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TESTING OF HEATING AND VENTILATING EQUIPMENT WITH THE DUCT TEST RIG

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SYNOPSIS

Canadian research into residential ventilation and combustion venting revealed that the installed performance of exhaust equipment, ducting passages, and site-built chimneys was largely unknown. It became necessary to establish actual characteristics in order to be better able to predict the safety and effectiveness of various ventilation measures.

For this reason, Canada Mortgage and Housing Corporation (CMHC), the federal agency responsible for housing policy, had a research device designed and fabricated. The duct test rig (DTR) can be used for taking a wide variety of field measurements. It uses the principal of a zero-pressure difference across the duct opening to negate the effects of the measurement device. There is an internal fan capable of creating flows in a measurable range of 2-390 L/s, and both heat-generating and temperature-sensing attachments to assess duct thermal performance. The fan can be used to generate the pressure-vs-flow characteristics of passive devices, or to aid in fan system flow measurement.

Contractors across Canada used the DTR to test 205 houses in the winter of 1988-1989. Preliminary analysis is available on the installed flows of exhaust equipment. Data analysis is ongoing on the areas such as the following: chimney performance, chimney and duct leakage areas, and the comparison of installed exhaust and intake flows.

1. INTRODUCTION

The flow of air through ducts, fans, and chimneys has always been somewhat mysterious to most householders, and unfortunately also to many of the tradespeople installing or maintaining these systems. Canada Mortgage and Housing Corporation (CMHC), the federal agency responsible for housing policy, has been investigating both combustion venting and house ventilation issues through the 1980's. The CMHC Research Division looked at the conditions under which chimneys must function, the venting characteristics of the chimney itself, and the interplay between these factors. The field research quickly proved that the designed characteristics of air-moving devices and their actual installed performance were very different.

For example, an early survey of the airtightness of

Canadian houses allowed CMHC to predict the number of dwellings where the backdrafting of furnace chimneys would occur [1]. This could be calculated from the interaction of the envelope leakiness area and the capacity of exhaust devices, a combination that could produce excessive house depressurization. The field-tested incidence of spillage was lower than these predictions. Upon further inspection of test houses, it became apparent that the exhaust flows of fans in the houses were far below the rated values used in the estimations. This was proven again when provincial authorities in British Columbia started to insist upon well-installed exhaust fans. They found that this increased the incidence of combustion spillage in their vicinity [2].

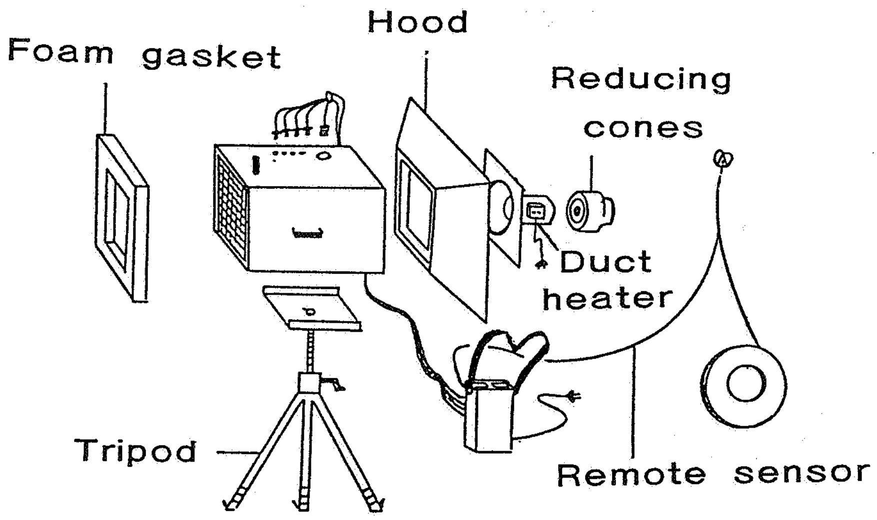
New codes and standards in Canada are specifying levels of house ventilation and limits to house depressurization. In order to justify or design such levels, an accurate means of estimating airflow in houses is required.

CMHC has just completed a two part research project to this end. In the first stage, a consultant designed, constructed, and calibrated a test device. This is called the "duct test rig", and is suitable for testing the flow and thermal characteristics of ducts and chimneys, both active and passive [3]. It was designed to provide the same ease of use and accuracy that blower doors have accomplished in the testing of house airtightness. The second stage involved the use of two duct test rigs to monitor the performance of ducts and chimneys in a wide sample of Canadian houses [4].

