Delta P^{.5422}$
	G	1.6 → 8	10→220	$0.5023 * \Delta P^{.5074}$
EDDY (#2)	A	165 → 390	20→110	$36.861 * \sqrt{\Delta P}$
	B	100 → 245	30→170	$18.718 * \sqrt{\Delta P}$
	C	40 → 115	25→190	$8.342 * \sqrt{\Delta P}'$
	D	20 → 63	25→220	$4.2422 * \sqrt{\Delta P}$
	E	13 → 33	35→220	$2.2348 * \sqrt{\Delta P}$
	F	7 → 19	35→220	$1.0837 * \Delta P^{.5259}$
	G	2 → 9	10→210	$0.4897 * \Delta P^{.5480}$

4. COMPUTERIZED DATA COLLECTION PROCEDURES

The project adopted a flexible and innovative approach to field data collection. Field crews had the option of using either paper forms for data collection, or lap-top computers in houses. The use of lap-top computers was preferable for research purposes, because technicians could enter their own data directly, eliminating possible errors, and because the computers can guide the test and ensure a complete data set.

Another important advantage to be obtained from the use of computers, on site, is that error-traps in the program can automatically highlight data inputs which are out of range and need correction. The computer can also immediately calculate the derived values for the systems being tested (eg. Characteristic Length), and thereby alert the technician when investigation is warranted.

A computer program was written to serve the purposes of this project, and two lap-top computers were obtained for the field crews. The computers were high quality, high speed, MS DOS machines with back-lit screens to facilitate use in a wide variety of locations.

The software was written in dBase and relied on a form generating program to load the data entries into the data base. The program was menu-driven, and required the user to select a house from the registered house data base, and then select a device and test. The program contained utilities to assist the field technician in saving and backing up data. The forms generated on the computer screen were almost identical to those that are used in the field manual for paper data collection.

An instruction manual for the field survey software is provided in Appendix 4, along with examples of the user menu and the screen layout. Line listings of the key part of the data collection and processing program are presented in Appendix 5: A USERS GUIDE TO THE DTR BASE.

The program was user-friendly, and reasonably functional in the field. It was used by the field crews about 50% of the time. Some of the field crews did not obtain the necessary training, or did not have the required background to use the lap-top computers properly, and therefore preferred to use the paper forms. Quite often there was inadequate time to use the computer program in the field because of all the extra steps involved in loading and saving data, and reviewing computer calculations.

Under ideal conditions, the field crews would have included a third person whose sole responsibility would have been computer operation, data recording, and data checking. Without this person, a computer is more likely to be used back in the hotel room or office after the day of testing. Even when used at the end of the day, however, the computer serves a useful function in avoiding an excessive paper load, and ensuring a much more complete, and less error prone, data base.

The electronic and paper data received from field crews was entered (or merged) into a massive data base program, on an on-going basis, during the course of the survey. All the data was reviewed and checked for completeness and accuracy. Calculations were improved by adding temperature and density corrections for air flows. The entire data base was then recalculated and reformatted, using the revised flow equations for the DTR.

A few simple statistical summaries were generated from the DTR Base and are presented in the Results section of this paper. Detailed analysis and interpretation and results are expected to occur at the CMHC Research Division, or as part of follow-up projects.

5. RESULTS OF THE FIELD TESTS

5.1 The DTR Base

All the data collected during the survey has been condensed and organized into fifteen dBase files. The largest of these files is titled "Housing.DBF", and contains all of the details on each house collected through the phone interviews, and through the house descriptions and addenda completed on site.

The remaining test data, along with derived values, has been organized by a device, using self-explanatory file names:

Bathroom Fans	Bathroom.DBF
Kitchen Fans	Kitchen.DBF
Dryers	Dryer.DBF
Vacuums	Vacuum.DBF
Furnace Chimneys	Furchim.DBF
Wood Stove Chimneys	Woodstov.DBF
Fireplace Chimneys	Fireplac.DBF
Heating Systems Test 1	Heasys1.DBF
Heating Systems Test 2	Heasys2.DBF
Heating Ducts	Heatduct.DBF
Passive Ducts	Ducts.DBF

Within these database files, the data has been organized into fields, corresponding with the order of data collection described in the test procedures and test data collection forms.

