#2759

RESIDENTIAL COMBUSTION

VENTING FAILURE

A SYSTEMS APPROACH

SUMMARY REPORT

Prepared for:

The Research Division

Policy Development and Research Sector

Canada Mortgage and Housing Corporation

Prepared by:

Scanada Sheltair Consortium

July 30, 1987

Canada Mortgage and Housing Corporation, the Federal Government's 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 statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

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Principal Consultants:	John C. Haysom Michael C. Swinton Scanada Consultants Limited
	Sebastian Moffatt Sheltair Scientific Inc.
Project Manager for CMHC:	Don Fugler
CMHC Scientific Authority:	Jim H. White

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ABSTRACT

The project reported on here was designed to expand on previous studies of the problem of incomplete venting of the products of combustion 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. The work was subdivided into seven separate but closely coordinated sub-projects -

- *a country-wide survey of approximately 1000 houses to derive an estimate of the extent of the problem*
- *refinement and extension of FLUE SIMULATOR, a computer model originally developed for CMHC by Scanada Consultants Limited in 1984-85, to make it easier to use and to allow it to model a wider variety of furnace/flue/house systems*
- *refinement of existing field detection/diagnosis procedures (checklists) to improve their accuracy and facilitate their use by a wider variety of potential users*
- *study of the pollutants likely to be released in a house as a result of failed or incomplete venting of combustion products and study of the health hazards these pollutants might represent*
- *review of remedial measures, available or on the horizon, for correcting or avoiding combustion venting problems and research and development of the more promising such measures*
- *on-site investigation of problem houses found in the country-wide survey as case studies for the other sub-projects*
- *drafting of a strategy for communicating the results of the project to the appropriate audiences in order to encourage the initiation of measures to reduce the combustion venting problem.*

The results indicate that a significant portion of the housing stock has potential for combustion venting failure to occur regularly, but such failures are not necessarily life-or health-threatening. The project has resulted in marked improvement in understanding of the combustion venting process and has identified a number of effective preventative and remedial measures.

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munities and, in view of the lack of evidence of significant safety hazards, does NOT include major efforts to alert the general public.

The project 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 has also highlighted areas that require additional research before firm conclusions on the hazards associated with combustion venting failures can be reached. CMHC and other organizations have commissioned further investigations, the results of which will supplement the findings of this project.

INTRODUCTION

Over the period from November 1985 to September 1986, Canada Mortgage and Housing Corporation (CMHC) retained the Scanada Sheltair Consortium to carry out a project entitled -

Residential Combustion Venting Failure - A Systems Approach.

This project was a follow-up to several preceding projects carried out by the consortium members and others with sponsorship from CMHC and, in some cases, Energy Mines and Resources, Canada (References 4-14). All of these projects were concerned with the issue of improper and incomplete venting of the products of combustion from fuel-burning appliances in houses.

There has been growing concern in recent years that the Canadian housing stock is becoming more prone to combustion venting failures that could result in health- and/or life-threatening hazards. This perceived trend is believed to be due to a number of factors:

- widespread conversion from oil heating to gas heating, often without proper safeguards such as the installation of chimney liners
- decreases in the frequency and effectiveness of furnace servicing
- the construction of more nearly airtight new houses and the retrofit air sealing of existing houses
- increased use of powerful exhaust equipment such as range-top barbecues

The preceding projects had included:

- the development of on-site procedures (checklists) for detecting and diagnosing a house's propensity to combustion venting failure
- the development of a detailed theoretical computer-based model (the FLUE SIMULATOR model) of the combustion venting

process to aid in understanding the failure mechanisms and the circumstances that give rise to them

This two-pronged field/theoretical approach adopted by CMHC proved to have a significant synergistic effect - the field work provided data to help refine and validate the model and the model helped in interpreting the field data and in designing further field work.

The project reported on here was designed to expand the work in both areas and to achieve even greater integration of the results in order to approach a more nearly comprehensive understanding of the extent and nature of the combustion venting problem in the Canadian housing stock. The work was subdivided into seven separate but closely coordinated sub-projects:

- a cross-country survey of more than 1000 houses to derive an estimate of the extent of the problem

- refinement and extension of the FLUE SIMULATOR computer model to make it easier to use and to allow it to model a wider variety of furnace/flue/house systems

- refinement of the field detection/diagnosis procedures (checklists) to improve their accuracy and facilitate their use by a wider variety of potential users

- study of the pollutants likely to be released in a house by failed or incomplete venting of combustion products and study of the health hazards related to these pollutants

- review of remedial measures available or on the horizon for correcting or avoiding combustion venting problems and research and development of the more promising such measures

- on-site investigation of problem houses found in the cross-country survey as case studies for many of the other sub-projects

- drafting of a strategy for communicating the results of the project to the appropriate audiences in order to encourage the initiation of measures to reduce the combustion venting problem.

The purpose of this report is to summarize and correlate the results of all of these sub-projects. The detailed procedures and results of each sub-project are available in one or more separate reports.

TERMINOLOGY

Venting vs. Ventilation

Venting is a specific term referring to the direct removal of pollutants from an indoor environment by "capturing" or collecting the pollutants where they are generated and exhausting them directly to the outdoors.

Ventilation is a more general term referring to the provision of quality air (i.e. air that is fit for breathing or combustion) in an indoor environment. Ventilation usually involves the drawing in of outdoor air, the distribution of such to areas where it is needed, and the recapturing of "used" air, which is either vented or treated and recirculated, or both.

It is highlighted in this report that one cause of improper combustion venting is that the venting system is not planned as part of the overall house ventilation system.

Spillage

The flow of combustion products out of the dilution device of a combustion appliance or out of leaks in its venting system into the room where the combustion appliance is located. This is caused by a condition where there is insufficient flow in the venting system to remove all of the combustion products emanating from the appliance.

Pressure Induced Spillage

Spillage caused by house and/or furnace room depressurization. House and furnace room depressurization is generally caused by a large demand for indoor air by air exhausting equipment, relative to a small supply of fresh air due to a tight building envelope, and insufficient fresh air openings.

Backdrafting

A condition where all of the flow in a flue is downwards and all of the combustion products from connected appliances, if operating, flow out their dilution devices along with the backdrafting air. Backdrafting can initially be caused by house depressurization or by downdrafting winds, but can sustain itself without either of the above, once started.

Flue Pipe - Vent Connector

The conduit connecting the flue collar of a heating appliance to a chimney. The term "flue pipe" is commonly used by the oil industry, and "vent connector" by the gas industry. Other terms commonly used in the industry are "stove pipe" and "chimney connector".

Dilution/Draft Control Devices

Dilution or draft control devices admit room air into the venting system to mix with the stack gases for the purpose of controlling the draft at the heating appliance exit. Such devices include draft hoods (draft diverters) on gas appliances and barometric dampers on oil furnaces.

Draft - Driving Pressure

The "driving pressures" that cause air and combustion products to flow in a chimney can be calculated using fundamental equations of fluid mechanics that account for buoyancy effects, wind effects, and house depressurization. The buoyancy component of the driving pressure has been labelled "theoretical draft" by the heating industry. In the field, "theoretical draft" is not easily measured because it causes the air to flow in the chimney which in turn dissipates most of that pressure into a friction pressure loss. Attempts have been made to measure theoretical draft by quickly blocking the venting system at its inlet - the blocking stops the flow and eliminates friction loss - and the pressure difference between the inside of the vent and the room is then measured. However, the theoretical draft changes so rapidly under blocked-flue conditions that the results are difficult to interpret. As a compromise the same measurement is made with the venting system operating normally, and it is recognized that the resulting pressure difference is smaller than the theoretical draft due to friction losses. That measured pressure difference under normal operating conditions is called "draft" by the industry.

of temperatures around the dilution air inlet of a backdrafting gas furnace after 64 seconds of operation. The hot spots vary, depending on whether the chimney is blocked, partially blocked or backdrafting. For example, blockage produces hotter temperatures at the upper portion of a furnace inlet and backdrafting at the lower portion. Partial spillage is best detected in the corners. On the basis of extensive temperature data similar to Table 1.1, it was concluded that the best location for mounting detectors on gas furnaces is the high centre of the inlet, about 25 mm below the upper lip. (Detectors on flues with dampers must be located at the lower lip of the dilution air inlet, however, to avoid convective heat currents after the damper closes.) Detectors on water heaters are best located so as to bridge the gap between the lower rim of the drafthood and the top of the tank, as shown in Figure 1.1.

Prototype sensors were developed and field tested under a variety of conditions, and were shown to successfully indicate spillage events of varying intensity and duration. A delay was built into the detector by mounting dots on the cold side of the plastic. This delay was found to be at least 15 seconds; the higher the dot temperature, the longer the delay. Each detector incorporated a series of heat sensitive dots at different indicating temperatures, which made possible an assessment of the duration - and indirectly the severity - of spillage by counting the number of dots that had changed from white to black. Interpretation of spillage events by the temperature ratings of black dots is summarized on Page 11 and 12.

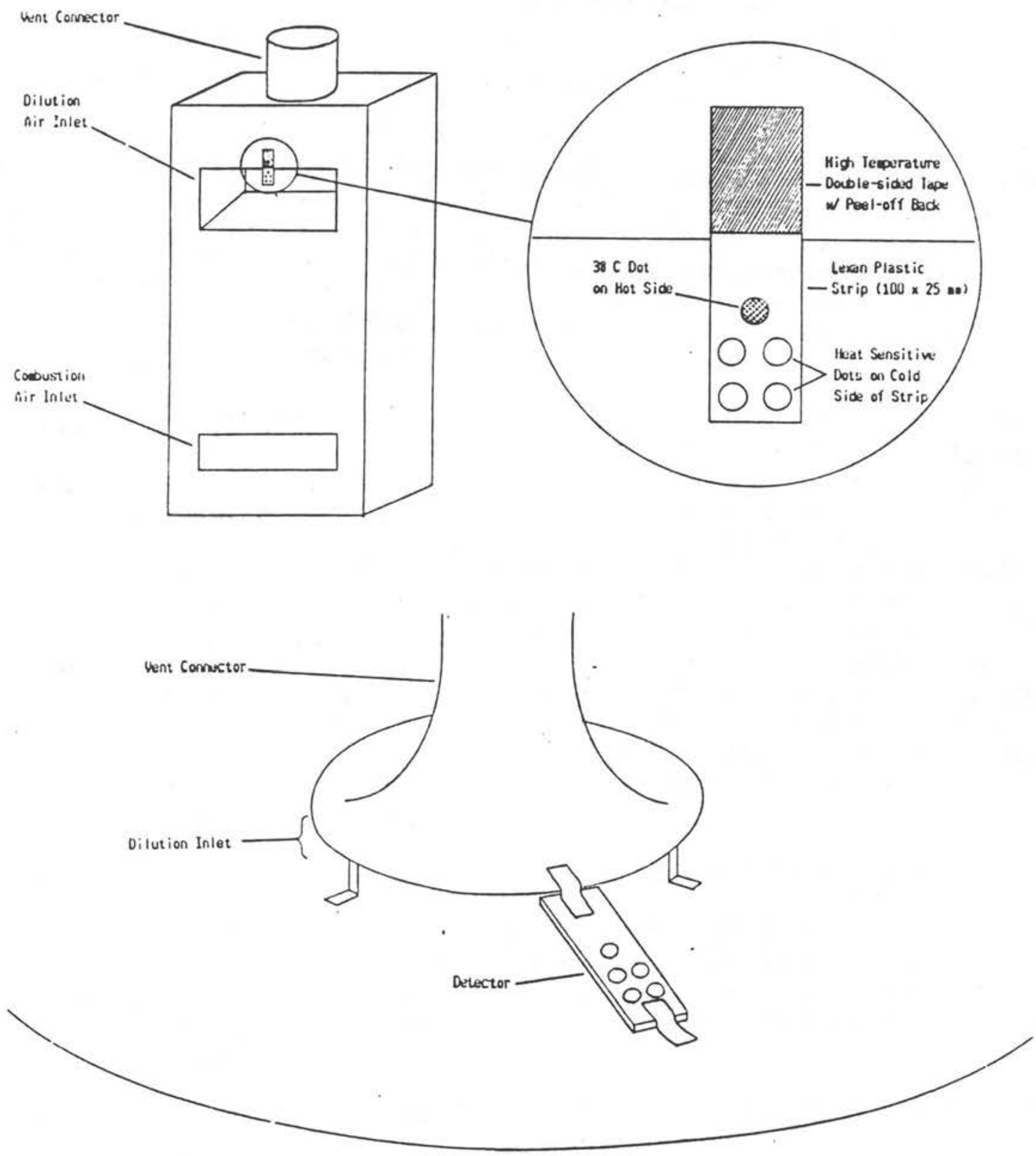


FIGURE 1.1: Dot Detector for Gas-Fired Furnaces and Water Heaters

5. A 121°C DOT ON THE COLD SIDE, 42mm BELOW TOP OF INLET

   This "hot" dot translates to gas temperatures of approximately 142°C, which represent the upper range of temperatures recorded from spillage gases during field testing. A 121°C DOT, therefore, indicates furnaces with MAJOR FAILURES, due to large or frequent quantities of very hot spillage gases around the detector.