2. PROCEDURE

The duct test rig (DTR) uses the pressure drop across calibrated orifices to calculate airflows. The flow range that can be measured is 2-390 L/s. The DTR has a built-in axial fan which can be used to create pressures and flows in passive devices, such as chimneys and air intake ducts. Comparing the flow response to the imposed pressures across a system allows the calculation of its aerodynamic characteristics. The controllable fan also permits the DTR operator to adjust the pressure across the inlet of an active device being measured (eg. a kitchen exhaust fan). By setting this pressure to zero, the DTR operator ensures that the measurement device does not significantly change the normal flow of the fan by increasing the flow resistance at the fan face. The Dutch Flow Finder uses much the same principal [5]. A diagram of the DTR construction is shown in Figure 1; a photo of the DTR in field use is shown in Figure 2.

Figure 1: Duct Test Rig Components

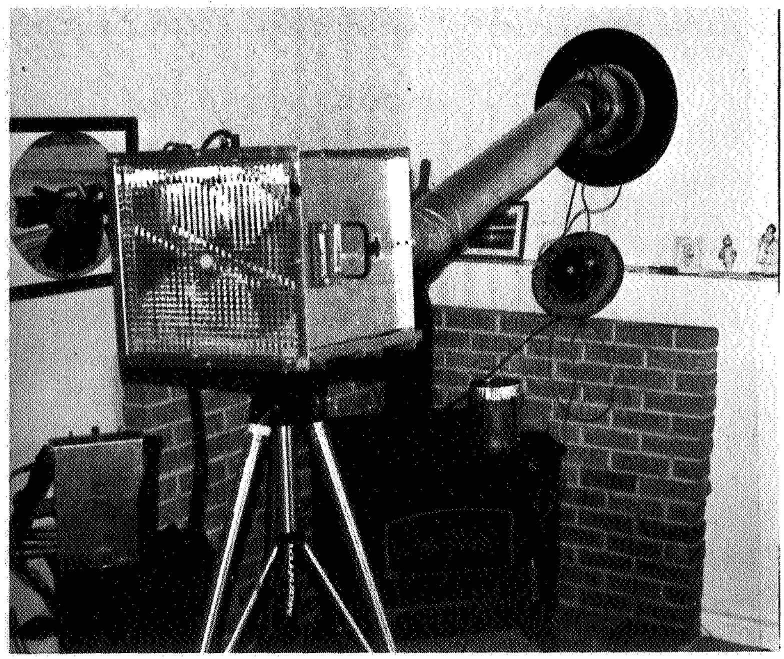


The DTR comes with a number of attachments and accessories. There is a fabric hood to facilitate attachment to open fireplaces as well as spun aluminum cones to reduce the opening size to various duct diameters. For thermal testing, a duct heater can be mounted directly on the DTR to produce a measured heat input to a duct or chimney. A remote sensor is used to measure the temperature at a distance from the DTR. Airflows can be calculated on-site using a programmed calculator mounted on a control module. A photographic tripod permits the operator to elevate the DTR and operate it without having to support the weight. The control module contains fan speed controls, pressure transducers, and a temperature readout.

There is a wide range of tests that can be undertaken using the DTR. In a typical house in the Duct and Chimney Survey, the technician would measure the free flow of all exhaust devices, such as bathroom and kitchen exhaust fans, clothes dryers, and central vacuum systems vented to the outside. Frequently the DTR was also used to establish the ability of the fan to vent when aided or impaired by various levels of pressure across the fan. For instance, is the fan flow severely degraded by a house depressuization of 10 Pa? By blocking the fan outlet at the outside wall, the leakage area of the ducting system could also be measured.

Technicians employed the DTR to measure chimney characteristics as well, including pressure-vs-flow, leakage area, and the thermal characteristics of the chimneys. Passive inlets could be measured in the same way. When a house was equipped with a forced air heating

Figure 2: Testing with DTR



system, technicians measured the total flows from the supply air registers, and compared the results to the estimated furnace output, to determine the effectiveness of the distribution system.

The above is a list of the potential test array. In the Duct and Chimney Survey project, it was not possible to perform all tests in all houses due to limitations of time and money. A full spectrum of tests would also endanger the generally cooperative attitude of the people who had volunteered their houses for testing, as a well-equipped house might take days to test thoroughly. Due to these restraints, only a selection of the possible tests was performed in any given house.

Contractors eventually inspected 20 houses in each of 10 cities, and 5 houses in an eleventh, for a total of 205 dwellings. Each city sample was designed to be representative of the existing stock in terms of house size, design, age, appliance usage, etc. While there is little statistical basis to the house selection, the results of the survey should be typical of the housing stock in and around the cities sampled. A rough quota system was used to ensure a minimum sampling of all desired air-moving devices.