Users Guide to the DTR BASE

The USERS GUIDE TO THE DTR BASE (Appendix 5) includes extensive background information on each of the device databases, including:

1) a data collection form with sequential numbering of every data entry point;
2) a list of field names used by the software; and,
3) line listings for input and calculation programs used during the survey and for programs used to update calculations (after revising data) and for calculating statistics.

The standard format for the Guide is intended to make for convenient reference. Numbers on each of the data collection forms correspond to the numerical ordering in the list of field names. Although the field names are intended to be largely self-explanatory, the numbering key provides a convenient cross reference between entries in the database, and data collected during the test procedure or otherwise recorded on the data collection forms.

Each record in each database contains a house I.D. number. This house I.D. number uniquely identifies each of the 205 test houses. The I.D. number is alphanumeric, and includes an abbreviation to identify the region in which the house is located. For example, BCKEL070 would be house number 70 in Kelowna B.C. These house I.D. numbers can be used to correlate data or records in any of the databases by region, by house, or by specific housing characteristics. More details on the program variables and calculations are presented in the Guide.

5.2 Sample Size and Composition

The data base includes data on a 205 house sample, each of which was tested for a full half-day with a two or three man field crew.

Table 5 presents the sample size of each type of device tested, including subtotals for different types of furnace, wood stove and fireplace chimneys. Table 6 presents the sample size for each test in each device. In addition to this actual sample size, the quotas that were originally targeted for these tests are listed for comparison purposes. With the noticeable exception of heating and fresh air ducts, quotas were exceeded for almost all of the tests. The difficulty in achieving quotas with the ducts relates largely to the problems encountered in finding appropriate ducts to be tested.

TABLE 5 SAMPLE SIZE FOR EACH TYPE OF DEVICE

DEVICE	TYPE/ DESCRIPTION	SAMPLE SIZE SUBTOTAL	TOTAL
BATH	Wall or Ceiling Mounted		107
KITCHEN FAN	Range Hood or Stove Top		62
CLOTHES DRYER	Electric/Gas with 100mm Duct		61
WHOLE-HOUSE VACUUM	Vented to Outdoors		24
CHIMNEY FURNACES	1 Masonry Unlined	10	
	2 Masonry Tile Lined	41	
	3 Masonry Metal Lined	17	
	4 A Vent	2	
	5 B Vent	44	
	6 A Vent with Galvanized Exterior	3	
			117
WOODSTOVES	1 Masonry Unlined	0	
	2 Masonry Tile Lined	13	
	3 Masonry Metal Lined	6	
	4 A Vent	8	
	5 B Vent	1	
			28
FIREPLACES	1 Factory-built Metal	12	
	2 Masonry Unlined	8	
	3 Masonry Tile Lined	17	
			37
HEATING SYSTEM	Forced-air Furnace		43
HEATING DUCT	Uninsulated Duct in Basement		32
PASSIVE DUCT	Fresh Air Duct to House		16

In some cases, quotas were purposely ignored, to allow field crews to conduct more detailed testing on specific systems, to investigate issues identified during discussions between the research team and CMHC project manager. These extra tests provided useful insights into the data analysis and commentaries, but are not directly reflected in data base.

Appendix 6 is a collection of photographs on the housing sample. Photographs for each house has been organized by region, and identified by the house I.D. number. Exterior photographs include portions of the exposed chimneys. Interior photographs provide useful details on the configuration of the heating systems. In many cases additional photographs have been taken to illustrate particular test set-up configurations for the DTR on other ventilation devices.

