

Residential Combustion Venting Failure - A Systems Approach

Project 3: Task 1

**Refinements to the Chimney Safety Test:
Determining House Depressurization Limits**

RESIDENTIAL COMBUSTION VENTING FAILURE

A SYSTEMS APPROACH

FINAL TECHNICAL REPORT

PROJECT 3: TASK 1

REFINEMENTS TO THE CHIMNEY SAFETY TESTS:

DETERMINING HOUSE DEPRESSURIZATION LIMITS

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The Research Division
Policy Development and Research Sector
Canada Mortgage and Housing Corporation

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STATEMENT OF PART V FUNDS

Canada Mortgage and Housing Corporation, the Federal Governments' housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

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PROJECT 3: TASK1, DETERMINING HOUSE DEPRESSURIZATION LIMITS

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SUMMARY

This brief report describes progress made in refining House Depressurization Limits (HDL) as part of the refinement of chimney safety tests. Work on developing chimney safety tests constituted a sub-project in a larger research effort undertaken by the Scanada-Sheltair Consortium Inc. on behalf of CMHC, titled "Residential Combustion Venting Failure - A Systems Approach."

The House Depressurization Limits are intended to define safe house operating pressures for naturally aspirated combustion appliances. Once nominal limits can be established for different types of appliance chimney systems, chimney safety test procedures can be used to determine whether a particular house is likely to exceed its HDL.

In order to establish HDL's, an attempt was made to determine the minimum driving pressures on the flue gas under worst case weather and operating conditions. The total driving pressure is composed of the wind acting at the chimney top, the net chimney/house buoyancy, and the net furnace buoyancy acting at the base of the vent connector.

Although wind pressures are occasionally zero (a no wind situation), such conditions are extremely rare for Canadian cities, and an argument is made for assuming a minimum driving pressure of 1 Pascal due to wind effects (roughly equivalent to a six kilometer per hour wind).

The buoyancy of the flue and furnace are assumed to be affected by such key variables as balance temperature (i.e. the outdoor operating temperatures), the height of the house, the type of appliance, the location and construction of the flue, the existence of a pilot light, the mass of the appliance, and whether two appliances share the same flue.

The stand-by driving pressures for a typical configuration were modeled with the FLUE SIMULATOR program, and estimated to be approximately 3 Pascals (in addition to the wind effect). This assumes a balance temperature of 10 °C for furnaces, and an appliance recovery pressure of 3 Pascals (ignoring flue buoyancy) for DHW heaters in the summer time. Taller, interior placed chimney are assumed to benefit from an incremental 1 Pascal driving pressure. Appliances with heavy heat exchangers (eg. a boiler or a massive furnace) may also benefit from an additional 1 Pascal due to the extra thermal mass.

A table of HDL's has been prepared which identifies most types of appliances and chimney configurations. The minimum HDL is 4 Pascals, and the maximum is 7 Pascals.

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1.0 INTRODUCTION

This report describes some of the theoretical work undertaken to refine procedures for recognizing combustion venting problems in houses.

In particular, an evaluation has been made of safe house operating pressures for naturally aspirated combustion appliances.

The Maximum Allowable Depressurization (MAD) Limits developed for the Combustion Safety Check have been renamed as part of this on-going refinement to the Safety Checks and other test procedures. The term MAD Limit has been replaced in favour of HOUSE DEPRESSURIZATION LIMIT (HDL), in the interest of clarity and brevity. Sections 2 and 3 of this report describe progress made in refining these House Depressurization Limits.

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2.0 DETERMINING HOUSE DEPRESSURIZATION LIMITS

As has been indicated in previous work by Sheltair and by Scanada, improper venting of combustion gases from an appliance occurs when the house depressurization exceeds the sum of driving pressures on the flue gas at any instant in time. Therefore, the task of determining whether a combustion appliance will be vented properly hinges on whether the sum of driving pressures on the flue gas is greater than attainable house depressurizations overall, or at least a very large portion, of its operating time.

There are thus four central questions which require resolution prior to determination of H.D. Limits:

1. What are the maximum attainable house depressurizations for a given house configuration?
2. What are the typical minimum driving pressures on the flue gas for different types of installations?
3. What is the probability of coincident occurrence of 1 and 2 above; and what is the implied duration?
4. How much coincidence must be expected before an appliance is considered to be improperly vented, and/or unsafe?

The first question is addressed in Parts 2 and 3 of this report, which describes the assessment procedures and the "worst-case" tests that are used to establish the attainable house depressurization for any particular type of dwelling.

The remaining three questions require that assumptions be made about how houses are operating, and about the degree of risk that should be

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considered acceptable. While it is still too early to be definite about the nature of risk, it should be possible to refine and clarify assumptions about the minimum driving pressures, so as to arrive at improved Table of House Depressurization Limits. The new limits can serve as interim guidelines, until such time as improvements are shown to be necessary. The field evaluation of problem house, which will take place as part of this project, and the expected field application of the HDLs by contractors who will be trained in the test procedures, will help to reveal deficiencies in these interim Limits.

DETERMINING MINIMUM DRIVING PRESSURES ON THE FLUE GAS

What are typical driving pressures on the flue gas for different types of installation, over what portions of the operating cycle?

The components that add up to the total driving pressure have been identified as:

- wind acting at the chimney top,
- net chimney/house buoyancy, and
- net furnace buoyancy acting at the base of the vent connector.