In each region, the main survey contractor trained the local contractor and his aid, a mechanical contractor,on the usage of the DTR and the testing protocol, during the first 6 houses of their 20 house sample. A normal site visit would start with a homeowner interview and building inspection. The DTR would generally be assembled first on the furnace chimney (if available) to measure the chimney flows and thermal characteristics. The forced air ducting system, if present, would be tested subsequently. Fans, fan ducting, and air intake ducting would be completed before departure. Such testing would typically take three hours, permitting data gathering from two houses daily for each crew of two. The field testing took place from December 1988 through May 1989.

3. RESULTS

The DTR generally performed as expected during the Duct and Chimney Survey and there is a wealth of information now available from the study. Some of the results are usable in their present form, while others require extensive data analysis and manipulation.

Table 1 presents a summary of the exhaust flows found in the survey. The flows cited for bathroom and kitchen fans, clothes dryers, and central vacuum systems were all measured at neutral pressure: that is, they reflect the installed flow rates of those devices. As mentioned previously, there are data on the ability of these devices to function under other pressure levels. Figure 3 illustrates the response of two bathroom fans, one relatively unaffected by house pressure and a weak one that stalls at about 5 Pa house depressurization, a level readily achievable in many new Canadian houses.

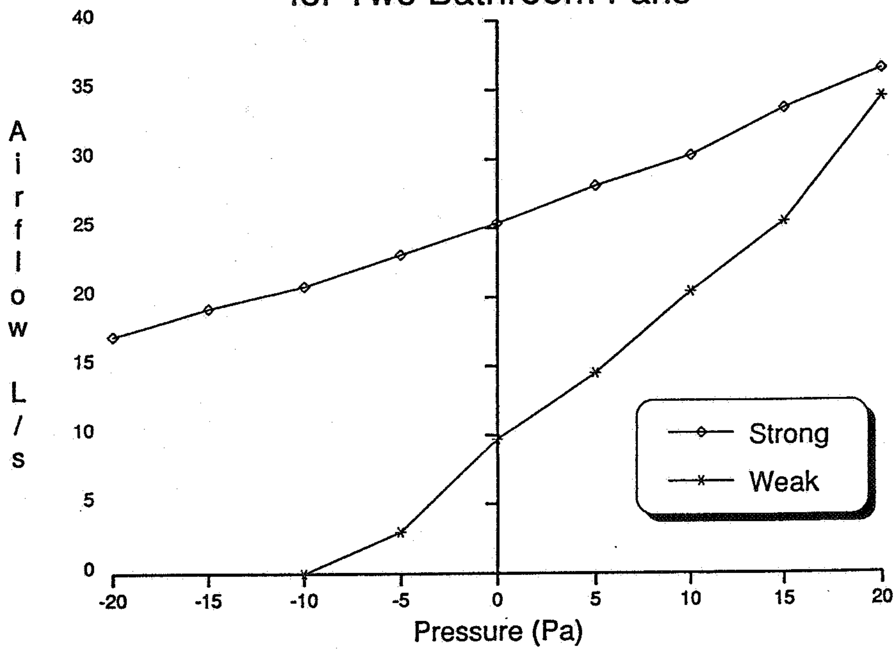
Table 1: Exhaust Flow Results

Device	Number Tested	Mean Flow (L/s)	Range (L/s)
Bathroom Fans	103	17	2 - 98
Kitchen Fans	62	59	3 - 155
Clothes Dryers	61	37	10 - 83
Central Vacuums	24	24	10 - 41
Chimneys at 10 Pa			
- Furnace	120	43	10 - 176
- Fireplace	35	104	23 - 229
- Woodstove	28	50	9 - 160

The data for all devices can be further analyzed in terms of flow vs duct diameter, equivalent duct length, appliance age, make and model, etc. Some of this work has been done, or is in progress. Figure 4 gives a graphical representation of the flows found from clothes dryers, with the data from one manufacturer superimposed on the bar graph.