TABLE 6 SAMPLE SIZE FOR EACH TEST

DEVICE	TEST	ACTUAL SAMPLE SIZE	QUOTAS
BATHROOM FANS	Test 1 Standard Inlet Flow (Zero Pa)	103	110
	Test 2 Negative Pressure of 10 Pa	59	30
	Test 3 Positive Pressure of 10 Pa	63	30
	Test 4 Standard Outlet Flow (Zero Pa)	13	30
KITCHEN FANS	Test 1 Standard Inlet Flow (Zero Pa)	62	53
	Test 2 Negative Pressure of 10 Pa	53	22
	Test 3 Positive Pressure of 10 Pa	52	22
	Test 4 Standard Outlet Flow (Zero Pa)	14	22
DRYER	Test 1 Standard Inlet Flow (Zero Pa)	61	51
	Test 2 Negative Pressure of 10 Pa	29	17
	Test 3 Positive Pressure of 10 Pa	29	17
VACUUM	Test 1 Standard Inlet Flow	24	31
	Test 4 Standard Outlet Flow	14	7
FURNACE CHIMNEY	Test 1 Flow vs. Pressure	117	160
	Test 2 Thermal Characteristics	82	54
	Test 3 Chimney Leakage	66	31
	Test 4 Vertical Chimney Leakage	65	54
WOODSTOVE	Test 1 Flow vs. Pressure	28	28
	Test 2 Thermal Characteristics	16	16
	Test 3 Chimney Leakage	20	18
FIREPLACE	Test 1 Flow vs. Pressure	37	35
	Test 2 Thermal Characteristics	22	22
	Test 3 Chimney Leakage	23	20
HEATING SYSTEM	Test 1 Temperature and Air Flow at Registers	39	49
	Test 3 Trunk Temp. and Return Flows	13	49
	Test 1 Standard Flow	30	49
HEATING DUCT	Test 2 Thermal Characteristics	29	49
	Test 3 Flow vs. Pressure	31	49
	Test 4 Leakage of Duct	29	49
	Test 1 Standard Flow	16	41
PASSIVE DUCT	Test 2 Thermal Characteristics	1	13
	Test 3 Flow vs. Pressure	10	0
	Test 4 Leakage of Duct	4	

5.3 Statistical Summaries and Comments From Field Crews

A statistical summary of the test results on all of the devices is presented below. Also included are comments from the field crews regarding variations made to test procedures, possible sources of errors, recommendations for future testing, and insights or interesting events.

More detailed comments on each house, along with the original data collection forms and house descriptions, have been organized by house and by region and bound together into binders. These binders comprise Appendix 7.

5.3.1 Bathroom fans

A statistical summary of test results on bathroom fans can be found in Table 7, including averages (Avg), standard deviations (SD), minimums (Min) and maximums (Max) for each test. Average air flow under standard conditions is low, at 17.2 L/s. Houses in Montreal appear to have lower flow for bathroom fans. This may be due to the predominantly older housing stock in these communities.

A few 'dead' fans were simply not tested by the technicians, because they were only cavitating (resulting in zero net flow). This could bias the data base, as it implies more flow that occurs on average if the non-functional fans have been included.

Surprisingly, although the industry assumes axial fans are much less powerful, the database shows no significant flow difference between axial and centrifugal fans. When fans are sorted for the number of duct fittings, and spilt into two groups, the less restrictive systems have an average flow of 18.1 L/s, where as the more restrictive air of flow is 13.4 L/s - only a small reduction.

Leakage values for bathroom fans may be positive and negative. Both numbers are valid. The air flow can be lost downstream of the fan, or gained upstream of the fan if there is a length of duct between it and the measuring instrument (in this case the DTR).