The dot detectors succeeded in identifying the great majority of spillage occurrences simulated in the test houses, and in discriminating between slight spillage - such as often occurs at start-up - and prolonged or unusual spillage. The dot detectors were unable to detect spillage events in some unusual locations, such as at the burner or through leaks in the flue. They were also unable to detect slight spillage at the corners of the inlet on gas furnaces, or slight spillage at openings other than the main opening to the dilution port (there are gaps at the top of the dilution port on some furnaces on which the dilution port is narrower than the main furnace housing), even if this spillage occurred on a continuous basis.

Detectors For Oil-Fired Appliances

Spillage detectors for oil-fired furnaces and boilers required a different design than those for gas furnaces, due to the absence of an open inlet for intercepting spillage gases. Initial testing with smoke detectors mounted at the ceiling level above the barometric damper of an oil furnace, indicated that conventional ionization-type smoke alarms were capable of detecting combustion gases, even when these gases were spilling at very low velocities, and for periods as short as 10 to 15 seconds. Replacing the siren in a conventional smoke alarm with a pulse counter, produced an excellent device for counting spillage events from oil furnaces. Unfortunately, these converted smoke alarms entailed material costs of $30 to $40 each, considerably above the $10 allocation, and the concept was rejected for application in the Canada-wide survey. Smoke alarm and counter technology seemed more appropriate for follow-up investigations on oil furnaces where some kind of spillage was known to be occurring, and where frequency and duration of spillage was of interest.

Instead of using smoke detectors, a spillage detector for oil furnaces was developed and tested using a series of heat sensitive dots - similar to the detector for gas appliances. Extensive testing on one test house indicated that the swing plate of the barometric damper was the only suitable location for a heat sensitive detector. The variability of leakage around a damper makes interception of gases impossible. The dots are instead mounted directly on the exterior face of the swing plate. Whenever hot gases spill around the damper, the swing plate is heated and the dots change colour.

The design of the spillage detector for oil furnaces is illustrated in Figure 1.2. The dots are mounted on a foil tape with a peel-off adhesive backing and include a range of temperatures identical to the gas appliance dot detectors. The dot detectors were found to be easy to apply and extremely easy to read. The high conductivity of the metal damper insures that the surface temperature of the dots reach the temperature of gas on the opposite side of the face within seconds. The precise time delay was not measured under controlled conditions. Testing of the detectors in three random houses showed the detectors to work well. Under normal operating conditions the vertical face of the barometric damper is bathed in draft air at ambient temperatures. Despite warming of the damper duct, and the flue connector, the damper face was found to remain close to room temperature even during extended periods of furnace operation. Radiative heat gain from a hot flue connector was found to be insignificant. Even closed, poorly balanced dampers remained relatively cool.

In some cases dots were found to change colour extremely rapidly under conditions of major spillage from a hot firing appliance. This rapid response results in the oil furnace detectors not having a reliable time delay, as with the gas appliances. Consequently the oil-furnace dot detectors cannot discriminate between a start-up spillage problem and a prolonged spillage problem. In retrospect it might have been worthwhile to mount some of the dots on a double-sided foam tape to add insulation between the dot and the damper and lengthen the response time. Also, it was later discovered that cleaning and balancing of the barometric damper before application of the detector should have been recommended - it is suspected that a badly sooted or imbalanced damper may not open properly and thus may not experience sufficient flow of dilution air to compensate for the heat gain from conduction or radiation. Thus the damper, and the detectors, may get hotter than normal even though there is no spillage of combustion products.

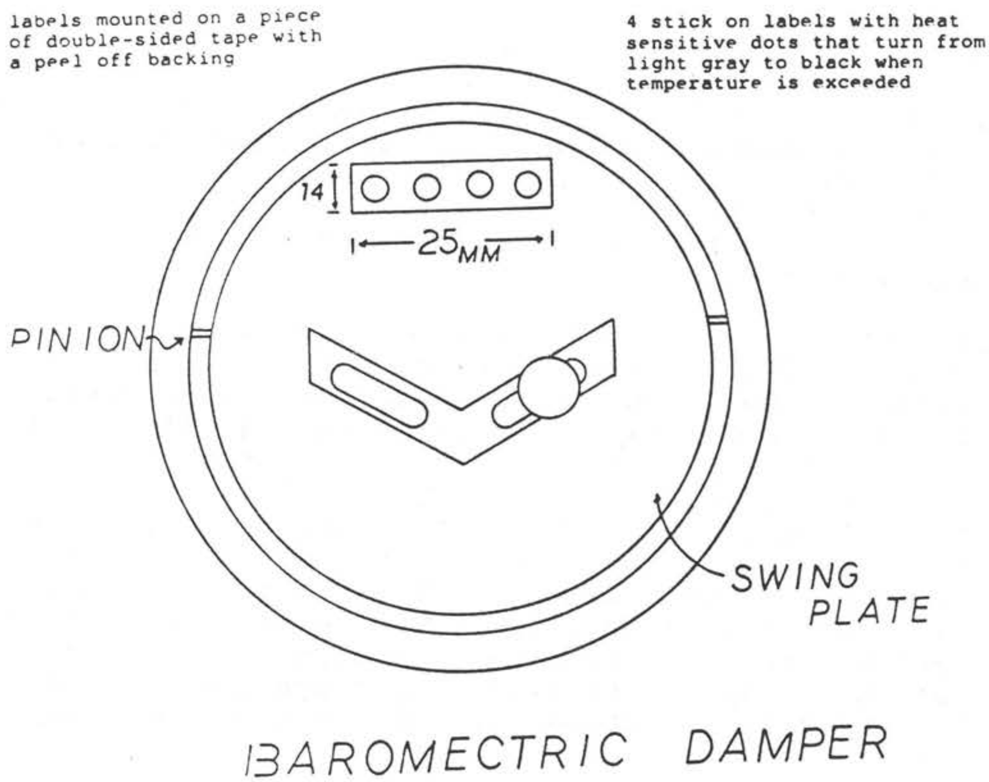


FIGURE 1.2: Spillage Detector for Oil Furnaces

Fireplace Spillage Detectors

Three different strategies were examined for detecting spillage from fireplaces: carbon monoxide, temperature and particle density.

Carbon monoxide detectors are costly, but were found to be suitable in most cases for detecting spillage from fireplaces, especially fires that are smoldering.

The use of heat sensitive materials was found inappropriate for fireplace spillage detectors because of the extreme temperature range that can be found in front of a fire under normal operating conditions. If the materials are located above the lip of the fireplace opening, so as to avoid radiative heat gain from the fire, the spillage gas temperatures become too cool for detection due to the large dilution area.

Ionization type smoke alarms as fireplace spillage detectors were found to work well for detecting certain types of fireplace spillage and to be reasonable in cost. Smoke alarms were observed to perform well as long as they were mounted on the centre face of the mantle above the fireplace or in an equivalent location, as illustrated in Figure 1.4. In most cases where spillage occurred along the entire length of the fireplace opening, the smoke alarm succeeded in detecting the spillage. This is true for spillage from a hot wood fire, a newspaper fire, a wet wood fire and glowing embers. Spillage from the top corners of the fireplace opening - typical of slight spillage occurrences - could not be detected. Response time of the alarm was usually less than 10 seconds.

Unfortunately, further testing of wood fire spillage gas composition in Vancouver test houses indicated that spillage from low ember wood fires will sometimes not be detected by a ionization type smoke alarm due to the low particle density. To detect spillage from low ember fires it was found necessary to use a carbon monoxide detector, in combination with a smoke detector, mounted at the level of the mantle. As long as the carbon monoxide detector is sufficiently sensitive (in the 20 to 50 ppm range) a combination CO/smoke detector is capable of detecting virtually all kinds of significant spillage from a wood burning fireplace.

A new type of CO detector was discovered, and found to be suitable for use in the Canada-wide survey. The CO detector and smoke alarm are connected to a circuit board, and then wired to pulse counters for recording the frequency and duration of fireplace spillage events.

The cost of materials for these combination CO/smoke detectors was in the range of $150. This precluded the widespread deployment of fireplace spillage detectors. It was therefore decided to install fireplace spillage detectors in only a few of the houses in which furnace and/or water heater detectors were also installed.

INSTALLATION OF SPILLAGE DETECTORS

In order to sample a wide range of houses in a range of climatic zones representative of all of Canada, the Canada-wide survey was conducted in five regions:

British Columbia
Winnipeg, Manitoba
Toronto, Ontario
Ottawa, Ontario/Hull, Quebec
Prince Edward Island

In each of these five regions, a different approach was used to locate a random sample of householders and houses for participation in the study. The different types of installers included staff from the five consulting companies supervising the regional installations, temporary employees, an oil furnace serviceman, gas furnace service companies, plumbing contractors, ventilation contractors, insulation contractors, propane suppliers and energy auditors. A $10 stipend covered labour costs for each installation. Non-standard appliances were mostly excluded from the survey. In regions where natural gas was not available (e.g. P.E.I. and the interior of B.C.), detectors were installed on oil furnaces and occasionally on propane-fired water heaters. No oil-fired water heaters were included in the survey.

Detectors were installed in 937 houses, slightly less than the goal of 1,000, despite the distribution of 220 detectors to each region (extra 10%). Failed installations were due to several reasons, but primarily resulted from poorly motivated sub-contractors who quickly lost interest in installing detectors when visiting houses for other purposes.

The final distribution of oil and gas heated houses in each region of the survey is illustrated in Figure 1.3. The installation reports completed by installers included information on the types of appliances and houses in the survey, and on the frequency of fireplace use by the householders. Information on fireplace use was then used to select a sample of houses in which to install the fireplace spillage detectors.

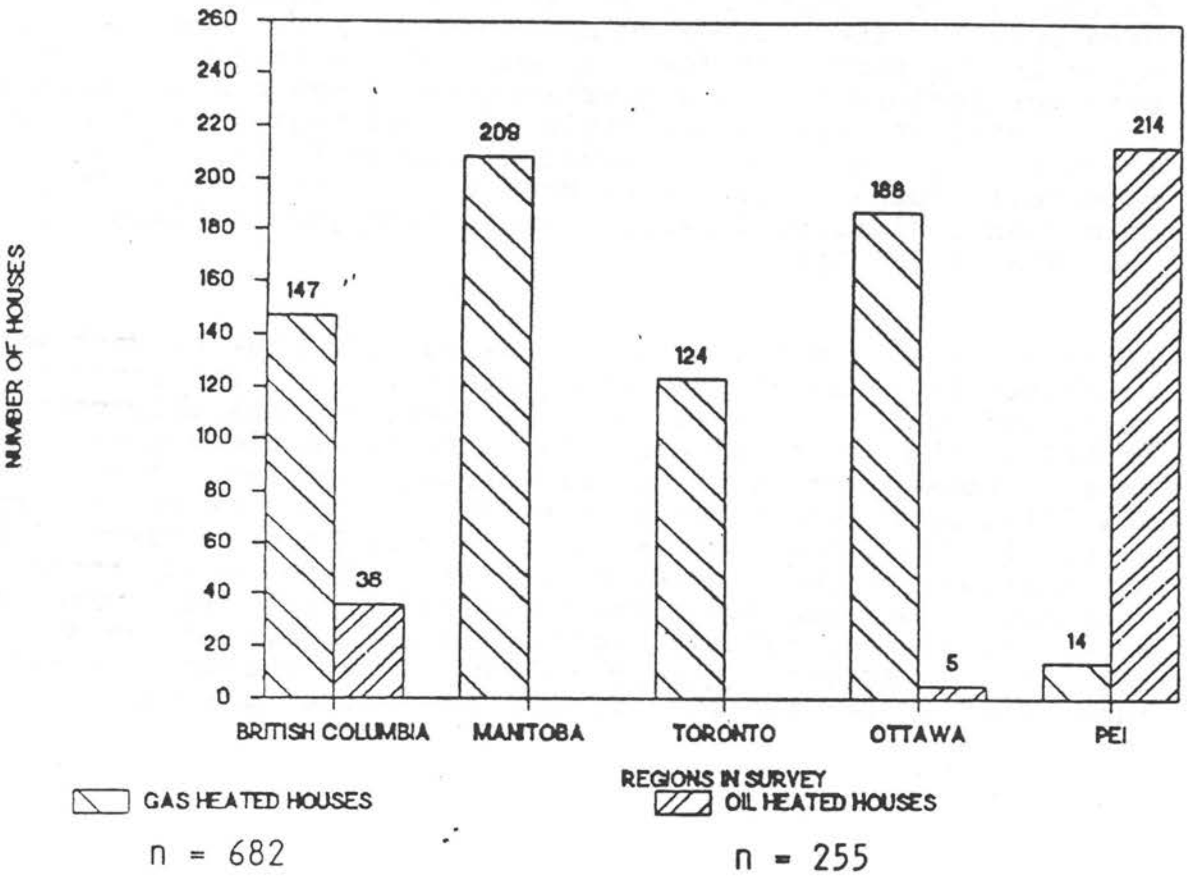


FIGURE 1.2: Regional Distribution of Oil- and Gas-heated Houses in the Survey

TELEPHONE SURVEY TO IDENTIFY SPILLAGE HOUSES

A telephone questionnaire was developed to obtain information from householders on the performance of the dot detectors in the survey houses. Customized versions of the questionnaire were developed for the various combinations of appliance and detector types in the survey houses. In addition to information on the detector performance, the questionnaire asked for information on the foundation type, house style, date of house construction, furnace location, chimney location, shared flues, chimney materials, furnace age, water heater age, fuel conversion, maintenance history, fireplace type, fireplace spillage history, and exhaust fan type.