Typical orders of magnitude of each of these are presented below.

2.1 Wind Pressures

The wind pressure acting at the chimney top is roughly independent of the buoyancy components (at least it is thought to be) and can be evaluated separately. The following table shows a possible relationship between horizontal wind speed at the top of the chimney and the driving pressure.

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DRIVING PRESSURE FOR VARYING WIND SPEEDS

Assuming a Wind Pressure Coefficient (C_2) of 0.5
and Pressure Equivalent to $C_1/2 \rho V^2$

Wind Speed		Driving Pressure (Pa)
(km/hr)	(m/s)	
0	0	0
5.0	1.4	0.6
6.4	1.8	1.0
10.0	2.8	2.5
15.0	4.2	5.5
20.0	5.6	9.8

Although, this relationship between wind speed and driving pressure has not yet been validated experimentally as part of this project, and will vary from installation to installation, the order of magnitude of the "near zero" quantities are useful to indicate the approximate relationship between wind speeds and driving pressures.

The average wind speed for Canadian cities is approximately 14 km/hr. Over most of Canada wind speeds will exceed 5 to 7 km/hr over 95% of the time. If 95% applicability is acceptable, then a minimum of 1 Pa can be counted on to assist the flue flow, and possibly more in very windy regions. Alternately, if a "worst- case" scenario is to be applied, the no wind condition must be adhered to for a contribution of 0 Pa. Choosing no-wind as the worst case is probably too strict (unless the health hazard from a single spillage event is greater than anticipated).

The no-wind condition occurs only about 3 or 4% of the time. There is likely a negative correlation between no wind and the use of fans and chimneys. Wind speeds are most often negligible during the late night and early morning -- times when exhaust appliances are rarely used, because people are sleeping. The lack of wind also lowers the heating load of the house, resulting in less frequent use of chimneys.

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Table 1
PERCENTAGE FREQUENCY OF CALM WINDS
FOR CANADIAN CITIES

<u>Airport</u>	<u>Percentage of time Winds are Calm*</u>
Ottawa	4.5%
Toronto	5.0%
Winnipeg	2.8%
Vancouver	8.6%**

* Calm refers to wind speeds below the accuracy of the measurement equipment, ususally in the range of 0 to 4 kilometer per hour.

** Calm periods are primarily at night.

2.2 Buoyancy of the Flue and Furnace

Balance Temperatures

Before modeling the net buoyancy of the flue and furnace, an assumption must be made regarding the indoor/outdoor temperatures under worst case conditions. Normally the "free" heat supplied to a house by internal and solar gains, will permit the outdoor temperature to drop to 5, 10, or 15 C before furnace operation becomes a regular occurrence. The balance temperature for any particular house will vary with the quantity of fire heat, and the UA value for the building.

Since it is difficult to adapt the HDLs to account for variations in the balance temperature, a single balance temperature may need to be chosen for all houses in any particular region. Home heating fuel suppliers are well informed about balance temperatures and should be polled to establish the statistical probability of furnace operation at given outdoor temperatures for houses in each climatic case.

In the meantime a general assumption has been made that furnace operation

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is unlikely at outdoor temperatures of 10 C, if indoor temperatures are 20 C, (i.e. at a difference of 10 C or less).

Typical Pressure Parameters for Flues and Furnaces

Figure 1 shows two full cycles of furnace operation over one hour to illustrate typical orders of magnitude of driving pressure parameters for regular operation and backdrafting situations.

Characteristics of the Example:

- Two Storey house, ELA = 0.076 m²
- Naturally Aspirating Gas Furnace
- B-Vent, Interior Placement
- Outside Temperature = 10°C (as a regional average)
- Inside Temperature = 20°C
- Furnace turned on at t = 0
- Furnace turned on at t = 8 minutes
- Furnace turned on again at t = 40 minutes
- Furnace turned off again at t = 48 minutes
- Exhausts fans off at t = 0
- 150 litre exhaust fan on at t = 38 minutes and left on.

The furnace develops its buoyancy very quickly after start up, although the amount is not large - about 4 Pa.

The flue takes longer to reach its maximum, in fact longer than the 8 minutes of furnace run time in the example. Nevertheless over 20 Pa is developed in a few minutes. This would be less in a poorly designed flue. (The degradation in flue performance due to lack of insulation,