The negative and positive pressure tests are difficult to interpret. Some error can be associated with air flow bypassing the bathroom fan unit. In other words, in addition to the flow passing through the DTR and into the fan of duct system, there is additional flow passing through the DTR and around the grill and the duct flange into the cavity surrounding the installed exhaust fan. With positive pressure, the exhaust flow is exaggerated; with negative pressure the exhaust flow is underestimated. On some tests, the field technicians spent extra time taping joints around the bathroom fan to eliminate this "non-exhausted" flow, but this was not usual. This non-exhausted flow may explain why, in some cases, the response of the fan to pressures is identical for both a negative and positive hood pressure. More typically, flows from bathroom fans varied greatly with changes in hood pressures. In house QBMTL319, a false ceiling around the bathroom fan required the technician to thoroughly taped the DTR to the perimeter of the grill. In this case flow differential was quite noticeable at only 10 Pascals, with an increase of 7 L/s under positive hood pressure, and a decrease of 10 L/s with negative hood pressure.

In order to measure leakage through the fan duct system, both tests 1 and 4 (ie. air flow at inlet and at outlet respectively) had to be completed on a single fan. This was only done on 12% of the sample, due to the difficult set-up.

Technicians observed that the foam gasket around the DTR actually breaks down over time and begins to account for a some small amount of the flow through the foam. This is not normally an issue of a bathroom fan, because of the small quantity of flow, and the compression that it occurs when the DTR is jacked up against the ceiling.

The vast majority of bathroom fans were ceiling mounted units, with diameters of 75 to 100 mm. Tremendous variations existed in the duct lengths. Most bathroom fan grilles were described as clean (that is more than 75% open). It was more often the case for outlets to be blocked. Approximately 20% of the bathroom fans were shown to have very dirty blades. It appears homeowners only clean the grilles.

Many fans were in poor condition, and technicians could hear the bearings grinding. In two cases, fans that were non-functional were repaired on the spot, to allow testing for some flow.

In one house, the fan exhaust was accidentally dumping into a basement (Toronto). In an other case, the duct for the bathroom exhaust fan was non-functional because insulation from the attic had the filled the duct. This was solved by turning the DTR to high speed and blowing insulation clear of the duct.

At least one house in Calgary, was observed with serious water stains around each of the bathroom fan inlet grilles. This was possibly due to condensation inside the ducts.

In two cases, bathroom fans exhausting through attics terminated short of the roof, and were generating huge mould patches.

At least two houses were observed with the bathroom fan backdraft-damper installed backwards and therefore blocked.

In one house in Montreal two bathroom fans were ducted through the same duct. If both fans were turned on, only one worked.

Perhaps 5 to 10 percent of newer houses had no exterior outlet for the bathroom exhaust, and instead allowed ducts to terminate behind the perforated soffit. In one case the blow-back had caused icicles to block the grill of the fan; in an other case house painters had painted the outlet damper shut and it had to be pried open prior to testing.

The low flows, poor response to static pressure, high leakage rates and generally poor condition of bathroom fans in the DTR Base suggest that huge numbers of bathroom fans across Canada should be replaced or serviced.

5.3.2 Kitchen fans

A statistical summary of test results for kitchen fans is also presented in Table 7. All air flows are density corrected for STP.

Average airflow under standard conditions was 58.7 L/s. This was reduced to 51.5 L/s with 10 Pa of negative pressure at the hood. A large standard deviation, and the extremes in airflows, emphasize the variety of kitchen fans present in existing houses. Flows are much larger for kitchen fans than bathroom fans, although this is skewed by the down-draft, cook-top kitchen fans which are especially powerful.

Unlike bathroom fans, kitchen fans were sometimes blocked at the inlet by grease from cooking. This was as much as 75% of the free area.

Many kitchen fans have very short duct lengths and are essentially through - the - wall units. Measuring duct leakage was not warranted for such systems.

In a number of cases, springs on backdampers were too strong for the kitchen fans to overcome. This resulted in high back pressure and little or no venting air flow. In two houses, at least, these were removed by the field technicians. Grease also caused dampers to weigh down and stay closed. In general, exhaust flows for kitchen fans are greatly influenced by the condition of the backdraft damper.