After a 2 to 3 month monitoring period, all householders were contacted by regional telephone interviewers. The interviews required about 12 minutes each, and were successfully completed on 808 of the survey houses. Failures to complete questionnaires on some houses were a result of language problems, householders unwilling or unable to go to the furnace room, or other difficulties. If requested, interviewers provided householders with explanations of their detector results. A follow-up letter with recommendations was later mailed to all householders where black dots indicated a prolonged spillage event. All of the data collected on detector performance and house characteristics was input into a computer spreadsheet for further analysis.

A SECOND SURVEY TO TEST THE RELIABILITY OF HOUSEHOLDER DATA

The survey design required householders to examine the dot detectors and communicate their findings by telephone. This approach permitted the inclusion of a large sample while minimizing labour costs. However, the involvement of householders in this survey increased the risk of inaccurate data, especially since some householders experienced difficulty interpreting the dot detectors. To investigate the reliability of householder responses, surveys were conducted by trained technicians who visited the survey houses, shortly after telephoning the householders, and examined the dot detectors to corroborate the householders' interpretations. In total 121 houses were visited.

In two of the houses, householders had incorrectly reported five black dots when in fact the detectors had five white dots, a breakdown in communications which could not be explained. (In retrospect, it may have been worthwhile to include one black "reference" dot on each detector in addition to the white dots.) With the exception of these two houses, the survey by experts showed no major problems or inaccuracies with householders' interpretations, and demonstrated a high degree of accuracy for all the householders' responses.

ANALYSIS OF SPILLAGE INCIDENCE RECORDED BY DETECTORS

Gas Heated Houses

A summary of the spillage detector results for gas heated houses is presented in Table 1.2.

Of the 606 gas heated houses, 2.2% had 5 dots, up to and including the 121°C dot, change colour and can be assumed to have experienced a major venting failure. An additional 7.8% of the sample had either 4 dots (71°C) or 3 dots (54°C) change colour, indicating a prolonged venting failure on at least one occasion (such as start-up spillage of more than a minute duration, or continuous major spillage from cooler operating appliances, or prolonged backdrafting in colder weather). In total, about 10% of the gas heated houses had experienced prolonged and unusual amounts of combustion gas spillage over the monitoring period. These houses are referred to as "spillage houses".

Sixty-five percent of the gas heated survey houses had 2 dots (38°C) change colour, indicating they had experienced either start-up spillage on one occasion or prolonged spillage of small quantities of combustion gas. Twenty-four percent of the houses surveyed had experienced no combustion gas spillage. The most common situation was for both the furnace and water heater to change the colour of the dots in the range of 38°C to 54°C. There was no strong tendency for houses with a major problem with one appliance to experience problems with the other appliance.

Oil Heated Houses

Spillage/detector results for oil heated houses are summarized in Table 1.3.

Of the 217 houses with oil furnace detectors, about 5% had 4 black dots (121°C). An additional 22.6% of the survey had 3 black dots (71°C). A further 23% of the houses had 2 black dots (54°C). In total these results indicate that approximately 1/2 (55%) of the oil-heated houses experienced significant combustion gas spillage. Because oil furnace detectors have a faster response time than the gas appliance detectors, some of these events may have involved start-up spillage of hot gases for durations of only 10 or

15 seconds. Another 1/3 of the oil houses experienced very slight spillage, sufficient to exceed the 38°C dot temperature. Only 15% experienced no spillage event over the monitoring period.

Characterizing Spillage Problem Houses

The large number of factors that can influence combustion gas spillage events in houses prevents the development of strong correlations between particular house characteristics and spillage problems. No statistical correlations were calculated as part of this research, although a detailed, statistical analysis of the survey data was conducted as part of a separate contract. Instead, this report attempts only to identify general trends.

To permit easy recognition of trends which might explain spillage problems, the data on house characteristics was summarized and presented graphically. Characteristics of the spillage houses could then be compared with the total sample. Specific features of the gas heated houses which appear to correlate with prolonged combustion gas spillage include the following:

1. Houses located in the Winnipeg region.

   Figure 1.4 presents distribution of gas heated houses by region. A disproportionally large number of spillage houses were located in the Winnipeg region, and it is assumed that this is a reflection of the colder climate and correspondingly tighter housing stock as well as the widespread use of stucco exterior cladding in Winnipeg.

2. Pre-1945 construction and post-1975.

   Both the oldest and the newest houses indicate higher than average spillage incidence. The strongest trend is towards increased problems in the pre-1945 houses, which may be related to chimney deterioration, liners, leaks, poor maintenance and fuel conversions. The higher incidence of spillage in post-1975 houses may be related to house depressurization, since new houses tend to be much tighter and are more likely to incorporate exhaust fans.

TABLE 1.2: Spillage Incidents in Gas* Heated Houses

NUMBER OF HOUSES

MAXIMUM DOT TEMPERATURE (°C) EXCEEDED ON AT LEAST ONE DETECTOR	HOUSES WITH DHW AND FURNACE DETECTORS	HOUSES WITH ONLY A FURNACE DETECTOR	HOUSES WITH ONLY A DHW DETECTOR	TOTAL	(%)
121	6	7	0	13	(2.2)
71	17	3	1	21	(3.5)
54	18	7	1	26	(4.3)
38 (cold side)	230	65	10	305	(50)
38 (hot side)	42	26	26	94	(15.5)
<38 (no black dots)	94	44	9	147	(24.3)
	407	152	47	606	(100)

* GAS includes natural gas and propane fuels.

TABLE 1.3: Spillage Incidents* in Oil-Heated Houses

MAXIMUM DOT TEMPERATURE (°C) EXCEEDED	NUMBER OF HOUSES	(%)
121	11	(5.1)
71	49	(22.6)
54	50	(23.0)
38	74	(34.0)
<38 (no black dots)	33	(15.2)
	217	(100)

* An unknown portion of these "spillage incidents" may involve malfunctioning barometric dampers, and NOT combustion gas spillage.

3. One storey houses.

   A strong trend is evident for increased spillages in one and one-and-a-half storey houses, in comparison with two and two-and-a-half storey houses.

4. Exterior chimney and masonry chimneys with metal liners.

   Figure 1.5 presents the distribution of survey and spillage houses with different types and locations of chimneys. There is a trend towards greater spillage problems with exterior chimneys and with masonry chimneys with improperly sized metal liners. Although lining a chimney should generally improve draft and reduce spillage potential, the effect of a new liner is to reduce the chimney's flow capacity. Thus the liner can contribute to spillage unless the the firing rates of the appliances served by the chimney are reduced to match the reduced flue size.

5. Houses with three or more exhaust fans.

   Not surprisingly, houses with the potential for high exhaust rates appear more likely to encounter spillage, presumably as a result of house depressurization when that exhaust capacity is used.

6. Houses with two open brick fireplaces.

   This may not be due to simultaneous operation of both fireplaces, but could indicate that fireplaces in such houses are more frequently used.

7. Appliances that had not been serviced within the last year.

   A higher proportion of spillage houses occurred amongst those houses where the last service call was more than one year previous.

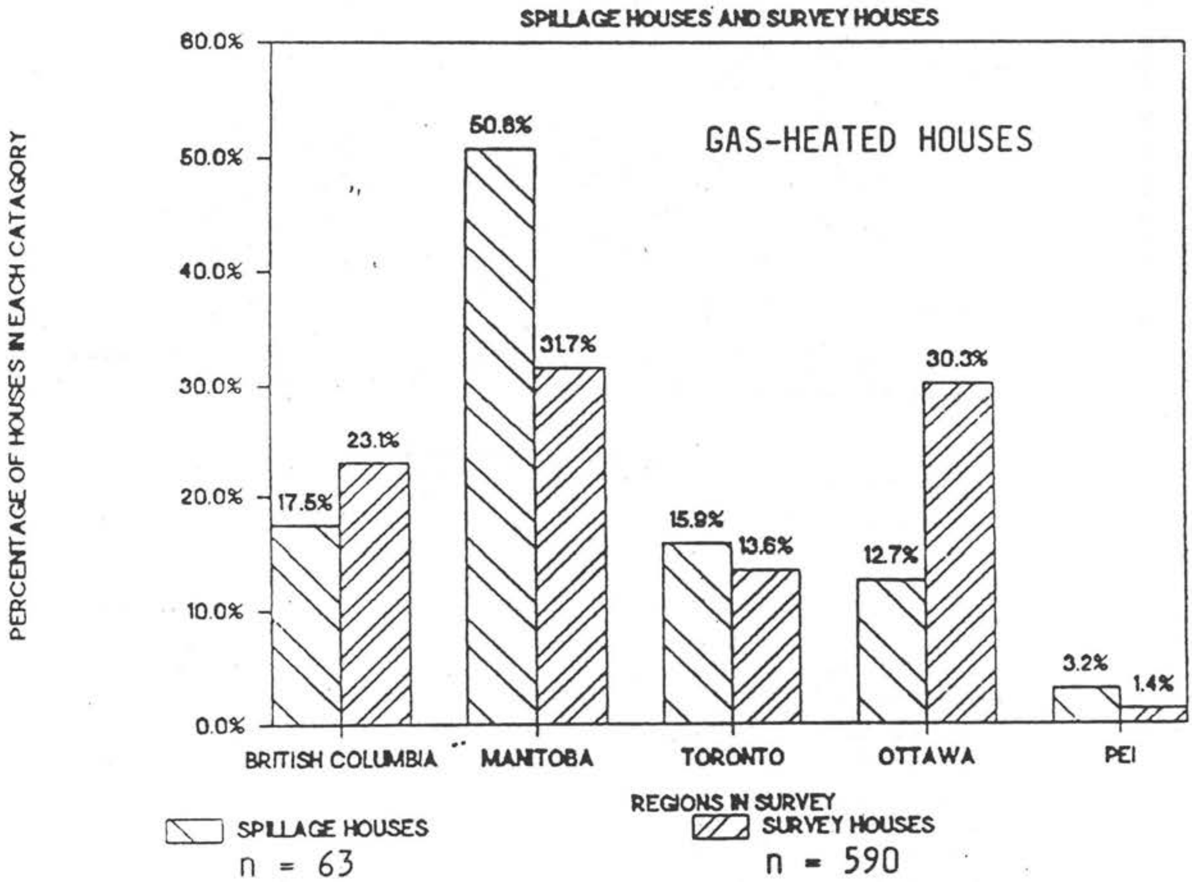
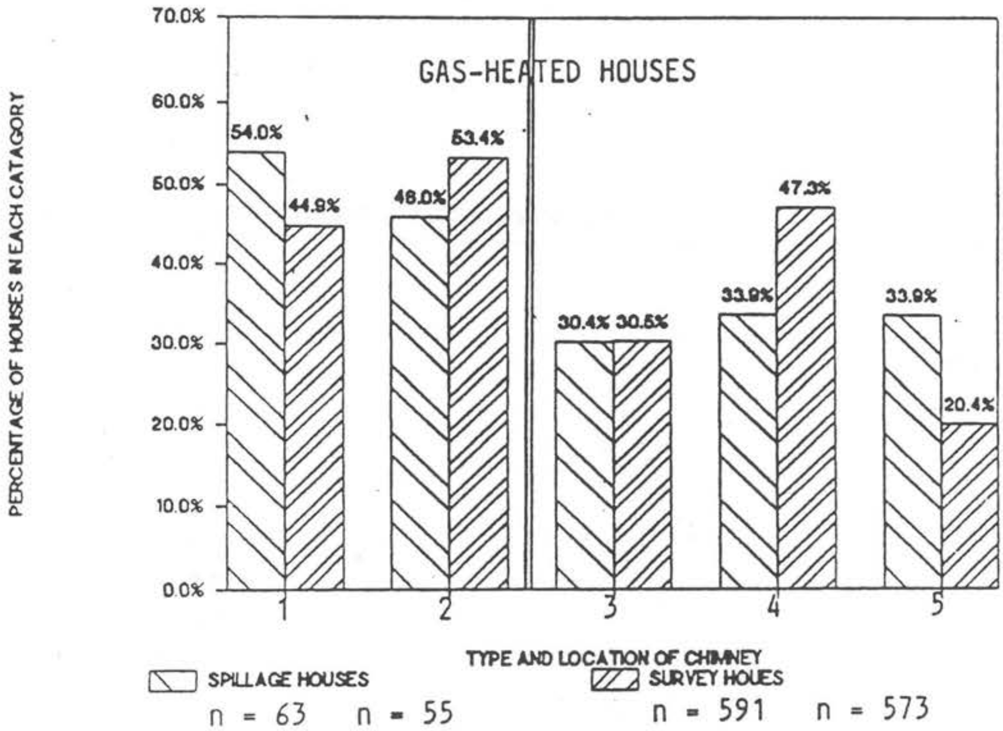


FIGURE 1.4: Distribution of Gas-heated Houses by Region



LOCATION OF CHIMNEY

1 Exterior chimney
2 Interior chimney

TYPE OF CHIMNEY

3 Masonry chimney
4 Metal chimney
5 Masonry chimney with metal liner

FIGURE 1.5: Distribution of House by Type and Location of Chimney

Characteristics of oil-heated houses which appeared to correlate with spillage were similar in all cases to the gas-heated houses, although the trends were less distinct. Only in the case of exterior chimneys and masonry chimneys was a strong trend apparent towards a higher incidence of spillage.