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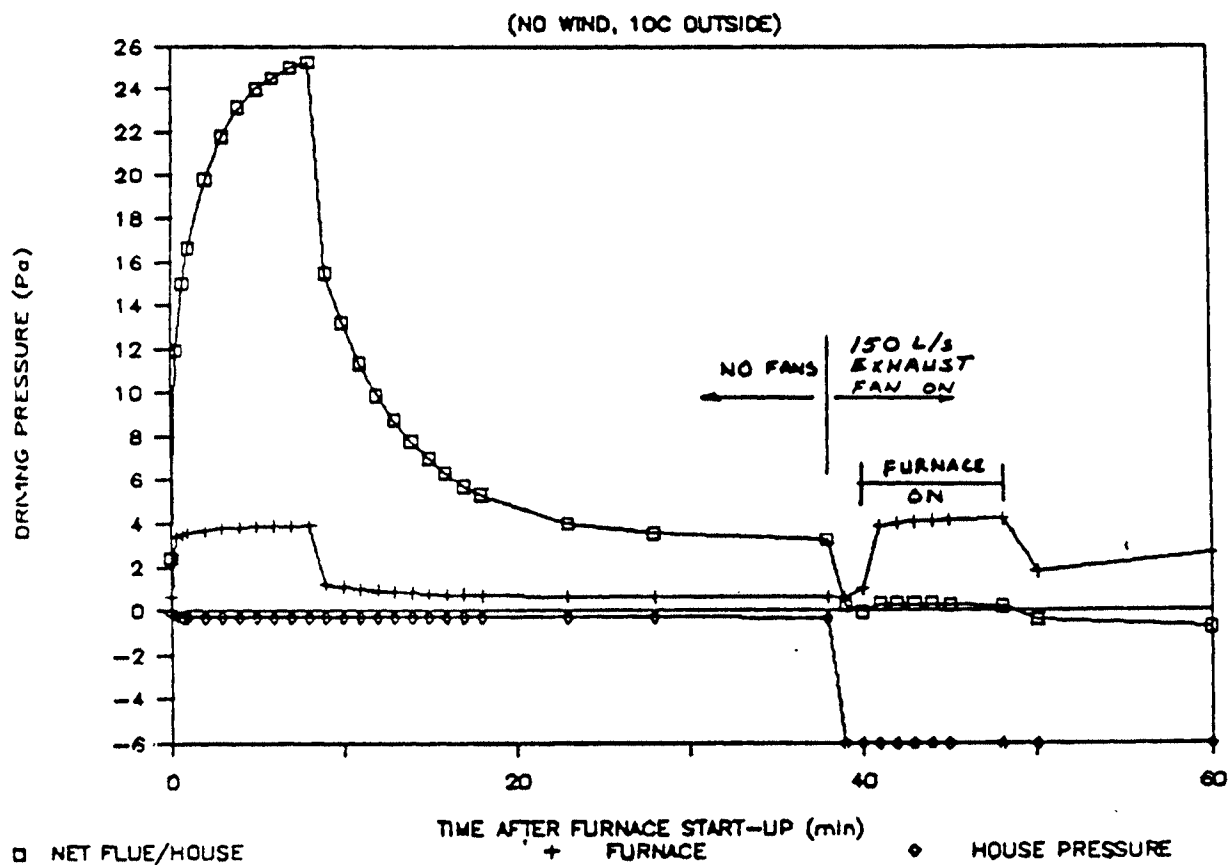


FIGURE 1: Flue and Furnace Pressure Parameters

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and exterior placement is being investigated by the CMHC Research Division.)

More important are the minimum driving pressures in the cycle which fall to about 3 Pa for the flue after half-an-hour of standby, and to a fraction of a Pascal in the furnace. These driving pressures that result from prolonged standby periods are the "weak links" in the cycle.

The last 20 minutes of simulation show what happens if 6 Pa of house depressurization occurs 2 minutes before furnace start-up and is maintained during the next furnace cycle. Because of backdrafting, the 20 or so Pascals that would have been available in the flue in normal operation are turned into near 0 driving pressure. The furnace develops slightly more potential buoyancy, about 4 1/2 Pa, but only about 3 Pa of this is actually converted to driving pressure on the flue.

Another key point illustrated in the example is that as the furnace buoyancy develops after start-up, the flue buoyancy is dropping -- in this example very quickly. Therefore, gains in furnace driving pressure coincide with drops in flue driving pressure. Because the furnace has been idle for some time, the flue structure is now cool and its buoyancy is lost quickly in backdrafting. It therefore appears that either standby flue driving pressure or the operating furnace driving pressure could form the basis of maximum available driving pressure, but not both added together. (The Critical Vent Establishment Pressure (CVEP) investigated by Consumers' Gas and the University of Toronto is made up of fractions of both the flue pressure, which is dropping due to depressurization by a door fan, and the furnace pressure, which is rising in their test. Their final result is not very different from either one separately measured at their respective steady-state conditions.)

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These results support the contention that the minimum available driving pressures at prolonged standby can form the basis of establishing the limits of house depressurization that will avoid prolonged backdrafting occurrence. However, other methods would also be legitimate depending on the circumstance.

Influence of Flue Construction

To investigate the standby condition further, FLUESIM was used to generate Figure 2 which illustrates the effects of standby duration on flue gas temperature for various kinds of flues with different pilot light capacities. The resulting driving pressure are indicated on the right-hand scale. These examples are:

	<u>Flue Construction</u>	<u>Pilot Light Capacity (W)</u>
#1	Interior B-Vent	350 W
#2	Exterior B-Vent	175 W
#3	Exterior Masonry (unlined)	350 W

Two other cases were run but are not shown. These are: exterior B-vent with 350 W and the interior B-vent with 175 W. Their results fall approximately in between the first two results shown, with differences of less than 1/2°C in the mean flue gas temperature from the interior B-vent and 350 W pilot.

The duration of standby, and the flue construction are shown to be critical elements of the problem. Note also that, by implication, furnace mass plays an important role and is interrelated to the effect of standby duration. Further work is required to plot these results against the furnace thermal time constant.