Many kitchen fans encountered in this survey were recirculating units, and thus were not described or tested in the DTR Base. At least two units were judged to be partially recirculating, a feature which complicated the test set-up procedure. Some of the recirculating units had never had the knockouts removed from above the fan enclosure, and thus were not even recirculating.

Some of the sheet metal hoods around kitchen fans were quite leaky. These leaks contribute some error to the pressure tests conducted from indoors, since a percentage of the air flow occurs out of the leaky hood instead of the kitchen fan.

TABLE 7: CALCULATED RESULTS FOR EXHAUST FANS

BATHROOM FANS	AVG	SD	(%)	MIN	MAX
Air Flow (L/s) Under Standard Conditions (103 fans)	17.2	13.2	77	1.7	97.6
Air Flow (L/s) with Negative Pressure of 10 Pa (29 fans)	14.4	13.8	76	1.4	85.9
Average Flow Loss Due to Leakage (L/s) (8 fans)	5.78	*	*	*	*
KITCHEN FANS					
Air Flow (L/s) Under Standard Conditions (62 fans)	58.5	34.4	59	3.9	157.1
Air Flow (L/s) with Negative Pressure of 10 Pa (51 Fans)	51.5	36.9	72	5.2	191.0
Average Flow Loss Due to Leakage (L/s) (6 fans)	12.6	*	*	*	*
DRYERS					
Air Flow (L/s) Under Standard Conditions	37.6	13.6	35	9.5	84.1
Air Flow (L/s) with Negative Pressure at 10 Pa (29 fans)	38.3	16.0	41	4.1	83.1
VACUUMS					
Air Flows (L/s) Under Standard Conditions (24 fans)	23.9	7.9	33	9.8	41.0
Percentage Loss Due to Leakage (%)	17.6	*	*	*	*
Percentage Gained Due to Leakage	18.2	*	*	*	*

5.3.3 Dryers

A statistical summary of test results for dryers is presented in Table 7. All air flows are density corrected for STP. Dryer temperature settings were not adjusted before testing. Temperatures were sometimes as high as 72C, although they were more typically in the 50 to 60 C range.

The average air flow for dryers is 37.6 L/sec. Air flow increases only slightly with when assisted by a negative pressure at the dryer outlet as can be seen from the flow vs. pressure results.

Air flows from dryers are more consistent than other types of exhaust devices, but the installed flows are significantly less than the 75 L/s typically specified by manufacturers.

Unlike other exhaust devices, where just 3 or 4 manufacturers predominate, dryers in the DTR Base include a huge variety of makes and models. Many dryers in this sample were extremely old and decrepit, but still seemed to exhaust and perform well. One gas-fired dryer is included in the sample (House ALCAL158); it had hotter than usual flow (70 C) and good flow (43 L/s).

All dryers had outlets of 100 millimetre diameter. Frequently the exhaust ducting was a combination of flexible plastic and sheet metal.

On one occasion, a dryer hose was noticed to have six-90 degree bends. Householders often use 5 metres of flex-duct for a one metre run. This practice helps to explain the low flows. Presumably it also affects dryer efficiency.

The snow load around houses in winter made testing flows through dryers difficult. In the coldest weather, field test crews had no choice but to disconnect the dryer from the wall and feed flow from the duct directly to the DTR. This approach may exaggerate actual flows through dryers.

Dryers were tested at "as found", without any attempt to clean filters. In this way, the DTR Base statistically reflects the average condition - a partially plugged filter. In one case, the technician noted the filter was overdue for cleaning and decided to remove the lint from the filter and repeat the test. Flow was increased by 15%. No check has been done to see the impact of filling a clothes dryer with clothes on the amount of exhaust flow.

5.3.4 Central Vacuum Systems

A statistical summary of test results for vacuum systems is presented in Table 7. All air flows are density corrected for STP. Temperatures at the outlet of vacuums could rise as high as 60C, and thus needed to be density corrected when the data base was recalculated. An average temperature difference of 50C was used for this purpose.