Fireplace Detector Results

Fireplace spillage was monitored in only 5 houses. The monitoring extended over a 4 week period. All five houses experienced some amount of fireplace spillage. Householders burned wood an average of 6.6 times over this period, and the CO and smoke detectors recorded between 2 and 17 spillage events in each house. These houses had long periods of spillage, (14 minutes and 3 minutes). The average was 1.25 spillage events per fire, for a duration of 30 seconds each.

In general, the fireplace survey was too brief and the sample too limited to provide a clear indication of typical fireplace spillage frequency. However, the results suggest that spillage may be a normal aspect of fireplace operation, even when householders are unaware of any problems. None of the occupants in these five survey houses had noticed any spillage, or any wood aroma from their fireplace.

PROJECT 2: MODIFICATIONS AND REFINEMENTS TO THE FLUE SIMULATOR MODEL

CHANGES TO THE MODEL

The FLUE SIMULATOR MODEL, as it stood at the outset of this project, was a first generation research tool that was developed to investigate problems in venting of the products of combustion from combustion appliances in houses. The primary focus of the model was not the performance of individual components of the system but the interactions between those components which lead to venting failures under circumstances that would not normally be considered hazardous. The first generation program (Reference 13) was able to meet its objectives, in spite of the many simplifications, assumptions and theory-based but not rigorously validated algorithms that were used in the model. However,there was a need to improve the model in several ways:

- to refine the accuracy of critical components (or modules) of the model
- to investigate more complex phenomena that appeared to have a critical role in determining venting performance
- to expand the capability of the model to encompass a wider variety of combustion devices and installations; and
- to make the model easier to use

Before undertaking further development of the model, it was necessary to have a detailed plan of action based on a thorough review of the model's capabilities and its possible areas of improvement.

The following were the objectives of the review process:

- to highlight the simplifications, assumptions, and hypothesis used in the model, as well as phenomena not modelled
- to suggest how these might lead to error and by what order of magnitude and in what circumstances

- to identify shortcomings in the present scope of the model (i.e. what other types of combustion systems should it be able to model?)

- to identify shortcomings in usability of the model (accessibility, ease in making inputs, clarity of outputs, completeness of documentation)

- to develop a comprehensive research plan that would address the identified shortcomings of the existing program

The FLUE SIMULATOR program was provided for review to the following individuals:

J.H. White/D. Fugler, CMHC
S. Moffatt, Sheltair
A.C.S. Hayden, Canadian Combustion Research Laboratory, EMR
D. Eyre, Saskatchewan Research Council
G.K. Yuill, G.K. Yuill & Associates
G. Mousseau, Domus Software Limited
J. Chandler, Concord Scientific

As well, the program was reviewed internally by Scanada, using results of field tests collected in two previous projects as a basis for evaluating the accuracy of the model.

Although not all of the reviewers' suggestions could be acted upon, the results of the review process, combined with the original work plan for the Project and ongoing suggestions from users of the program and the Project Advisory Committee, resulted in Scanada's developing a much expanded and much easier to use model. The changes can be categorized as follows:

- refinements to the algorithms
- more efficient operation of the program
- the ability to model additional features and system types
- more "user-friendly" input and output processing
- revision of the User's Manual

Refinements to Algorithms

Treatment of Flow Boundary Layer

Previously, the gas flow in the flue pipe and flue had been assumed to occupy the entire volume of the flue pipe or flue. This had resulted in low velocities for a given mass flow, which in turn required the introduction of artificially high friction factors in order for the model's predictions to match field data. These algorithms have been revised to take into account the effect of the displacement thickness of the boundary layer in reducing the effective diameter of the flow path. Friction factors have been reduced to textbook values and good agreement with field data is maintained.

Barometric Damper

In the original model, a very simple algorithm for the operation of an oil furnace barometric damper was used. It was assumed to be fully open when flow was from the room into the flue pipe and fully closed (except for a small leakage allowance) when flow was from the flue pipe into the room. The new algorithm is based on data published by a manufacturer of barometric dampers (Field Controls, Mendota Illinois). The area is not actually calculated but is represented by a friction factor which varies with the flue pipe/room pressure difference. The damper is still assumed to be fully closed (again except for leakage) when flow is from the flue pipe to the room; i.e. when the pressure in the flue pipe is higher than that in the room.

Bi-directional Flow

The model assumes that flow in the flue pipe and flue is either all positive (up the flue) or all negative (down the flue). Under subcontract to the Consortium, the Saskatchewan Research Council has developed a separate experimental bi-directional flow module. This module can be used to investigate the combinations of factors that might lead to bi-directional flow and the effect that this occurrence might have on flue flows. If such an investigation indicates that bi-directional flow is likely to be a significant phenomenon and that it helps to explain field data that do not otherwise coincide with FLUE SIMULATOR's predictions, then the module can be integrated into FLUE SIMULATOR. However, this investigation and possible integration are beyond the scope of the present project.

More Efficient Operation of the Program

Efficiency of Program Code

The program code was reviewed in detail by Gilles Mousseau of Domus Software Ltd., who has extensive experience in Microsoft BASIC programming. He was able to suggest a number of small improvements, such as declaring a number of variables as integers, which should improve the speed of execution. These have been implemented.

Reduction in the Number of Iterations

The program must solve a number of simultaneous equations of a number of different orders. It does so iteratively, which results in speed of execution being a continuing area of concern. Dr. Paul Mandel of the Mathematics Department of Carleton University was consulted to determine if a direct solution was possible. He was not able to suggest a direct solution but was able to suggest a better method of arriving at a first approximation with which to begin the iterative process. This has been implemented and has resulted in a modest improvement in speed of execution.

Modelling Additional Features and System Types

Effect of Wind On House Depressurization

The user is now able to specify a primary orientation of the envelope leaks relative to the wind:

- primarily on the leeward side of the house
- primarily on the windward side of the house
- primarily on the sides of the house parallel to the wind direction
- evenly distributed on all sides
- sheltered (i.e. no wind effect)

The model then calculates an increment in house pressurization/depressurization based on wind pressure coefficients published in the Supplement to the National Building Code of Canada, 1985.

Outdoor Air Intakes

The user can now specify the size and vertical location of air intakes (e.g. make-up air intakes) as well as the number of elbows in any duct connected to such air intakes. The model adjusts the envelope equivalent leakage area (ELA) and vertical centre of leakage of the building envelope accordingly.

Flue Pipe Characteristics

The original model assumed the flue pipe (vent connector) was a single walled, steel pipe with only two elbows and no insulation. The user was only able to specify the diameter, rise and run. Now it is possible to specify more elbows, the rise and length of the intervening portions and details of inner and outer liners and insulation.

Shared Flues

The model will now take into account the presence of a user-specified shared water heater flue of specified diameter and energy input. This energy input can be chosen to represent standby conditions (pilot light or jacket losses) or full firing conditions.

Flue Pipe Draft Inducers

The work on remedial measures in Project 5 indicated that draft inducing fans installed in the flue pipe can be quite effective in overcoming or avoiding combustion venting problems. If the user specifies that such a draft inducer is present, the model now picks one of several possible fan characteristics best suited to the flue pipe diameter and furnace output capacity and uses it to input increases in flue draft into the iterative draft/flow/mass calculations.

Potential for Condensation in the Flue

Now that the model allows for boundary layer effects, it is possible to have it calculate the temperature of the boundary layer for each vertical element of the flue and compare that temperature with the dew point of the flue gas (taken to be 54°C) to determine if there is potential for condensation to occur. The printed output indicates, for each time interval, the lowest element at which the boundary layer temperature is below the dew point. It also indicates, in the summary table, the percentage of furnace on-time during which at least one element had its boundary layer temperature below the dew point.

Thermostat Control of Furnace

In addition to having the furnace respond to user-specified on and off times, it is now possible to have it respond to the relationship between the indoor air temperature and user- specified thermostat settings. The indoor air temperature, in turn, responds to a house heat loss/gain calculation module according to information on the house heat loss characteristics input by the user. If a thermostat setting is input, thermostat control over-rides fixed on and off times.

Wood-burning Appliances

A separate version of the model has been developed to model combustion and combustion venting in wood-burning appliances. This model, called "WOODSIM", has been kept separate from FLUE SIMULATOR because it is not as advanced, in terms of validation, testing and refinement, as the main model. Preliminary simulations of wood burning in fireplaces and in stoves have demonstrated good agreement between the model's predictions and known phenomena, such as prolonged spillage from a fireplace at low burn and modest house depressurization, and the fireplace's ability, when it is at full burn, to depressurize the house.

"User-friendly" Input and Output

Pseudo-graphic Input Screens

Users of the original FLUE SIMULATOR model had complained that it was difficult to understand exactly what information was being requested by some of the prompts in the input module (FLUEIN) and had suggested the use of on-screen graphics to clarify these points. However, not all MS-DOS computers are equipped to handle BASIC graphics. A solution was found in the form of a program called "Screen Handler" by DOMUS Software of Ottawa. This program facilitates the development of pseudo-graphic screens, using the extended ASCII box and line drawing characters, which can be displayed by computers equipped for only text display. It also facilitates error trapping on input data and linking of input screens to context-sensitive "help" screens. The help screens not only assist in operation of the program but also provide technical guidance on the selection of appropriate input data. All of these features have been incorporated so that the FLUE SIMULATOR model now has a high degree of "user-friendliness" in its input module. Figure 2.1 shows a typical input screen.

The non-graphic version of the input module has also been retained since the user-friendliness is not critical once a user is familiar with the program and the graphic version can not be modified by users who do not have the Screen Handler program and training in its use.

Library of Material Properties

The input module now also includes a library of material properties, which is accessible from certain input screens, to assist in the selection appropriate input data.

Graphic Output

Users whose computers do have BASIC graphics capabilities now have the choice of the normal printed output or on-screen plotting of temperature-, flow- or pressure-versus-time graphs. It is expected that most users who can take advantage of this option will do so since it allow rapid assessment of the results of a simulation. Figure 2.2 shows a typical graph of temperature versus time for a heat-up/cool-down simulation.

The detailed numerical data is stored on disk during the graphic display so that detailed analysis can also be done.

Additional Default Files

A number of additional default furnace/flue/house system configurations have been added as default files on the program disk to provide users with more direct routes to configuring the systems that they want to model.

Revision of the User's Manual

The User's Manual has been extensively revised to accommodate the above changes and to clarify a number of points that users have suggested required clarification.