Note that the driving pressures are very low after half-an-hour of standby. It may not be practical to specify such low limits for house depressurization. Furthermore, it may not be realistic to try to accommodate the poorer flue designs. Here, the furnace driving pressure

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at full operation may be more realistically used as a minimum available driving pressure since the furnace would take over where the flue failed.

Finally, to confound the issue more, a set of standby cool down runs were simulated with FLUESIM while stipulating a 3 Pa house depressurization. Given the results shown in Figure 2, we would expect that:

Flue #1 would start backdrafting after about 20 minutes of standby.

Flue #2 would start backdrafting after about 14 minutes of standby.

Flue #3 would start backdrafting after about 10 minutes of standby.

However, these predictions were not substantiated by the actual FLUESIM simulations, as illustrated in Figure 3. Flue #1 did not backdraft with half-an-hour, and actually took about one hour to backdraft. The greatest resistance to flue flow that occurred because of house depressurization resulted in less dilution flow through the dilution device relative to furnace stack gas flow. Thus warmer flue temperatures resulted, and more resistance to backdraft was obtained. This warmer flue gas also affected the exterior B-vent initially, although that flue experienced faster cooling of the flue gas as it approached stall conditions. The backdrafting occurred approximately as predicted, due to these cancelling effects.

The exterior masonry chimney fared poorly in comparison because the cold liner cooled down the flue gas even more rapidly, and this more than offset any gains in warmer chimney entrance temperatures caused by the slower air flow.

The interior chimney benefited from the reductions in draft air, although a sudden home depressurization after prolonged standby conditions could eliminate this type of compensation.

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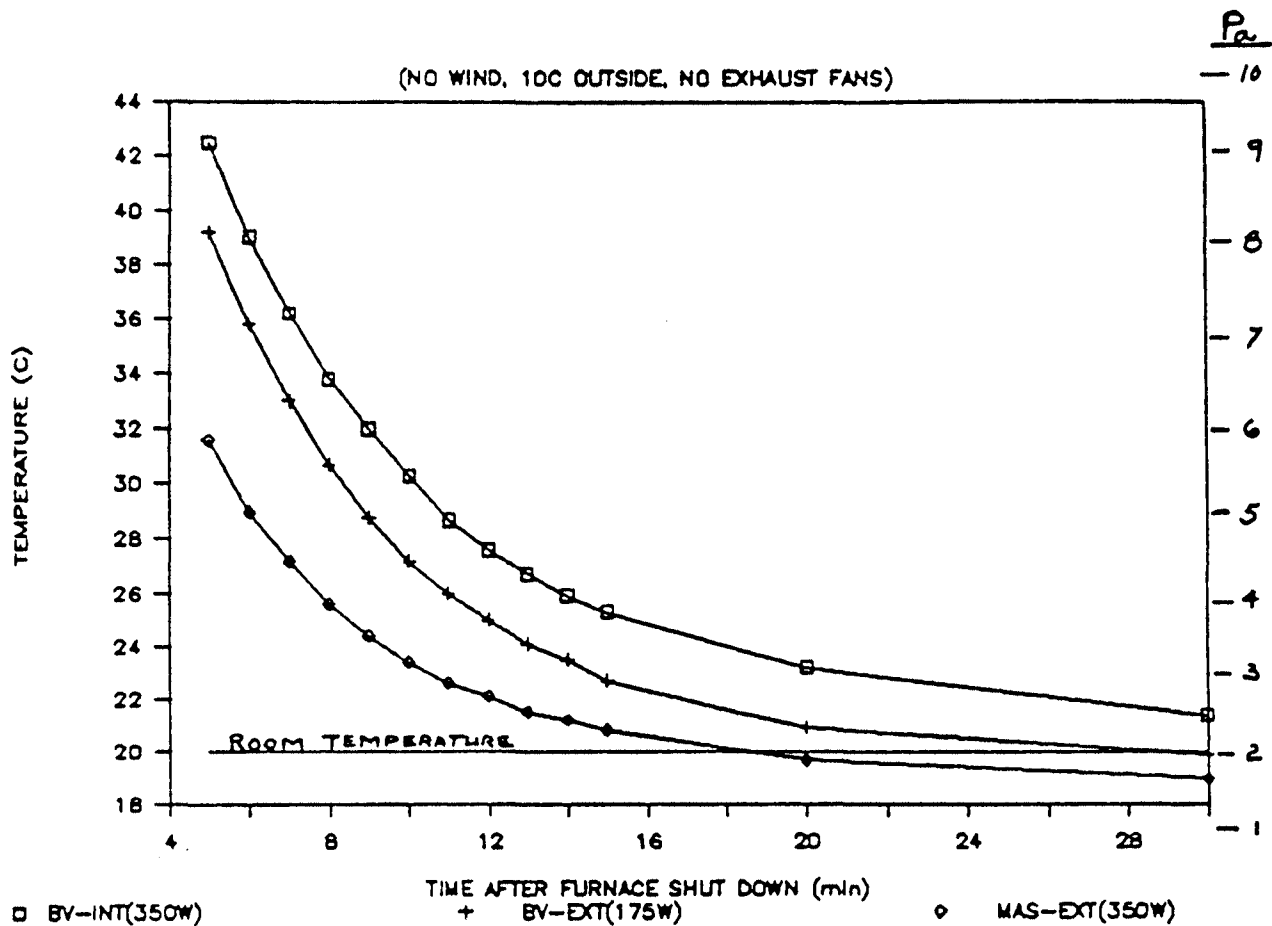