Air flows for vacuums averaged 23.9 L/s. Flows for vacuums are very consistent.

Most vacuums were tested without a hose attached, and with the DTR connected to the outlet. In at least two cases, technicians recorded the results of testing the same system with and without hoses (BCKEL052, BCVAN088). Attaching a hose had a significant impact, decreasing flows by 25 to 40% respectively.

Vacuum dust collection drums were often full (or at least half full) during tests but no testing was done to determine the impact of a full drum, on system flow. Vacuums were tested only if they exhausted to the outdoors. Most whole-house vacuums (approximately 75%) vent directly to the outdoors , and another 5 to 10 percent vent to the garage. Most (but not all) of the field crews considered a garage to be outdoors.

Air is shown to be lost or gained depending where the leaks occur in the ducting, or at the vacuum unit. Of the systems tested this averaged about 18% both lost and gained. All vacuums were fitted with 50 mm diameter plastic ducting, which is normally considered to be tighter than the sheet metal used for heating ducts. The high pressures in these systems contribute to leakage at the joins. One vacuum was noticed to have such high pressures that the hose regularly was blowing off at the elbow during the testing.

Typically air flows were less at the inlet than at the outlet although, in some cases, this reversed, since leakage losses could occur on both sides of the blower.

Technicians reported that neighbours often complain about the noise of the vacuum, because of the high velocities. Installers might consider using a larger duct for exhausting vacuum cleaners, to cut down on these velocity noises.

5.3.5 Furnace chimneys

A statistical summary of test results for furnace chimneys is presented in Table 8. More time was spent testing furnace chimneys than any other device, and a wealth of raw data can be found in the DTR Base. More in depth analysis is required before drawing many conclusions.

The characteristic length for tile lined, masonry furnace chimneys averaged 7.8m, including the vent connector. This was calculated using the total heat output of the DTR, 1 kW, heater.

On average, the impact of vent and flue restrictions was to reduce the "free area" of the system by only 10.3%. In some cases the restrictions in the system are compensated by leakage areas, particularly in the vent connector.

On average, the vertical portions of the chimneys lost 4.7 L/s at 50 Pa (with the chimney top plugged).

Flows through chimneys varied depending on the type and area of the flue, and the presence of a cap. More detailed statistics are required to expose the impact of these variables. Occasionally, very long vent connectors were observed to restrict flow (eg. Houses BCKEL074, QBMTL383, QBMTL222).

The photo collection in Appendix 6 provides an excellent reference for chimney types. The DTR Base includes a wide variety of furnaces, with many newer furnaces in Calgary, very old ones in Montreal, etc. Surprisingly, no mid-efficiency or high-efficiency furnaces were encountered.

TABLE 8 CALCULATED RESULTS FOR CHIMNEYS

FURNACES	Avg	SD	Min	Max
Reduction in Free Area of Vent(%) (all types)	10.25	*	-157.2	60.6
Characteristic Length (metres) of Tile-lined Masonry (including Vent Connector)	7.8	2.5	5.0	15.2
Air Flow (L/s) lost through Leakage in Vertical Tile-lined Masonry Chimney at 50 Pa	7.3	4.4	1.3	17.4
WOOD STOVES				
Characteristic length (m) of A Vent	25.0	22.2	3.5	53.2
Air Flow (L/s) lost through Leakage in A-Vents at 50 Pa	6.5	4.6	3.0	15.3
FIREPLACES				
Reduction in Free Area of Chimney (%) (all types)	22.6	*	*	*
Characteristic Length (m) using calculated heat input	14.48	28.2	2.54	133.85

5.3.6 Wood stoves

A statistical summary of test results for wood stoves is also presented in Table 8. The average characteristic length was 25 metres, very high relative to the furnace chimneys.