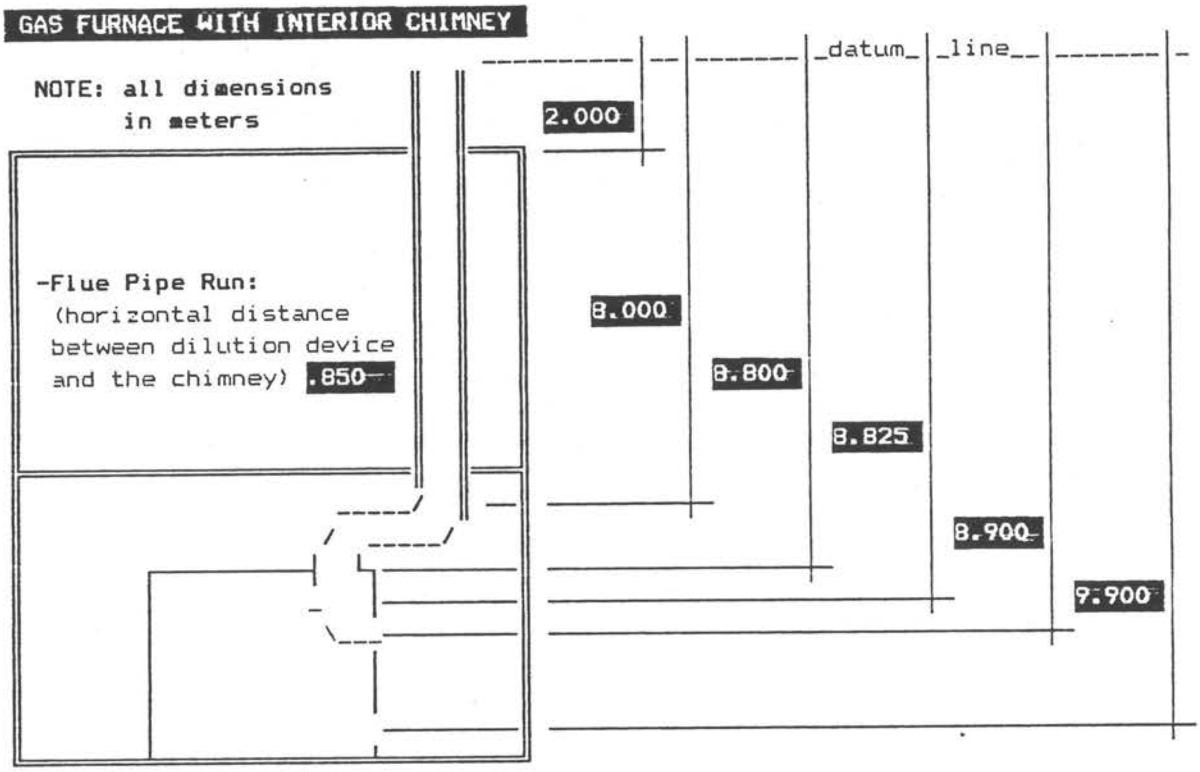


FIGURE 2.1: Example of a "Pseudo-graphic" Input Screen

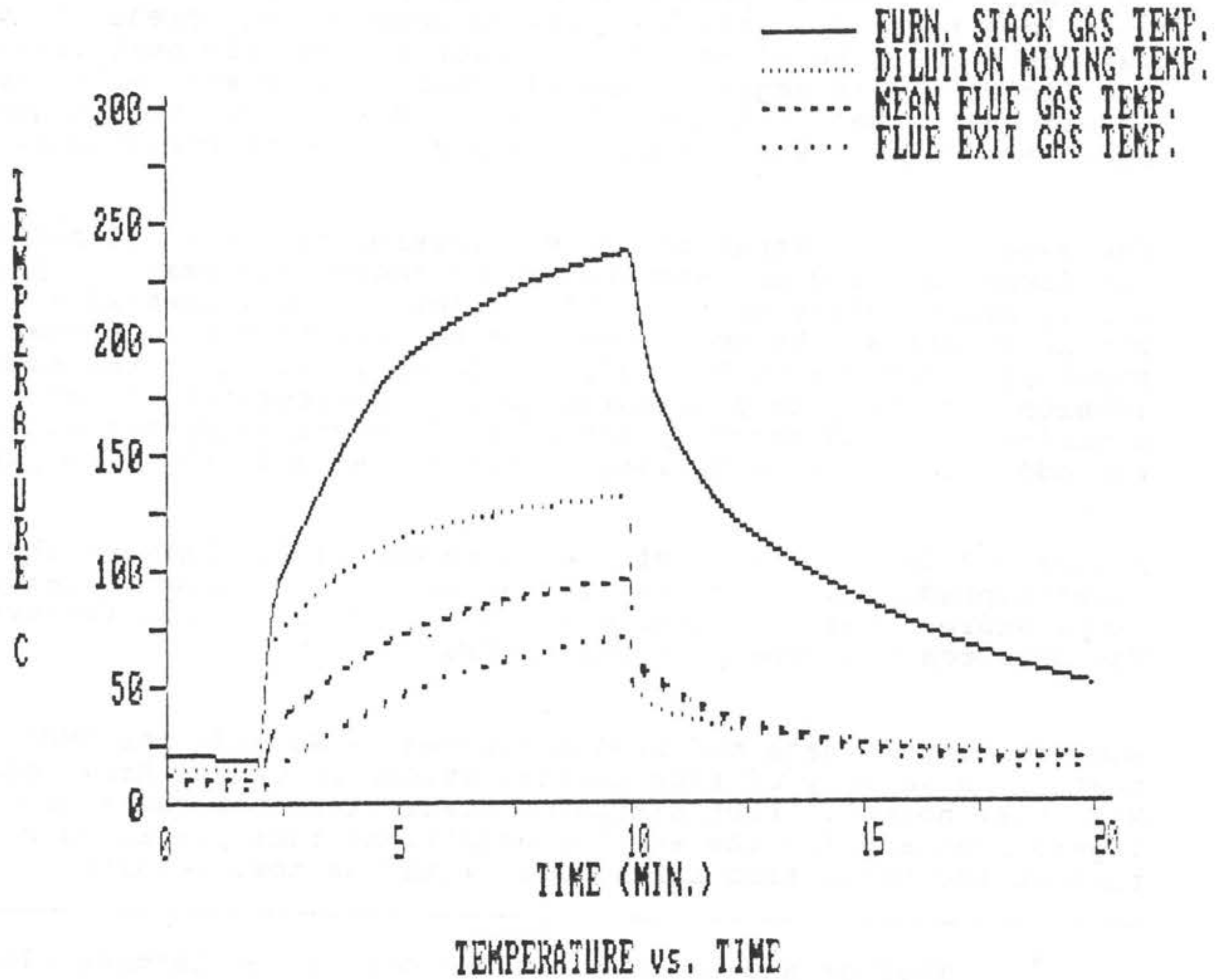


FIGURE 2.2: Example of a Graphic Output Screen

VALIDATION OF THE MODEL

The first version of the model was validated using test data provided by Esso Canada Limited and Consumers Gas Limited. It was found that, when the algorithms used normal text book values to describe physical phenomena such as flue friction factors and heat loss factors, agreement between measured and predicted data was not good. Therefore friction factors and film heat transfer coefficients were adjusted upwards considerably and, with these adjustments, the model was able to yield data that was in good agreement with measured data for a wide range of conditions.

The same data was input to the new version of the model and it was found that the adjustments are no longer necessary. In other words, based solely on first principles and published flow characteristics, the model seems to be able to simulate real physical phenomena rather well. This improvement in the model's inherent accuracy is attributed to the incorporation of an algorithm for the boundary layer/displacement thickness and to the added detail in modelling friction losses in the flue pipe.

Figure 2.3 is an example of the closeness of fit between the model's predictions and measured data. It is a plot of various temperatures over a heat-up/cool-down cycle of an oil furnace. The measured data was provided by Esso.

Additional test data had been collected by Scanada for CMHC in tests on a variety of flue configurations in CMHC's Armstrong Road test house*. FLUE SIMULATOR predictions for these configurations and for the weather conditions that prevailed at the time of the tests also agreed well with the test results.

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* Thermal and Aerodynamic Performance of Chimney Flues - Armstrong Field Testing Phase 1 and 2
Scanada Consultants Limited
July 1985

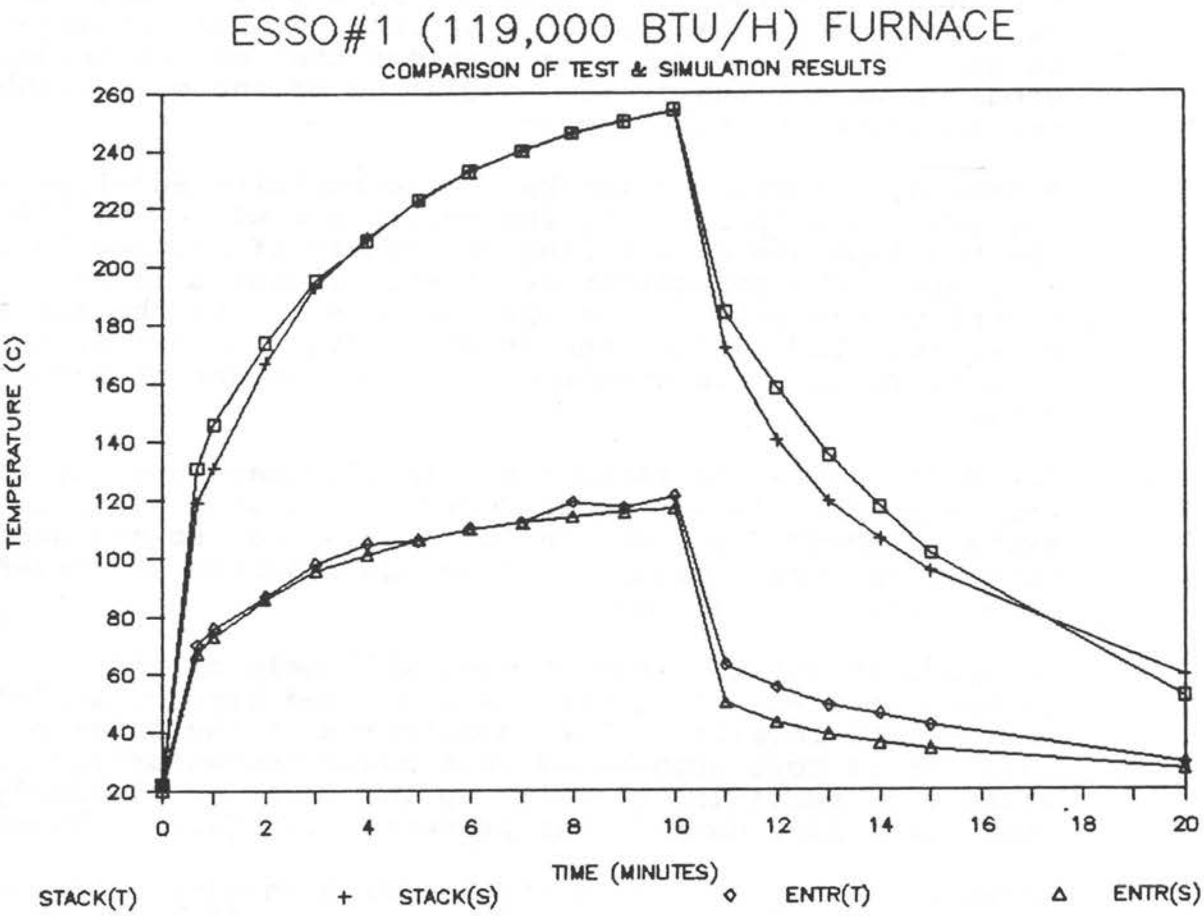

FIGURE 2.3: Comparison of FLUE SIMULATOR Simulation Result(s) with Test Results (T).

USE OF THE MODEL

A number of simulations were run to test the model's new features. These simulations produced some useful information:

- Mechanical in-line draft inducers should eliminate most or all spillage and backdrafting at start-up for the majority - if not all - house depressurizations that can be encountered. However, the standby operation of the pilot light is not protected by this device.

- Providing a fresh air intake in the building envelope will improve start-up draft by increasing the effective ELA of the envelope and by lowering the centre of leakage in the envelope. The effectiveness of this measures is proportional to the size of the opening relative to the ELA of the envelope. The smaller the envelope ELA, the larger the opening required to counteract a given amount of exhaust flow.

- The draft assisting chamber should eliminate most or all start-up spillage for house depressurizations up to the system's house depressurization limit. For severe depressurization cases, other measures are required to prevent or counteract backdrafting.

- Interior location of the chimney will help maintain a better minimum start-up draft after a prolonged standby period than an exterior location. The superiority of the interior location is most pronounced when house depressurization at standby is resisting air flow up the flue, or similarly if there is a flue damper that prevents flue flow at standby.

- Location of a flue inside the building envelope also contributes to preventing condensation from the flue gas on the flue liner. Although the B-vents studied showed a marginally greater potential for condensation when located outside, exterior masonry chimneys without metal liners showed substantially greater potential compared to the same chimney type placed inside.

- Unlined masonry chimneys are predicted to experience severe condensation in cold weather (-10°C), with exterior locations of such chimneys resulting in condensation over all of the top half of the chimney for the full cycle.

These simulations also revealed that the interrelations between the various elements of the venting system are indeed complex. For instance, under conditions that are favourable for proper venting - regular cycling of the furnace, moderate temperatures outdoors, draft inducing winds at the chimney top - the differences in performance of various types of venting systems lessen. Depending on the ambient conditions selected to investigate the effectiveness of one design over another, or one remedial measure over another, the conclusions drawn from those investigations may vary greatly. For example, under normal operating conditions, different types of chimneys and different chimney locations (inside vs outside) may not appear to make much difference. This was the conclusion taken after limited investigations with the first version of FLUE SIMULATOR and it resulted in some undeserved lack of credibility for the model (the fault was in the interpretation of the results rather than in their accuracy). More detailed investigation in this report has shown that, under circumstances that are less favourable to proper venting, the differences in performance of various configurations can be significantly different.

Thus, because of the vastly differing ranges of climate in Canada and because of the broad range of construction practice of Canadian homes, no single recommendation can be made that applies cost-effectively for all types of installation. The results and conclusions taken in this report should be used as general indicators of factors which can lead to venting problems in certain circumstances and what measures can be considered to resolve these problems. To take the next step, the FLUE SIMULATOR Model has been refined and made user-friendly to assist in evaluations of individual installations and of potential remedial measures.

PROJECT 3: REFINEMENT OF THE CHECKLISTS

Over two years prior to the commencement of this project, CMHC set out to develop a test for householders to use in detecting and diagnosing potential backdrafting problems (References 4, 5, 6, 9, 10). The backdraft test was seen as one means of addressing an unacceptably high incidence of carbon monoxide poisoning from chimney failures in housing as well as a means of counteracting a possible trend towards imbalanced ventilation in housing.

In the process of field testing the backdraft test, a great deal was discovered about combustion venting safety in housing. It is now recognized that backdrafting is a dynamic event, strongly influenced by house operation and weather variables. Cold, off-cycle backdrafting is understood to be one precursor to spillage problems and hot, operating backdrafts are seen to be only one of a number of possible failure mechanisms which result in significant spillage of combustion gases.

Backdrafting may be a common occurrence which may be only rarely associated with high levels of carbon monoxide but which may be responsible for intermittent or chronic air quality problems of less drastic nature in many houses. Backdrafting mechanisms can be complex, with short term flow reversal becoming stable in cold weather, or with one type of vent failure leading to another, and a relatively benign problem leading to the progressive degeneration of the venting system.

Trade persons were found to be largely uninformed about the potential for systems failures in housing, and a need was identified for a comprehensive safety checklist for use not only by householders, but by all contractors and inspectors involved with airtightness, ventilation and combustion venting in houses.

In short, the process of developing a simple backdraft field test procedure had evolved into a multifaceted endeavour with potential for influencing many aspects of the housing industry. Field trials of the checklist had raised numerous technical and policy issues which could only be resolved through further research and development.