FIGURE 2: Mean Flue Gas Temperature Decay (C)

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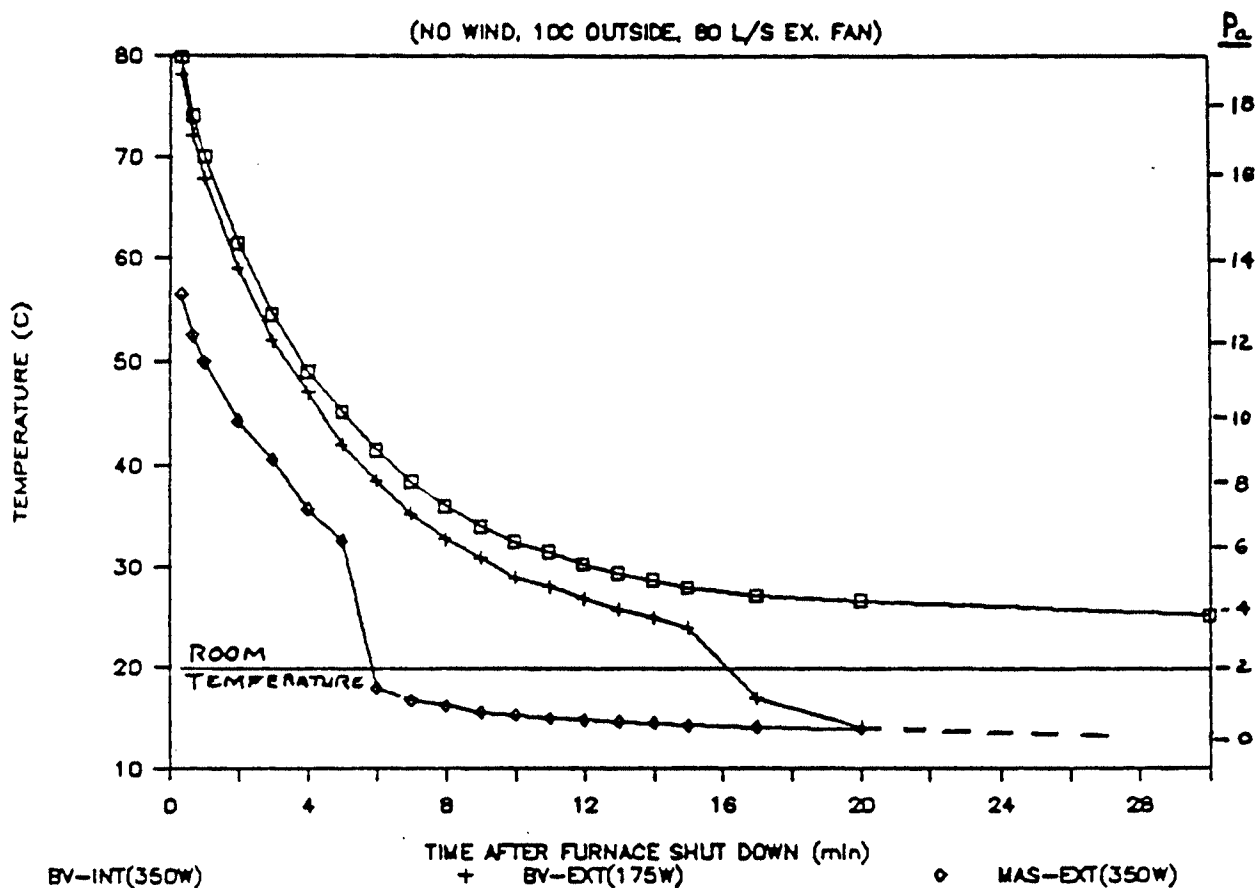


FIGURE 3: Mean Flue Gas Temperature Decay (C)

The immediate conclusion from these examples is that some chimney constructions have very low long term standby driving pressures, especially exterior unlined masonry chimneys, (exterior B-vents with flue dampers - were not modeled but should be similar to or worse than the unlined masonry). These types of chimney can experience driving pressures as low as 1 to 2 Pa - so small that they may not be practical to use for the HDLs. For such installations, using the maximum recoverable buoyancy pressures of the appliance may be more realistic, since these are more commonly in the 2 to 3 Pa range.

However further problems arise when using the buoyancy pressures of the appliance, since these often require several minutes of appliance operation -- with accompanying spillage -- before flue draft is re-established. Although the HDL may indicate the home is safe, in fact the householder can be frequently exposed to prolonged spillage. If the appliance is equipped with a spillage detector or a warning device, we are confronted with a situation where the safety check procedures reveal no venting problem, despite obvious indications to the contrary. The only solution may be to qualify the HDL for those types of chimney that tend to experience very low standby temperatures.

Gas DHW Heaters

DHW heaters are also likely to be vulnerable to prolonged spillage, if the house is kept tight at outdoor temperatures above 10°C. Thus a warning about prolonged spillage may be warranted, since 1 or 2 Pa of depressurization will be sufficient to cause standby backdrafting.

Confirmation of spillage incidents on weak furnace chimneys and DHW heaters (in summertime) may be forthcoming as problem houses are investigated during the Canada Wide Survey. Until such time, the best approach for these conditions is probably to base the HDL on the appliance recovery pressures and ignore the flue buoyancy.