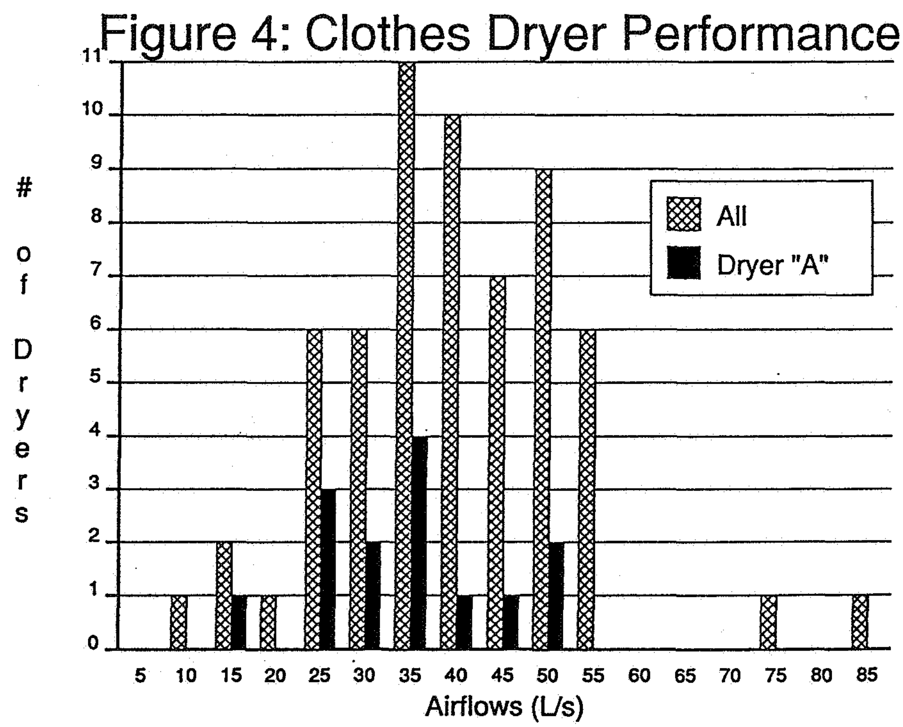
This data can be used by researchers or designers who want to determine the exhaust flow rates from Canadian (or to some extent, North American) houses. For comparison, the flow rates of the intake or make-up air ducts in the survey averaged about 15 L/s at the maximum recommended house depressurization of 5 Pa. These intake flows fall far short of the exhaust flow rates.

Figure 3: Flow vs. Pressure
for Two Bathroom Fans



The chimney exhaust flow rates are somewhat artificial, in that they represent the flow through the chimney measured under a 10 Pa pressurization of the chimney or vent connector base. This has been calculated as roughly equivalent to the flows found due to normal operation of the combustion devices. Since the DTR could not test a chimney with a combustion device in operation, this level of chimney base pressurization has been used as a rough surrogate. In abnormal conditions (eg. very high firing rates, high wind, etc.), these flows will be an underestimate of the true flows but, for most conditions, the listed flows will be reasonable estimates. As with the fan data, the chimney flow rates can be further broken down in terms of chimney size, height, material, etc. from the survey data.

Table 2 shows some results of duct leakage calculations for chimneys and forced air heating ducts. They were tested by pressurizing the chimney or duct with the DTR with the other end blocked. The leakage is quoted in terms of litres per second of flow at 50 Pa of positive pressure, normalized by the internal surface area of the chimney or duct. The leakage measurements were not



performed on every device in the survey.

Observations by the field testers may prove as valuable as the numerical data collected. They suggest that the typical Canadian exhaust fan installations are largely ineffective, but that this ineffectiveness cannot be readily perceived. There are several instances where the proud homeowner waited for test results on their exhaust fan, only to find that it was not creating any flow. Exhaust outlets were plugged or inoperative, ducting was incomplete or too constrained, or the fans had no ability to move air against any depressurization. Forced air ducting systems distributed only a portion of the furnace output through the supply registers, making it difficult to properly adjust or balance the circulation system. In the 205 houses, there were a great number of blatant heating and ventilating deficiencies. For instance, in one house the barometric damper on the oil furnace chimney had been installed backwards and maintained that way for years. This caused the damper

Table 2: Leakage Testing Results

Device	Number Tested	Leakage Area (cm^2 per m^2 of chimney surface)
Furnace Chimneys	62	4.8
Fireplace Chimneys	19	15.4
Heating System Ducts	29	13.3

only to open under pressurization, producing smoke spillage into the house. When the chimney demanded more air, the damper would shut tightly. It is clear that current inspection and maintenance practices often do not catch such dangerous and obvious deficiencies.

4. DISCUSSION

One of the prime purposes of this project was to establish the exhaust flow rates found in Canadian housing, in order to aid in ventilation system design. This has been successfully completed, and the data is now available on such devices as kitchen and bathroom exhaust fans, clothes dryers, central vacuum cleaners, etc. The database is large enough to isolate the effects of duct construction, duct size, fan type, etc. and is available from CMHC for further analysis.

A second project objective was to determine the characteristics of chimneys so that combustion appliance design and modeling could be accomplished with some knowledge of the venting system performance over time. Once again there is a sizeable database which can be manipulated to isolate the effects of chimney size, height, material of construction, etc. At the time of writing this paper, some of this analysis has been done (eg. see Table 2). One question that remains is the true form of the flow-vs-pressure and thermal characteristics.