Previous research on the checklists was hampered by tight deadlines, lack of a comprehensive theoretical model of failure mechanisms and an emphasis on application as opposed to development. The intent of this project was to refocus on the issue of checklist design and to thoroughly investigate those design issues which are likely to influence the quality and practicality of the checklists. The object was to collect data on the range of variations that occur in typical housing and to determine the sensitivity of checklist results to simplifications in the test procedures.

More specifically, the refinement of the checklists was to address three areas of concern:

1. Necessity: Is the checklist an appropriate tool for recognizing or avoiding venting failures?

2. Suitability: Is the checklist customized as much as possible to meet the needs of each major user group, in terms of time, skill, responsibility, tools, costs and understanding?

3. Validity: Is the checklist capable of identifying existing and potential problems in most houses? ... but only real problems?

After lengthy discussion, a decision was made to develop separate tests/procedures for **identifying** and **diagnosing** combustion venting problems. It was felt that testing houses using complicated procedures and specialized equipment was inappropriate unless there was a high potential for, or a history of, venting problems. A better approach for identifying venting problems (in typical houses) was to conduct an assessment of the potential for problems - by **inspection** only - and conduct tests only if problems were likely. Alternatively, warning devices could be installed in houses as a "first-line" defense, and diagnostic tests conducted only when problems were known to exist.

The separation of identification and diagnosis meant that the diagnostic tests could become more refined; i.e. incorporating more detailed procedures for assessing the extent of spillage and the specific cause. It also seemed that a comprehensive **series** of "chimney safety tests" would be required to cope with all possible venting failures. And the testing procedures would need to be complimented by advice on appropriate remedial measures, in the form of a Guide or Manual that could be used on-site by users of the tests. The development of chimney safety tests was undertaken as an alternative to promoting a simple checklist for widespread application.

For a majority of houses, emphasis would be placed on the use of inspections and/or warning devices, instead of a checklist procedure. The initial research into development and testing of spillage detector devices had indicated strong potential for use of warning devices in houses - much of which has been confirmed through the Project 5 research on Remedial Measures.

Thus the original backdraft checklist has grown into the five following 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 were developed to assist tradesmen in diagnosing venting failures and all are presented in a manual entitled "Chimney-Safety Tests".

Because of continuous revisions to the test procedures during the course of this research project, not all of these test have had thorough field trials nor have all been thoroughly documented. In particular, the Venting System Pre-test has been altered significantly as part of the preparation of this final report and thus needs further evaluation. Also the Chimney Performance Test requires further refinement and the Chimney Safety Inspection documentation requires additional text to describe how to recognize the different types of maintenance required.

The research that took place to refine and evaluate these tests and to resolve critical design features is reviewed next.

REFINING THE CHIMNEY SAFETY TESTS

A variety of field research studies and experiments were conducted during the refinement of the Chimney Safety Tests to resolve design issues and evaluate the accuracy and user acceptability of the test procedures. The most critical issues are described below:

Determining House Depressurization Limits**

As has been indicated in previous work by members of the Consortium, improper venting of combustion gases from an appliance occurs when the house depressurization exceeds the sum of driving pressures on the flue gas. Therefore, the task of determining whether a combustion appliance will experience pressure-induced spillage hinges on whether the sum of driving pressures on the flue gas is greater than attainable house depressurizations over all, or at least a very large portion of its operating time.

While it is still too early to be definite about how often (if at all) a house should be allowed to be depressurized in excess of the driving pressures in the chimney, it was possible during this project to refine and clarify assumptions about the minimum driving pressures in the chimney, and to develop an improved table of "House Depressurization Limits". Factors which influence the total driving pressure have been modelled using FLUE SIMULATOR, and are briefly described below.

<u>Wind</u>

Wind across the chimney top can add from 0.6 to 9.8 Pascals of driving pressure as wind speeds increase from 5 km/h to 20 km/h. Average wind speeds for Canadian cities exceed 5

** The Maximum Allowable Depressurization (MAD) Limits developed for the Combustion Safety Check (1985) have been renamed and re-evaluated as part of the on-going refinement to test procedures. The term MAD Limit has been replaced in favour of House Depressurization Limit (HDL) in the interest of clarity.

km/h 75 to 95% of the time and can reasonably be counted on to provide at least 1 Pascal of driving pressure to assist flue flow.

Balance Temperatures

An assumption is made that a house becomes "opened-up" to the outdoors, (or the furnace is no longer operating), once the indoor/outdoor temperature difference is less than 10°C, and thus the flue draft can count on a ΔT of at least 10°C.

Typical Stand-by Driving Pressures for Flues and Furnaces

After prolonged stand-by, minimum driving pressures in an interior B-vent drop to about 3 Pascals, or slightly more (4 Pa) for boilers and DHW heater (due to the heat retained in the water). An additional one storey of height can contribute another 1 Pa of draft, except for uninsulated exterior masonry chimneys.

Buoyancy Contribution by the Appliance

Exterior masonry chimneys may cool down and lose further buoyancy, experiencing driving pressure in the 1 to 2 Pascal range. However, on start-up, the appliance is capable of developing 2 or 3 Pascals of driving pressure due to the heat it generates. The amount of this buoyancy transferred to the flue pipe depends on how much is lost out the dilution port and to friction. This "recoverable" portion of this buoyancy thus may compensate for stand-by driving pressures in the flue lower than 3 Pascals. DHW heaters may develop greater buoyancy pressure than most other appliances due to their height. This would help to compensate for the lower indoor/outdoor temperature differences they must cope with during warm weather operation.

Specifying House Depressurization Limits

Based on the above assumptions, it is safe to assume a minimum driving pressure of 3 Pascals for all flues. In addition, an allowance of an additional 1 Pascal can be made for wind, another 1 Pascal for additional chimney height, another 1 Pascal for heavy furnaces or boilers, and another 1 Pascal for the additional input from a second appliance sharing the same flue.

Table 3.1 present the HDL's based on the above assumptions for use with the Venting Systems Test. The values are similar to the earlier Maximum Allowable Depressurization (MAD) limits (which were based mostly on empirical data) and should be adequate safety limits.

Predicting House Depressurization During the Venting Systems Pre-Test

The Venting System Pre-test is useful only to the extent that it can safely and quickly eliminate a large number of houses from a requirement for more costly or complex testing. It was felt important to use House Depressurization Limits as part of the Pre-test, since the HDL's automatically adjust the stringency of the test to the strength of the chimney systems. However, the use of HDL's, meant that the focus of the Pre-test inspection was to predict worst case depressurization.

House depressurization is primarily determined by the exhaust capacity, the intentional make-up air supply openings, the unintentional envelope leakage area (ELA), and the flow exponent for the envelope leakage. A procedure was developed to predict house depressurization - based on conservative assumptions about these variables - and then tested on 20 Case Study houses. The envelope leakage area proved to be the only variable that could not be predicted with confidence. The ELA estimation process, which is based on assumed values for normalized leakage areas per square metre of floor area which vary with climate and age of house, predicted leakage areas which were often a long way from reality*. (More details are provided in the Project 6 technical report.)

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* Scanada, in a concurrent separate project for Energy Mines and Resources, Canada, has developed an ELA estimation method based on construction type rather than age. It seems to yield more reliable results and can probably be adapted for use with the venting systems test. The EMR project is titled -

- Avoiding Moisture Problems When Retrofitting Canadian Houses to Conserve Energy

Table 3.1: House Depressurization Limits (HDL's)

Appliance	House Depressurization Limit (Pa)		
	Chimney Height to closest meter	Unlined Chimneys on exterior walls	Metal-lined, Insulated or Interior Chimneys
Gas-Fired Furnace or Boiler or Water Heater	4 or less	5	5
	5, 6,	5	6
	7 or more		7
Oil-Fired Furnace or Water Heater	4 or less	4	4
	5, 6	4	5
	7 or more	4	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

For the present, an alternative procedure has been adopted. This is to forego predicting ELA values, and simply adopt one standard ELA for existing (non-energy-efficient) Canadian houses, that would be less than 95% of the published data for typical houses of all ages and regions. In addition to this minimum ELA, a house is assumed to benefit from any installed make-up air ducts. Since the sizes of the make-up air ducts are known, it is possible to add the"installed ELA" to the assumed minimum ELA to arrive at a total ELA value. This approach results in a simple table for the Pre-test, that specifies allowable exhaust capacities for houses with different ELA values and different types of chimney systems. For example, a house with a gas furnace with a 6 m high B-vent is predicted to be safe if it has no more than 50 L/s in unbalanced exhaust flow. If the exhaust capacity exceeds 50 L/s, the very conservative prediction of house depressurization exceeds the HDL and a test of the house or perhaps installation of some warning device is warranted.

Further Refinements of the Venting Systems Test

A variety of alternative procedures were explored, with a view to clarifying or simplifying the test.

Is furnace blower operation required?

Measurements on a test house into the affect of furnace blower operation with different configurations of interior doorways closed, demonstrated that significant pressure differences could be created between rooms or zones in a house, especially the basement area. These finding were confirmed during the Case Study investigations (Project 6) and it was concluded that door closing and blower operations must be included in the test.

Blower door procedures

An attempt was made to customize the test for application by blower door operators. For example, operating the exhaust devices while maintaining a constant house depressurization, offers the potential for greater instrument accuracy and minimal wind interference. However, due to the variations in flow exponents for different house envelopes, pressure differences in houses are not additive, and it becomes difficult to extrapolate these results to ambient pressure conditions. (These difficulties are discussed further in the detailed technical report on this sub-project.) The only value derived from using a blower door is the ability to accurately predict house depressurization for different exhaust capacities - a relatively minor benefit.

Is fireplace testing required?

Continuous difficulties were encountered when including fireplaces in the Venting Systems Test. For example, the low HDL's for fireplaces caused many of the Case Study houses to fail the test. The operation of fireplaces (using a propane burner as a wood fire simulator) is complicated and time consuming especially for occasional users of the test, and is problematic as the fire often spills due to fan operation. Fireplaces may often cause the house to exceed the HDL for the furnace. Moreover, remedial measures for fireplaces are not commercially available. These are all good arguments for not including fireplaces in a standard test for pressure induced spillage potential. However, since fireplaces appear to be implicated in many of the venting failures revealed during this research project, the current version of the test still includes the fireplace option.

How much spillage is acceptable?

The test includes a check for excessive combustion gas spillage during house depressurization as a means of identifying spillage from unusually weak chimneys - easily influenced by house depressurization - or from chimneys with blockages or other venting problems. Since most chimneys spill for some length of time at start-up, it was necessary to establish an acceptable duration for spillage. FLUE SIMULATOR modelling of appliances with varying dilution-air-area/flue-area ratios indicated that backdrafting in excess of 15 seconds duration is likely to continue indefinitely. Partial spillage, on the other hand, may disappear after minutes of operation, as the flue warms. A 30 second spillage event, or a period roughly equivalent to 10% of a typical appliance operating cycle, was arbitrarily deemed to be a maximum acceptable duration.

The following pages present somewhat more detailed descriptions of the tests/procedures that resulted from this research. Full details are provided in the technical report on this sub-project.

SUMMARY OF THE CHIMNEY SAFETY TESTS

The manual presents five test procedures. These procedures break into the following two groups:

1. <u>Venting systems tests</u> These tests can be competently administered by any member of the building service trades and do not require special expertise in heating systems. The tests are designed to detect the susceptibility of the chimney system to combustion gas spillage events caused by the combined operation of fans, fireplaces and any other venting system which exhausts air from the house.

2. <u>Furnace/flue tests</u> These tests are designed to be conducted exclusively by members of the heating trades. They are intended to permit detection of combustion gas spillage problems which could be caused by (a) a leaky heat exchanger, (b) weak chimney draft due to leaks or constrictions within the flue, or (c) various maintenance problems which can be determined by careful inspection of the chimney, flue, flue connector, furnace system and furnace room.

Each of the five tests is described in detail in the manual which provides step-by-step instructions on how to perform each test. The manual also provides special checklists and report forms to facilitate the delivery of each test.

VENTING SYSTEMS TEST

The venting systems test is a detailed test procedure designed to ensure that the operation of household venting systems does not adversely affect chimney operation. The procedure can be used to test (a) the impact of fan and fireplace operation on the chimney serving the furnace and hot water appliances and (b) the impact of fan and furnace operation on the chimney serving a fireplace. In both cases, a manometer is used to determine if the maximum depressurization which can be produced by the combined operation of all venting systems, exclusive of the test chimney itself, exceeds the maximum safe level prescribed for chimneys similar to the test chimney. This maximum safe level is referred to as the House Depressurization Limit. The checklist designed for use with the Venting Systems Test to ensure safe and thorough procedures are followed is shown on the following pages.

In addition, both the furnace and fireplace are operated with the house at the maximum level of depressurization attainable with the exhaust equipment installed in the house to determine if excessive combustion gas spillage can be observed. The test requires 40-80 minutes to complete and requires no special expertise in heating systems. Tools required for the test cost approximately $170.