Furnace Mass:

One apparently important factor requiring further consideration is furnace mass and its respective time constant. The oil furnace tested by Scanada at Armstrong, and those tested by ESSO, have much heavier heat exchangers and hence have time constants¹ of approximately 1 hour, much longer than conventional gas boilers and the heavier gas furnaces or gas boilers can maintain warmer flue gas temperatures longer. Increasing the HDL by at least 1 Pa should be reasonable, unless the appliance is expected to be idle for periods longer than 1 1/2 hours.

Chimney Height:

The effect of chimney height has not been investigated in detail, but is now thought to be less relevant, especially for exterior chimneys. Calculations by Jim White of CMHC have shown that chimneys have a limited effective height regardless of their un-insulated overall length. This is substantiated by the modeling of the exterior masonry chimney: the flue gases at standby were significantly cooler than room temperature in the upper half of the flue, and thus were less buoyant than the house air against which the flue is competing. Thus, it is not clear that the two storey house chimney would fare better than the bungalow chimney if it were unlined and on the exterior. Only with better flue designs (interior, and/or lined) would there be a noticeable (1 Pa) difference with the added height of a 3 storey house, or the reduced height of a bungalow.

¹Cool down time constants are defined as the ratio of the heat capacity of the heat exchanger to the product of the mass flow rate of air through the furnace at standby and the heat capacity of air.

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3.0 CONCLUSIONS: SPECIFYING HOUSE DEPRESSURIZATION LIMITS

Based on the limited modeling conducted with FLUESIM, it is safe to assume a minimum standby pressure of 3 Pa for interior flues with pilot lights. In addition, an allowance of an additional 1 Pascal can be made for wind, for additional chimney height, for heavy furnaces or boilers, and for the additional input from a second appliance sharing the same flue. Table 2 presents the incremental driving pressures for each of these contributing factors. Thus the HDL for the interior 8-vent can vary from 4 to 7 Pa, but on average will be 5 or 6 Pascals. Exterior chimneys, or unlined chimneys, would show the same HDLs, except for increments due to chimney height. Moreover HDLs for the exterior and unlined flues would not necessary protect houses from occasional prolonged spillage.

Despite a more detailed examination of the factors which influence flue driving pressures, the predicted pressures do not vary much from the original MAD Limits. This should not be surprising, since the MAD Limits were based on a wealth of empirical data. However, the emphasis has changed in several areas with less emphasis on chimney height, and more emphasis on the type of flue and the type of appliances.

HDLs are presented in Table 3.

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TABLE 2
HDLs FOR AN INTERIOR B-VENT
IN A TWO OR THREE STOREY HOUSE

<u>Contributing Factors</u>	<u>Incremental Driving Pressure</u>
Standby Driving Pressure (T = 10°C)	3 Pa
Wind Effect (avg. wind >6 km/hr)	1 Pa
Additional 2 or 3 metres Chimney Height (e.g. 2-1/2 storey house)	1 Pa
Heavy Heat Exchanger (Boiler or massive Furnace)	1 Pa
Common Flue with DHW Heater (350 w pilot plus thermal mass and incremental operating time)	<u>1 Pa</u>
Maximum HDL	7 Pa
Minimum HDL	4 Pa

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Table 3
HOUSE DEPRESSURIZATION LIMITS (HDLs)

Appliance	Chimney Height to Closest meter	H. D. Limit in Pascals	
		Unlined Chimneys on Exterior Walls	Metal-lined, Insulated or Interior Chimneys
Gas-Fired Furnace or Boiler or Water Heater	4 or less 5, 6 7 or more	5 5 5	5 6 7
Oil-Fired Furnace or Water Heater	4 or less 5, 6 7 or more	4 4 4	4 5 6
Fireplace (wood or gas)	N/A	3	4
Airtight Wood- Stove or Fireplace	N/A	10	10
Appliances with Retrofitted Induced Draft Fans	N/A	15	15

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REFINEMENTS TO THE CHIMNEY SAFETY TESTS:
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APPENDIX 1
OVERALL PROJECT SUMMARY

Prepared for:
The Research Division
Policy Development and Research Sector
Canada Mortgage and Housing Corporation

Prepared by:
Scanada Sheltair Consortium

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The project reported on here was designed to expand on previous studies of the problem of incomplete venting of combustion products from heating appliances in order to approach a more nearly comprehensive understanding of the extent and nature of the problem in the Canadian housing stock. This project, which was carried out for Canada Mortgage and Housing Corporation by the Scanada Sheltair Consortium Inc., consisted of the seven sub-projects described below.

PROJECT 1 COUNTRY-WIDE SURVEY

Spillage detectors were installed on the draft hoods or barometric dampers of gas and oil furnaces and water heaters in 937 houses spread throughout the Vancouver, Winnipeg, Toronto, Ottawa and Charlottetown regions. The detectors were left in place for approximately 2 months in late winter.

Of the gas heated houses surveyed, 10% had experienced prolonged and unusual amounts of combustion gas spillage and 65% had experienced either short duration start-up spillage or prolonged spillage of small amounts of combustion gas. Of the oil heated houses, 55% had experienced significant spillage of high temperature combustion gas, but some of these spillage events may have been of only short duration.