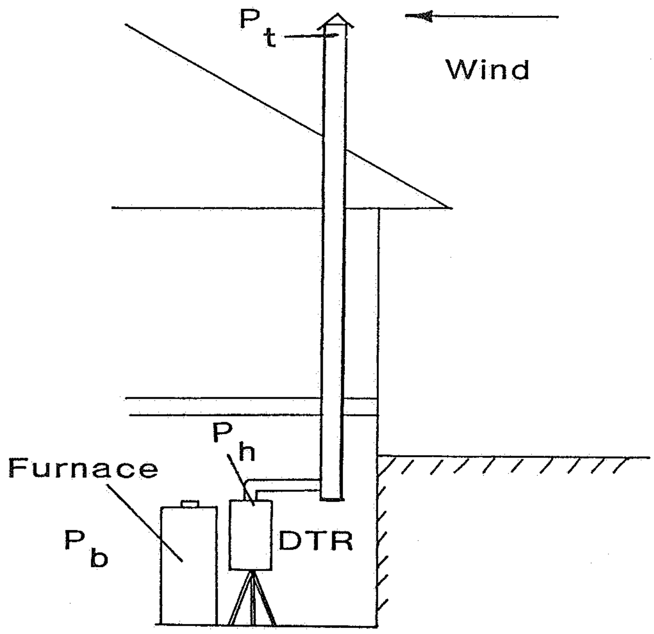
The DTR generated specified pressure differences during the flow vs pressure testing, at 10 Pa intervals. Refer to Figure 5 for an illustration of the test conditions. For instance, at the first interval, the hood pressure (P_h) minus the basement (or appliance room) pressure (P_b) equals 10 Pa. This does not translate to 10 Pa across the chimney, as the basement pressure varies significantly from the chimney top pressure (P_t). To find the actual pressure difference affecting the chimney flow, it would be necessary to relate P_b and P_t, which involves knowing outside weather conditions (wind and temperature) plus the location of the neutral pressure plane of building tested. Some of this can be gathered or assumed from the test data, but all assumptions affect the accuracy of the calculated characteristic.

During parallel testing using the DTR on an Ottawa chimney study [6], the effects of wind and stack effect on the chimney chracteristic measurements became apparent. From previous experience on leakage flows, the researchers expected the flow vs pressure characteristic to assume the form of Q = C*P^n, where:

Q is the flow in L/s,
C is a constant in L/(sPa^n)
P is the pressure difference in Pa, and
n is the non-dimensional exponent.

The exponent value was expected to vary between 1 for laminar flow and 0.5 for fully turbulent flow. The results in the chimney testing showed that the exponent

Figure 5: Chimney Testing



values often ranged between 0.4-0.5, especially when testing bigger chimneys and during windy conditions. Wind and natural draft effects were causing an additional pressure difference across the chimney that was not included in the above calculation. The contractors have suggested two alternatives: accept that the calculated characteristics reflect the actual working conditions of chimneys, or use data available from chimney thermal testing to remove the wind and stack effects. At the time of writing this paper, these calculations have not been completed.

Similarly, the thermal characteristics of chimneys are affected by their time response. Chimneys were heated using 1-2 kW heaters (in addition to the DTR fan heat). The contractor argued from preliminary testing that a chimney-top steady-state temperature was obtained within five minutes, using even such low power inputs during cold weather. (This is not as unlikely as it first appears. This input heat should be compared to the typical heat contained in the flue gases, not to input rating of the appliance.) Although householders were asked to refrain from using the furnace immediately prior to the testing, it is also likely that the relative amount of cooldown time, from the previous furnace firing, will also bias the results. More definitive answers will be known after further analysis.

5. CONCLUSIONS

While much of the analysis of results from the Duct and Chimney Survey remains to be done, there are some preliminary conclusions available.

1) The duct test rig generally performed as designed. It proved to be relatively easy to measure the flows due to active devices and to establish the pressure-vs-flow characteristics for passive ducts. Some additional theoretical work is necessary to translate the data from fan-forced testing of chimneys.

2) An adequate library of installed exhaust flows in Canadian housing now exists for accurate estimation of house ventilation rates or depressurization limits.

3) The performance of the kitchen and bathroom fans, and the make-up air ducts used in Canadian housing, is far below the designed and required flows. In a significant number of cases, they moved almost no air.

4) There are many chimneys in Canada with high air leakage rates that will affect their ability to vent.

6. ACKNOWLEDGMENTS

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