VENTING SYSTEMS TEST CHECKLIST

1. Preparation

Complete test identification on report form
Record outdoor temperature and wind
Switch off fans
Switch off furnace
Switch off water heater (if operating)
Install fireplace emulator
Close-up fireplace
Close windows and exterior doors and hatches
Close interior doorways to passive rooms and basement rooms
Set-up pressure gauge
Extend pressure tap to exterior
Zero gauge
Record pressure fluctuations
Install pressure averaging system, if required

2. Test

Operate blower and record pressure
Open basement and furnace room doors
Operate two-way fans and record pressure
Operate exhaust fans and record pressure

_______ *dryer*	_______ *bath 1*	_______ *bath 2*
_______ *bath 3*	_______ *kitchen range*	
_______ *barbecue*	_______ *vacuum*	_______ *other*

Open fireplace doors, damper and air supply
Open window (or door) to outdoors
Light fireplace emulator
Check for spillage and record
Close window (or door) and record pressure

Repeat for second fireplace
Check furnace for backdrafting and open window if present
Adjust house thermostat to high and begin timing
If window was previously opened to avoid furnace backdrafting, close it
Check spillage along flue pipe
Record the duration of start-up spillage
If spillage exceeds 30 seconds, open a window, let furnace cool, and check again.
Run a hot water tap to operate water heater
Time spillage from water heater
Check spillage along flue pipe
Record duration and quality of spillage (furnace and water heater)
Shut off fireplace emulators and close fireplace doors
Record pressure

3. Clean-Up

Reset house thermostat
Turn off the hot water tap
Switch off exhaust fans
Open doors and windows (as found)
Switch off furnace blower
Reset two-way fan controls (e.g., Heat Recovery Ventilator)
Pack up gauge and tubing
Pack up fireplace emulators

THE VENTING SYSTEMS PRE-TEST

Many houses may not require a venting systems test because they are configured in such a manner that there is no possibility that venting systems operation will adversely affect chimney performance. The venting systems pre-test provides a simple technique by which such "venting-safe" houses can be accurately identified on the basis of information obtained during a brief inspection. The venting systems pre-test involves a visual inspection of the house and the use of reference tables. A very conservative (i.e. low) assumption is made about the leakage area of the house, and the exhaust capacity is estimated using default values for different types of exhaust devices. It then becomes possible to predict the house depressurization under worst case conditions, and compare this value to the House Depressurization Limit. The assessment takes about 10-15 minutes. It can be safely assumed that houses which pass this assessment need not be subjected to the more rigorous and time-consuming venting systems test.

CHIMNEY PERFORMANCE TEST

This test provides a simple way to determine if the flue serving an oil- or gas-fired appliance is capable of providing adequate draft. The test involves using a thermometer to measure flue gas temperature and a manometer to measure the draft in the flue after the furnace has had time to warm-up. Gas temperatures outside a prescribed range (150^{0}C to 400^{0}C) may indicate potential for fire safety or condensation problems. If the temperature is within the prescribed range but the measured draft is too low (i.e. less than 6 Pascals), a problem with leaks or constrictions in the chimney flue is indicated.

Chimneys with low draft should be diagnosed and repaired immediately since they are particularly susceptible to pressure-induced spillage. An effort should be made to determine if the flue is blocked or broken or performing poorly due to poor design or construction.

The chimney performance test requires about 10 minutes to complete. A manometer is required.

THE HEAT EXCHANGER LEAKAGE TEST

The heat exchanger test provides a quick and accurate method of determining if the heat exchanger in an oil or gas forced air furnace has a major leak. Major leaks are those which are capable of permitting excessive combustion gas spillage from the combustion chamber into the living space.

Combustion gas spillage from heat exchangers in forced air furnaces can occur in two ways. First, before the furnace blower starts to operate, combustion gases may leak from the combustion chamber into the forced air plenum since the chamber is pressurized with respect to the plenum. When the blower turns on, the leaked gases are blown throughout the house. Occupants may notice this leakage as a sudden blast of smelly or dirty air when the blower turns on.

The second form of heat exchanger leakage occurs when the blower fan starts to operate. If leaks are present in the heat exchanger, the fan may force house air through the leaks into the heat exchanger. This stream of air may cause the combustion flame to be distorted and cooled, leading to sooting and carbon monoxide production.

If the leak is very large, larger amounts of air can enter the combustion chamber which pressurizes the chamber. This leads to further problems such as rumbling and back-puffing in an oil furnace or continuous spillage through the dilution air inlet of a gas furnace.

The heat exchanger leakage test can detect furnaces which may be experiencing these kinds of problems. Furthermore, since spillage caused by a leaky heat exchanger is very similar to spillage caused by house depressurization, poor chimney draft, or a flue blockage, the test is a useful diagnostic method for positively identifying or eliminating one of these possible causes.

The test can be performed on gas or oil-fired furnaces. The exit port(s) of the heat exchanger is temporarily blocked, and the circulating blower is switched on. A smoke pencil and flashlight are used to detect air movement out of the heat exchanger at the combustion air intake (gas) or inspection port (oil). Definite air flow indicates an excessively leaky heat exchanger.

The heat exchanger leakage test can be completed in about 15 minutes. A smoke pencil and flashlight are required.

THE CHIMNEY SAFETY INSPECTION

The chimney safety inspection is a visual check for maintenance problems in the chimney system. A thorough inspection is often the quickest way to identify the source of chimney venting problems or the potential for chimney problems. In addition, the inspection can be helpful in deciding what other chimney venting tests may be required, if evidence of spillage has been detected during the inspection.

A Chimney Safety Inspection Checklist (SIC List) is used to guide the inspection and to pinpoint possible repairs or improvements which may be required to improve the performance and safety of the chimney system. The SIC List sets out possible maintenance actions which should be considered for each part of the venting system, including the chimney, liner, flue connector, furnace, and furnace room. The water heater venting system and the fireplace chimney are also inspected if applicable.

No special certificates or licenses are required to perform the inspection. However, it should be performed by individuals with a working knowledge of heating systems and an awareness of the applicable codes or regulations.

The chimney safety inspection can be completed in about 20 minutes. No special equipment is required.

PROJECT 4: HAZARD ASSESSMENT

The health and safety hazards associated with combustion venting failures in houses in Canada have never been well documented or investigated. This project offered an opportunity to make a significant contribution to knowledge in this area.

The CMHC report on Hazardous Heating and Ventilating Conditions in Housing, prepared by Hatch Associates Ltd. in 1983, (Reference 3) identified numerous variations and combinations of venting failures associated with carbon monoxide poisoning incidents. The vague and often contradictory field reports on these incidents, on which the Hatch report was necessarily based, provided little insight into the principle causes and little guidance on how to prevent such serious accidents. Hatch Associates discovered great differences across the country in technical resources, reporting procedures and records keeping, and in general understanding of the combustion venting process and the hazards associated with it. For these reasons it may never be recognized how much serious health and safety damage has been caused by venting failures. Documented cases may represent only the "tip of the iceberg".

The difficulty in making an accurate risk assessment is compounded by the variety and unpredictability of combustion pollutant generation rates and a lack of knowledge on the health hazard from long term, low level exposures to these pollutants. Combustion pollutants in housing may include nitrogen oxides, carbon dioxide, aldehydes, particulates, sulphur dioxide, hydrocarbons and sizable quantities of water vapour. All of these substances can affect the health and comfort of occupants. However, unless carbon monoxide is present in significant quantities, the effects on health will not normally be recorded. Hatch Associates determined that virtually all reported health incidents related to vent failures have featured carbon monoxide only. Both acute and chronic health impairment can be misdiagnosed since the symptoms are non-specific.

A need existed to investigate the real nature of the health and safety risk associated with venting failures. The results of such an investigation combined with the results of the Canada-Wide Survey (Project 1) and the Problem House Follow-up (Project 6) would assist in making intelligent decisions about the need for detection and diagnostic procedures, the most appropriate type of communications strategy, and the cost-benefit relationship of remedial measures.

There was a special need to develop improved understanding of the effect of system failures, such as gas furnace backdrafting caused by downwinds or house depressurization, transient furnace spillage at start-up, and backdrafting of smoldering fireplaces. The severity of such failures is closely related to the configuration, operation and occupancy of the house - factors which affect concentrations of pollutants, exposure times and sensitivities. Although it was not possible to address all of these issues in the context of this project, it was hoped that it would be possible to determine the relative severity of different types of failures and to recognize the key variables influencing health and safety hazards that fall within the scope of the safety checklists.

In short, this sub-project was intended to achieve two primary objectives:

- to provide a context for evaluating the severity of system venting failures in Canadian housing, and

- to provide a vehicle for expressing the results of the project directly in terms of health risk.

The work was divided into five tasks -

1. Review of current knowledge on pollutant generation due to improper venting of combustion appliances.

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 housing.

Each of these tasks is described below.

REVIEW OF CURRENT KNOWLEDGE

An initial review of the literature was conducted by Occupational Environment Evaluation Controls Consultants Inc. (OEEC).

The literature review had two primary objectives: to establish typical emission (or generation) rates of specific combustion pollutants for typical vented heating appliances in houses; and to establish the effect of maintenance or tuning for inadequate combustion air or poor chimney draft on the emission rate.

The literature review accessed the following information sources:

- original journal articles
- recent air pollution texts
- Canadian Institute for Scientific and Technical Information, National Research Council of Canada
- Institute for Research in Construction Library, National Research Council of Canada
- 1985 LBL Indoor Air Pollution Data Base, Lawrence Berkeley Laboratory

In total, 27 separate items were reviewed. In addition, discussions were held with resource persons at Health and Welfare, Canada.

To avoid overstepping time and budget allocations, the initial literature review was confined to the 1983-1986 time-frame. In retrospect this was a poor decision, since much of the more recent research on pollutant emission rates from combustion appliances has focused exclusively on unvented space heaters, and airtight wood stoves. The operation of these appliances does not fall within the scope of the present research and it is difficult to generalize from research work on these appliances, since their design is so unlike typical furnaces and fireplaces. Nevertheless, the extensive research work on space heaters in houses has helped to clarify the general types and concentrations of pollutants that can be expected during venting failures.

The literature review indicated a trend in current combustion appliance studies towards characterizing the effect of different factors on pollutant emission rates. These factors include:

1. type of appliance
2. manufacturer
3. unit age
4. tuning (fuel-gas mixture optimization)
5. building specific factors, such as occupant use patterns

The focus on unvented space heaters, however, means little research is now being conducted on the pollution emissions associated with vented gas water heaters, furnaces, gas clothes dryers, and oil-fired space heaters and furnaces.

The literature suggests that combustion-derived indoor air pollutants released in homes during chimney failure scenarios will include: carbon monoxide, carbon dioxide, sulphur dioxide, nitrogen oxide, aliphatic, aromatic and polycyclic hydrocarbons, aldehydes, and particulates. Of these, the pollutants of main concern for the health of occupants would include carbon monoxide, sulphur dioxide, nitrogen oxide, aldehydes, and certain hydrocarbons.

A further literature review with a longer time frame was undertaken by Sheltair to obtain statistics on likely emission rates for wood-, gas-, oil-, and propane-fired vented appliances. Special attention was given to studies conducted by utilities and the Canadian Combustion Research Laboratory. On the basis of this more extensive literature review, tables were prepared listing typical pollutant generation rates for different appliances, tuned and untuned. A range of flue gas emission rates found in the literature has been presented in Table 4.1. Considerable difficulty was encountered in cross referencing statistics from different research reports, because of different units and measuring techniques. Of special interest were worst case emission rates for particular appliances, sometimes simulated during research studies by means of reducing the venturi intake of primary air shutters. These worst case emission rates are needed to predict the highest concentrations of pollutants that are likely to be encountered indoors as a result of venting failures. The literature review also provided generalized insights into how pollutant emission rates might vary with the operation of an appliance. These are briefly summarized below:

1. A yellow flame on a gas appliance generally increases carbon monoxide and nitrogen dioxide concentrations, while reducing the total NO_x concentration. An exception to this rule would be new appliances designed to burn with a yellow-tipped flame.

2. Inadequate air supply to the burner of a gas-fired appliance will sometimes reduce the nitrogen dioxide emissions but will greatly increase carbon monoxide emission.

3. Excess air supply to the burner of a gas-fired appliance usually has little effect on emission rates of CO or NO_2.

4. The temperature of the heat exchanger on a gas-fired furnace is unlikely to affect emission rates significantly.

5. Low burn rates in a wood stove or fireplace are likely to be accompanied by increases in the production of carbon monoxide, hydrocarbons, and polycyclic organic materials (POM's).

6. Emissions from oil burners during the 10 to 30 second start-up period (when spillage is most frequent) may contain increased particle and CO concentrations and may need to be analyzed separately from the post start-up emissions.

7. Gas furnace CO emission rates in the first several minutes following start-up are up to ten times the steady state rates. This dynamic variation in emission rate makes modelling more difficult.

TABLE 4.1: **Flue Gas Emission Rates** (Extracted from Various Field Research Reports - see detailed technical report on Project 4)

POLLUTANT	GAS FURNACE Tuned Avg.	Std. Dev.	Untuned Avg.	Std. Dev.	OIL FURNACE Tuned Avg.	FIREPLACE High Burn Avg.
CO	2.6	± 0.8	66.8	± 1.2	30	10×10^3
NO_2 ($K = 0.82\ hr^{-1}$)	2.36	± 1.2	4.86	± 1.94	100	150
$CO_2 (x10^3)$	38.4	± 6.6	39.7	± 6.6	66	
HCHO	0.062	± 0.048	0.217	± 0.141		
SO_2	**	**	**	**	220	120
HYDROCARBONS	*	*	*	*	3	2000
PARTICULATES	*	*	*	*	30	1000
POM	**	**	**	**	0.003	20

Notes: 1. Untuned refers to yellow flame conditions on a conventional gas furnace, caused by closing primary air intakes.