Preliminary analysis indicates that spillage problems seem to be related to the following house or heating system characteristics:

- Winnipeg houses (believed to be more nearly airtight due to extensive use of stucco)
- pre-1945 houses
- post-1975 houses
- one storey houses
- exterior chimneys
- masonry chimneys with under-sized metal liners
- houses with three or more exhaust fans
- houses with two open masonry fireplaces
- poorly maintained heating appliances

PROJECT 2 MODIFICATIONS AND REFINEMENTS TO THE FLUE SIMULATOR MODEL

FLUE SIMULATOR, a detailed theoretical computer-based model of the combustion venting process had been developed for CMHC prior to this project. It is intended for use as an aid in understanding the mechanisms of combustion venting failure and the circumstances that give rise to them. The modifications undertaken in this project were intended

to make the program easier to use and to allow it to model a wider variety of furnace/flue/house systems. The modifications included -

- o refinements to algorithms
- o more efficient operation of the program
- o modelling additional features and system types
- o user-friendly input and output

The modified model was validated against field test data and used to investigate a number of issues.

A separate developmental version of the program, called "WOODSIM", was successfully developed to model the combustion and combustion venting process in wood stoves and fireplaces.

PROJECT 3 REFINEMENT OF THE CHECKLISTS

A procedure for identifying and diagnosing combustion venting failures had previously been developed for CMHC - the Residential Combustion Safety Checklist. This project provided an opportunity to refine the checklist and develop variations of it suitable for a variety of possible users such as furnace service personnel, air sealing contractors, homeowners, etc. Early in the project, it was decided to separate the identification procedures from the diagnostic procedures. This allowed the process of identifying houses with potential for combustion venting problems to remain relative simple and allowed the diagnostic process to become more complex since it would only be used on houses where the extra effort would likely be worthwhile. Thus the original backdraft checklist has grown into five separate tests/procedures -

Venting Systems Pre-test

- a quick, visual inspection procedure which identifies a house as either unlikely to experience pressure-induced spillage or requiring further investigation

Venting Systems Test

- a detailed test procedure for determining to what extent the combustion venting system of a house is affected by the envelope airtightness and operation of exhaust equipment, perhaps the clearest descendent of the old backdraft checklist.

Chimney Performance Test

- a simple method of determining whether a chimney is capable of providing adequate draft

Heat Exchanger Leakage Test

- a quick method of determining if the heat exchanger of a furnace has a major leak

Chimney Safety Inspection

- a visual check for maintenance problems in the chimney system

These tests/procedures are all presented in a manual entitled "Chimney Safety Tests". Full trials of the procedures were carried out on the case study houses investigated in Project 6.

PROJECT 4 HAZARD ASSESSMENT

Although little was known at the outset of this project about the frequency of combustion spillage, even less was known about how much of a health hazard such spillage represents. Therefore this sub-project was included to investigate the real nature of the health and safety risk associated with venting failures. The work was divided into five tasks -

1. Review of current knowledge on pollutant generation due to improper venting of combustion appliances (literature review).
2. Development of a computer program to predict levels of various pollutants under various combustion venting failure scenarios.
3. Acquisition and calibration of a set of instruments required to measure the various pollutants at the levels predicted by the computer model.
4. Monitoring pollutant levels in problem houses identified in the Country-wide Survey (Project 1) using the instruments acquired in Task 3.
5. Analysis of the results of Task 4 to arrive at an overall assessment of the health hazard represented by combustion venting failures in Canadian houses.

The results indicate that, in most houses, one would rarely encounter acute, immediately life-threatening concentrations of pollutants as a result of combustion spillage from furnaces or water heaters. However, chronic health risk due to low level, long term exposure to pollutants, particularly NO₂, may be a more significant problem which requires further investigation. High levels of CO do not seem to be caused by the problems which cause spillage and thus occur in spillage events only as a result of coincidence.

PROJECT 5 REMEDIAL MEASURES

Remedial measures for pressure-induced combustion venting problems were identified and researched for a number of different types of combustion appliances.

The remedial measures identified for FIREPLACES were:

Spillage Advisor

- This is an adjustable volume alarm triggered by a combination of particulate and CO detectors and intended to be mounted on the front of the mantle or on the wall just above the fireplace.

Airtight Glass Doors Combined With An Exterior Combustion Air Supply Duct

- The research indicated that conventional glass doors are not nearly airtight and do little to separate the fireplace from the house's pressure regime. Prototype doors using special glass, heavier than normal steel frames and special sealing techniques were fabricated and installed and tested. It was found that these doors increased the level of house depressurization required to cause prolonged spillage from the fireplace from 3 Pa to 22 Pa. It is estimated that the installed cost would be \$600. Further research on the effect of airtight doors on temperatures within the fireplace and flue and the possible hazard to surrounding combustible materials is required.

The remedial measures identified for GAS-FIRED APPLIANCES were:

Spillage Advisor

- This could be similar to the fireplace spillage advisor but would be triggered by a heat probe mounted in the dilution port of the appliance. The heat probes investigated could also be used to trigger other remedial measures discussed below.

Draft-inducing Fan

- A paddle-wheel-type fan mounted in the vent connector was found to increase the level of house depressurization required to cause irreversible spillage from a naturally aspirating gas furnace from 7 Pa to more than 20 Pa.