Air flow lost through leakage averaged 6.5 L/s at 50 Pa, similar to other types of chimneys. It was difficult to plug chimneys on woodstoves for a leakage test because many homeowners were concerned about broken shingles caused by persons walking on the roof.

Woodstove chimneys were noticed to be much more restricted by creosote than fireplace or furnace chimneys. Some very long flue connectors were noticed on wood stoves. House QBMTL210 had a 7 m flue connector, which included a heat-saver on the flue. The restriction from heat exchange pipes on the heat-saver reduced the "free area" of the vent by in excess of 70%.

Well-used chimneys on woodstoves typically had caps with evidence of corrosion..

Confusion existed in properly describing chimney types, with particular problems arising from differentiating a standard A vent from a 650C (high temperature) chimney. Even regulatory groups are confused by these terms. In some provinces, high temperature chimneys are referred to as 2000 degree chimneys. During the survey it became necessary to describe a "high temperature" chimney as any chimney with 50 mm or more of insulation.

Field crews usually connected the DTR to the flue connector of a wood stove, and, on occasion directly to the chimney. In a couple of cases, the DTR was hooked up to the woodstove itself for convenience (see Appendix 6).

5.3.7 Fireplaces

A statistical summary of test results for fireplaces is presented in Table 8. Fireplace chimneys displayed a very high characteristic length of 20.16 m. The average reduction in the "free area" of fireplace chimneys was 22.6%.

Flow measurement problems were experienced in at least two large masonry chimneys, where flow-versus-pressure tests could not be done, due to large and inexplicable changes in the DTR hood pressure. For example, in house QBMTL222, the DTR fan speed was increased to pressurize the chimney and hood pressures rose slowly from 0 to 5 pascals. At this point, flow pressures reversed and, despite increases in DTR speed, dropped below zero to -30 pascals. Windy conditions at the time of test may also have contributed to the fluctuation. Nevertheless, field technician were at a loss to explain repeated failures when trying to test this and one other chimney.

When inspecting fireplaces prior to testing, field crews almost always discovered fireplace dampers left open. Tile liners inside masonry chimneys were observed to be installed in a haphazard fashion, with many gaps which weaken the structure and collect creosote. Because the tile lining did not always continue through the entire chimney structure, it was sometimes impossible to determine if tile existed at all. The sample includes many varieties of fireplace chimneys, including one air-cooled, triple walled chimney (BCKEL031).

5.3.8 Heating systems

Simple statistical summaries of test results for heating systems are presented in Table 9. All air flows are density corrected for STP.

The average total air flow to supply registers in a house was 258.4 L/s. The total air flow at the inlet to the supply fan was not measured. This was not included as part of our testing procedures for two reasons; it is usually very difficult to access the plenum and disconnect it, and the air flows rates are above the DTR's measurement range. Most standard furnace "blowers" range from 400 to 500 L/s

On average, only 39.2% of the heat delivered to the forced-air system was reaching the registers.

The low duct efficiency is attributable to restrictive ducts and registers, duct leakage, and radiation losses. No single problem predominated. Homeowners frequently complained about rooms being insufficiently heated, particularly those rooms at the end of long duct runs. Not surprisingly, the longer the run, the greater the losses in air flow and heat. To some degree, the heat losses are overestimated, because a significant portion of the radiation is emitted from the boot and grille into the room, where it effectively contributes to room heating.

A number of houses were tested that had two or more furnace systems, which permitted more centralized duct layouts. These houses showed very good duct efficiency.

Register grilles were typically found to be very restrictive, reducing the boot area by 50-65%. Adjustable dampers on registers were often closed 50-75%.