Draft-assisting Chamber

- A chamber surrounding the appliance's dilution port and extending downwards contains combustion products flowing out of the dilution port and prolongs the period before they are

actually spilled into the room. It was expected that the chamber would also use the buoyancy of the contained combustion products to assist the flue in developing upward flow and thus would increase its resistance to house depressurization; however, the results obtained with the prototype tested did not live up to expectations. It is expected that modification of the design and testing with a furnace/flue/house combination more prone to pressure-induced spillage will improve this aspect of the chamber's performance.

The research on remedial measures for OIL-FIRED APPLIANCES indicated that stable backdrafting is unlikely to be a problem with oil-fired appliances since the pressure generated by the burner blowers is able to rapidly overcome backdrafting due to house depressurization and initiate upward flue flow. However, this pressurization of the flue system is what accounts for the start-up spillage associated with oil appliances and it is the duration of this spillage that remedial measures must address. The measures identified were:

Solenoid Valve

- By delaying the start of combustion until the burner has had a chance to overcome backdrafting and initiate upward flue flow, the solenoid valve reduces the duration of spillage but does not eliminate it altogether.

Draft-inducing Fan

- A fan, similar to that described above under gas appliances, mounted in the flue pipe downstream of the barometric damper is not needed to overcome backdrafting since the burner blower can do this. However, it does relieve pressurization of that portion of the flue pipe upstream of itself and hence reduces spillage from that portion. There can still be spillage from the downstream portion; but, since that portion does not include the barometric damper, it is easier to seal.

Elimination of the Barometric Damper

- Provision of a well-sealed flue pipe without a barometric damper is one obvious way to reduce spillage. However, elimination of the barometric damper exposes the burner to the full chimney draft and disturbs the combustion process of conventional burners. Therefore this procedure must include replacement of the conventional burner with a high pressure burner which is less influenced by flue pressure. Provision of an insulated flue liner is often included as part of this measure.

The work on MAKE-UP AIR SUPPLY remedial measures was less directed towards specific measures but served to clarify a number of general air supply issues. It indicated that the provision of additional supply air is not likely to be effective as a remedy for pressure-induced spillage of combustion products if the supply air is introduced unaided through an envelope opening of any size likely to be considered practical. It is only likely to be effective if a supply air fan is used and if that fan has a capacity at least equal to the total capacity of all exhaust equipment it is attempting to counteract. The discharge from such a supply air fan can be introduced essentially anywhere in the house, but is likely to create fewer thermal comfort problems if introduced in a normally unoccupied area such as the furnace room.

The knowledge generated in the remedial measures research and already available to Consortium members was synthesized into the draft Remedial Measures Guide, a manual intended to be a decision-making guide for tradesmen and contractors who have identified pressure-induced spillage problems in houses with vented fuel-fired appliances and want to know how best to remedy these problems. It is designed to accompany the Venting Systems Test. Although the draft Guide is not yet comprehensive and in some cases describes procedures which have not been thoroughly field tested and/or approved by regulatory authorities, it is hoped it will stimulate thought and discussion and improve current trade practices.

PROJECT 6 PROBLEM HOUSE FOLLOW-UP

Twenty of the houses identified in the country-wide survey as experiencing the worst combustion spillage problems were visited with the following objectives:

- to categorize and quantify the nature of venting failures
- to isolate contributing factors
- to collect field data on venting failures for use in the flue simulator model validation
- to measure the frequency and quantity of spillage in problem houses
- to measure the approximate impact on air quality of venting failures in houses
- to evaluate the effectiveness of the chimney safety tests in diagnosis of failures and identification of remedial measures
- to evaluate communications techniques
- to evaluate remedial measures under field conditions

In most of the houses, there were several factors that were assessed as contributing causes of the combustion spillage problem - thus confirming the "systems" nature of the problem. It is also worth noting that, in many houses, although the spillage observed was indeed pressure-induced,

it occurred at quite low levels of house depressurization because the chimneys were only able to generate very weak draft due to some problem such as a blocked or leaky flue. The main problem in these cases, therefore, was not depressurization but weak chimneys.

PROJECT 7 COMMUNICATIONS STRATEGY

As the survey revealed that the problem, while substantial, is not epidemic in proportion, there is no need to create widespread alarm in the general public. A communication strategy has been drafted with this in mind. It places emphasis on motivating the heating and housing industries to be aware of the combustion venting problem and its causes and to make effective use of the diagnostic tools and preventive and remedial measures developed in this project.

OVERALL PROJECT SUMMARY AND CONCLUSIONS

The project has gone a long way towards meeting its original objectives and has significantly advanced the state-of-the-art in this field.

It has led to improved understanding of the combustion venting process and confirmed the "systems" nature of the failures that lead to combustion venting problems.

It appears that a significant portion of the Canadian housing stock has potential for combustion venting failure to occur on a regular basis. In most cases, this is unlikely to lead to immediate life-threatening pollution levels, but long term chronic health hazards could be a problem; however this latter concern requires further investigation before any definite conclusion can be reached.

A number of techniques are available for identifying houses prone to combustion venting failure and for diagnosing the causes of such failure. There are also available a number of measures for preventing combustion venting failure in new houses and for remedying it in existing houses. A communication strategy has been drafted for conveying these techniques and measures to relevant people in the housing and heating industries and for encouraging them to make use these tools.