TABLE 9 CALCULATED RESULTS FOR HEATING SYSTEMS AND DUCTS

HEATING SYSTEMS	Avg	SD	Min	Max
Total Air Flow (L/s) delivered to Registers	258.4	79.0	94.5	440.6
Total Heat Delivered to Registers (kW)	10.9	3.9	2.0	18.6
Firing Rates of Furnaces (kW)	27.8	6.6	13.2	44.1
Percentage Heat Delivered to Registers (%)	39.2	*	*	*
HEATING DUCTS				
Characteristic Length of Duct (m)	22.3	20.1	2.98	115.5
PASSIVE DUCTS				
Air Flow (L/s) at 50 Pa	12.9	8.9	1.6	29.2

5.3.9 Heating ducts

A statistical summary of test results for heating ducts is presented in Table 9.

Most of the heating ducts had 125 mm diameter ducts, although a few had diameters of 75 and 100 mm.

The boots of heating ducts appear to account for the majority of leakage, since they are not taped at the joins. Boots are roughly installed, forced into position and bent. Many boots were cut too close to the wall, and blocked by the register, especially in older houses (eg. see photos for House QBMTL315).

Blocking grilles for the leakage test sometimes caused air to leak out under the carpet or through wall junctions.

In some cases a single house would have more than 10 different varieties of boots and registers. Some of the boots were of unusual construction (eg BCKEL033 with a 125 mm duct connected to a 250 mm boot). One heating duct was found detached at its boot and was repaired.

Most of the heating ducts tested were fully exposed to the basement. However, a few were only half exposed and were thus less likely to lose air and heat. Unfortunately the data sheets were not designed to record this situation.

Some heating ducts had a transition to 3.5 inch by 10 inch and then back to a circular duct to allow a rise to the second floor of the house. Some heating ducts were noticed to be tied directly into the main vertical plenum of the furnace, as opposed to trunk takeoffs.

Very few feeder ducts were taped at joints. Most ducts were thought to be quite clean with no large dirt deposits. Inspections were not always made of duct cleanliness, but it became self-evident, in retrospect, to the technician after the depressurization tests, since no lint or dirt deposits were ever found at the grill or on the floor in its vicinity.

Excessive bends and long duct lengths were common (BCKEL048, ALCAL262), often as a result of trying to avoid framing in exposed basements, or as a result of thoughtless installation.

5.3.10 Passive ducts

A statistical summary of passive duct performance is also presented in Table 9. Air flow at 10 Pascals averaged 13.9 L/s. This is just slightly less than the average air flow from a single bath fan operating against an identical 10 Pascals of pressure.

Only 5% of the housing stock appear to have passive fresh air ducts; an average of one per community for this survey. Because these scarce passive ducts were rarely encountered during the training period, field crews were not properly equipped to include them in their tests.

Far more frequently, fresh air ducts are connected to return air plenums, and operate as an "active" air supply system whenever the furnace blower operates. In Calgary, where this is a very common practice, these ducts were termed "passive" and included in this passive duct sample. In such cases, the ducts were tested with the furnace blower operating, and again with the blower not operating. The test configuration is described in the comments section of the data forms (Appendix 7).

Most flows through the ducts were low, in the 15-25 L/s range, even with the furnace running. House ALCAL122 had a 200 millimetre diameter duct which explains the high flow of 22 L/s under standard conditions.

Many houses in Calgary had both active and passive ducts, but the homeowners had blocked off the passive duct. Field technicians suspected that the homeowners would also have blocked off the active duct, had they known what it was.

Grills on passive and active fresh air ducts were noted to be heavily clogged with leaves and dirt that were wind borne to the outlet. They were tested as is.

Much of the thermal characteristic testing of the fresh air ducts was flawed due to warm outdoor temperatures. In other cases, flows through the ducts were high enough to ensure that no significant temperature rise occurred from one end of the duct to the other. In one case, the thermal testing of a passive duct showed a surprising 2 C rise above indoor temperatures at the duct terminations. Since the outdoor air temperature was 2 degrees C, the total increase was 21 C. Evidently low flow through 5 m of duct at the basement ceiling resulted in considerable amounts of heat gain from nearby heating ducts.

6. REFERENCES

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