2. K for NO_2 refers to an average decay rate for use in the Air Quality.

3. Emissions are calculated on basis of rated appliance input (kJ) and the mass (ug) of pollutant in flue gases prior to mixing with dilution air.

* No reliable data available.

** Insignificant.

A COMPUTER MODEL FOR PREDICTING INDOOR POLLUTANT CONCENTRATIONS

It was initially planned to combine two dynamic interactive computer modeling programs to provide a model of house performance that would predict both combustion venting failures and indoor pollutant concentrations. The FLUE SIMULATOR computer model was to be revised to incorporate the INFIL program developed by Yuill and Associates Ltd. for Energy Mines and Resources Canada. INFIL was developed to predict concentrations of pollutants in houses on the basis of pollutant generation rates, weather variables, and house air leakage parameters. Unfortunately, a lack of compatibility between program language and inputs prevented the adaption of INFIL for this project. As a next-best alternative, a less dynamic model was developed by Sheltair. It was used to predict pollutant concentrations in test houses and to assist in the investigations of case study houses.

Two separate equations were merged for this purpose. The first equation was taken from Indoor Air Pollution, by R. Wadden and P. Scheff (Reference 2). The Wadden and Scheff equation is a sophisticated mass-balance pollutant flow equation, and includes factors to account for source emission rates, indoor sink removal rates, efficiency of mixing, and air exchange rates.

The second equation adopted by Sheltair is the Air Infiltration Model developed by M. Sherman at Lawrence Berkely Laboratories (Reference 1). This equation (also employed in the INFIL model) predicts air infiltration rates on the basis of house characteristics, weather variables, and the leakage area of the building.

Both these equations were programmed into a computer spreadsheet for use during field testing. The spreadsheet allows the variables of both equations to be viewed simultaneously and allows the user to quickly alter the default inputs, as suits the purpose of the investigation. The program was debugged using case studies provided by Wadden and Scheff and by Jim White of CMHC, and by analyzing results of field tests on Vancouver test houses. It was hoped to use this spreadsheet model to better define the key variables affecting indoor pollutant concentrations, during venting failures, and to better characterize worst case conditions for Canadian houses. Unfortunately, a busy schedule of field testing prevented exploration of these issues using the computer model. However, the model was of great assistance in predicting the probable range of concentrations for various combustion pollutants that would be encountered in the case study houses; these prediction were used as a guide in selecting test equipment. It was also possible, during case study investigations, to compare empirical data collected during venting failures in a spillage house with the computer predictions. Figure 4.2 illustrates carbon dioxide concentrations in a spillage house during a simulated failure event, as measured using a CO_2 infrared analyzer. Figure 4.1 shows the Sheltair model's predictions for the same house. Reasonable agreement between predicted and measured values was achieved. (Refer to Case Study House 2053 in the Project 6 detailed technical report for details on house characteristics and the program input values.) Figure 4.3 shows the model's predicted concentrations for the same house over a six hour period with the furnace cycling on and off. The CO_2 concentration levels off at about 3000 ppm.

Further modeling of test houses, in combination with monitoring of air quality concentrations during actual failure events, is needed to improve the predictive capabilities of the model (for example, matching appliance cycle times to heating loads) and to make the model a more effective tool for use during problem house investigations.

FIGURE 4.1: Predicted CO_2 Concentrations During Furnace Venting Failure for Test House No. 2129

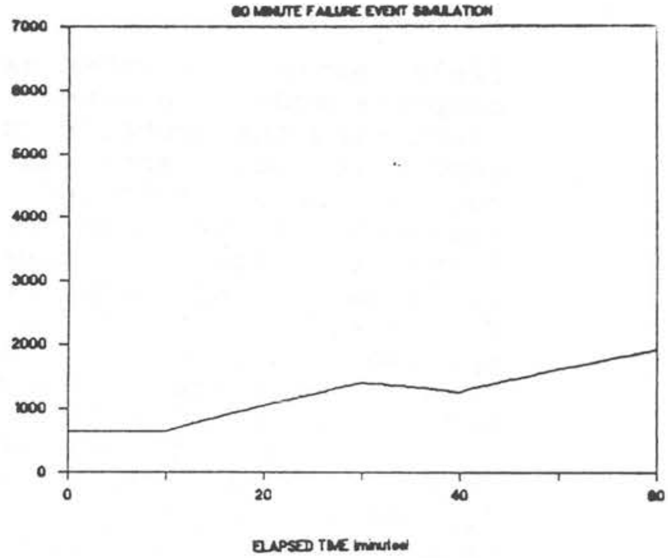


FIGURE 4.2: Measured CO_2 Concentratiions in Return Air Plenum During Furnace Venting Failure for Test House No. 2129

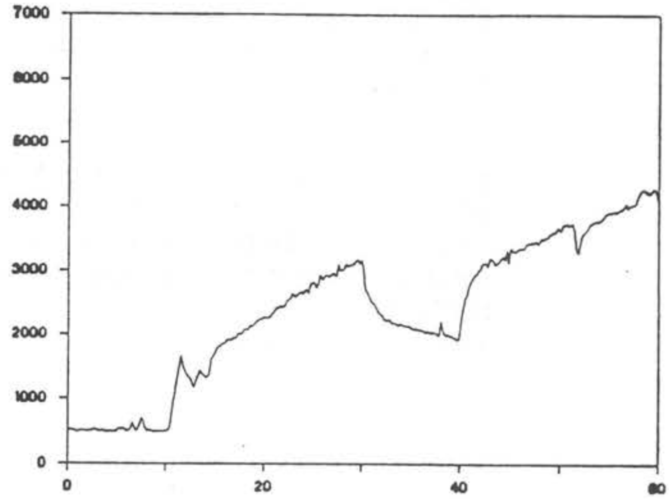
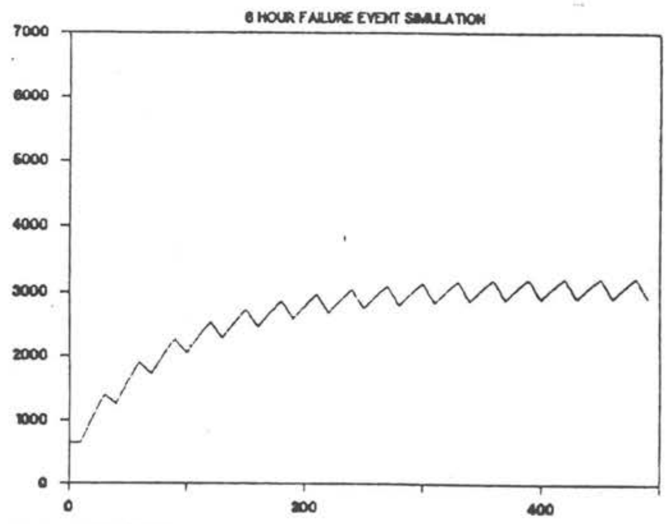


FIGURE 4.3: Predicted Long-Term CO_2 Concentrations for Repeated Venting Failures in Test House No. 2129



ACQUISITION AND CALIBRATION OF INSTRUMENTS FOR AIR QUALITY MONITORING IN PROBLEM HOUSES IDENTIFIED IN THE COUNTRY-WIDE SURVEY

OEEC Consultants recommended two alternative approaches to field monitoring. The first was to use accurate, continuous monitoring equipment in cases where portable devices were available; the second was to use a low cost detector tube or passive badge technique. A decision was made to use equipment capable of continuous monitoring, wherever possible, in order to -

- collect large amounts of data with minimum effort,
- present and analyze data rapidly in the field,
- compare house and system performance simultaneously with predictions from the computer model, and
- obtain data sufficiently accurate to allow for extrapolations over longer time periods.

A central component to the field testing strategy was the use of data logging equipment with a portable computer. In this way, the computer could be used for modeling concentrations in houses and for collecting extensive data on air pollutant concentrations and other parameters of house performance simultaneously during simulated failure events. In addition to pollutant concentrations, the data acquisition system continuously monitored the following:

- temperatures around the dilution air inlet of furnaces and water heaters
- indoor, outdoor, and flue temperatures
- indoor, outdoor, and flue velocity pressures
- wind speed and wind direction

Carbon monoxide was monitored using a portable analyzer with an electrochemical cell. Carbon dioxide was monitored with a portable digital infrared analyzer.

Nitrogen dioxide was monitored, initially with a portable monitor using an electrochemical cell. Due to poor performance and interference problems, this analyzer was replaced with a chemiluminescence NO_x monitor. Although this proved to be too heavy for use on field trips, it could be used on test houses in the Vancouver area. For monitoring of sulphur dioxide it was planned to use an electrochemical analyzer manufactured by Interscan; however, this analyzer was not available when needed. It was also not possible to obtain suitable portable electronic analyzers for measuring formaldehyde, hydrocarbons and particulates in the field investigations.

In the pilot tests, extensive use was made of sulphur hexafluoride (SF_6) as a tracer gas for determining both extent of spillage from a combustion appliance and the rate of air change for the house. However, this approach was rejected prior to tests of case study houses for two reasons. It was found that accurate estimates of air change in houses could be made using the decay of carbon dioxide following a combustion venting failure, and thus SF_6 was not required for this purpose. Also, when SF_6 was injected into the burner of a vented appliance in order to track quantities and movement of spillage gases, it was discovered that the gas, when heated to high temperatures, breaks into its constituent parts, which include fluoride, a highly poisonous gas. (A follow-up literature search into this problem revealed that at least one other researcher using SF_6 had discovered this problem.)

Continuous monitoring of pollutant concentrations does not permit sampling in many locations throughout the house. Experiments were conducted to determine if grab bag samples of household air from various locations in the house could be collected during failure events and then analyzed later for combustion pollutants. This would provide a means of typifying range and distribution of pollutants. It was found that CO, NO_2 and CO_2, remain relatively stable in the bags for periods of over two hours, and thus this approach was adopted during case study investigations.

Pilot Tests of the Field Testing Procedures

Delays in delivery of air quality monitoring equipment and continuous improvements to the test procedures did not allow as thorough an evaluation of the proposed field test protocol as had been intended. However, extensive air quality testing during simulated failures was conducted on four different test houses in the Vancouver area, and a considerable amount of data was successfully collected and analyzed prior to case study visits. The testing provided both an evaluation of the equipment and procedures, and a first look at what occurs in houses during venting failures.

To facilitate data collection in a variety of test houses, an interactive BASIC program was written for use with the data acquisition system. The program permitted the user to quickly select appropriate ranges and parameters for monitoring during different types of failures in different types of houses with different types of appliances. The pilot testing typically entailed a simulation of different types of failures over the course of a day, including backdrafting episodes provoked using a door fan at increasing levels of house depressurization, and spillage episodes at increasing levels of chimney blockage. Usually the furnace was allowed to cycle on and off for a period of one or two hours, while other factors were held constant.

Figures 4.4, 4.5, 4.6, and 4.7 are examples of data collected during a single failure event in a pilot test house. Figures 4.4 and 4.5 show temperatures inside the furnace flue and outside the air inlet of the furnace, respectively. During the first cycles, the furnace spills briefly at start-up, and then the flue temperature warms up and venting is re-established. During the final cycle, house depressurization is increased to 8 Pascals, and the furnace backdrafts throughout its entire operating cycle.

Figures 4.6 and 4.7 show CO_2 and NO_2 concentrations in the return air plenum of the forced air system during the three furnace cycles. This data is typical of other failures monitored in the test houses, in that pollutant concentrations in the return air duct rise rapidly following spillage and are quickly spread through the house. There is probably an exaggerated rise in the return air duct because of the static pressure drop created by the furnace fan, which draws the high concentrations of combustion gases in the furnace room into the return air plenum through leaks in the joints of the ductwork. If the return air plenum is to be used as a way of averaging air samples for the house as a whole, a location must be chosen as far away as possible from the furnace. It is typical for the concentrations of pollutants in the duct to rise and fall in parallel, and to follow by only several minutes the rise and fall in temperature outside the dilution air inlet. If full backdrafting is maintained throughout the furnace cycle, these temperatures are reduced because of the outdoor air coming down the chimney. The CO_2 level ratchets up during the first two cycles but at the end of the third cycle drops to close to ambient levels as the house is quickly flushed with outdoor air because of operation of the blower door. CO_2 level was generally found to be an excellent surrogate for the extent of spillage from a furnace, representing failure events more accurately than either flue temperatures or inlet temperatures.

Although nitrogen dioxide levels tend to parallel CO_2, they are less easy to monitor due to low concentrations and high deposition rates; as well, the NO_2 emission rate varies, depending on the combustion efficiency.

Figure 4.8 compares NO_x, NO_2, NO and CO_2 levels in a Vancouver pilot test house during a 90 minute failure simulation. The chimney was blocked during the cycles, and after the completion of the second cycle the primary air inlets were intentionally closed to simulate a poorly tuned furnace. The NO_x levels rise at a slower rate than CO_2, but with a similar pattern and decay. The CO_2 levels were in the range of 3,000 to 5,000 ppm after a 90 minute simulated venting failure, a range typical of a majority of the case study houses. The third cycle in the poorly tuned condition resulted in reduced generation of CO_2, NO_x and NO, but increased generation of NO_2, so that levels rose to what may be considered a health risk.

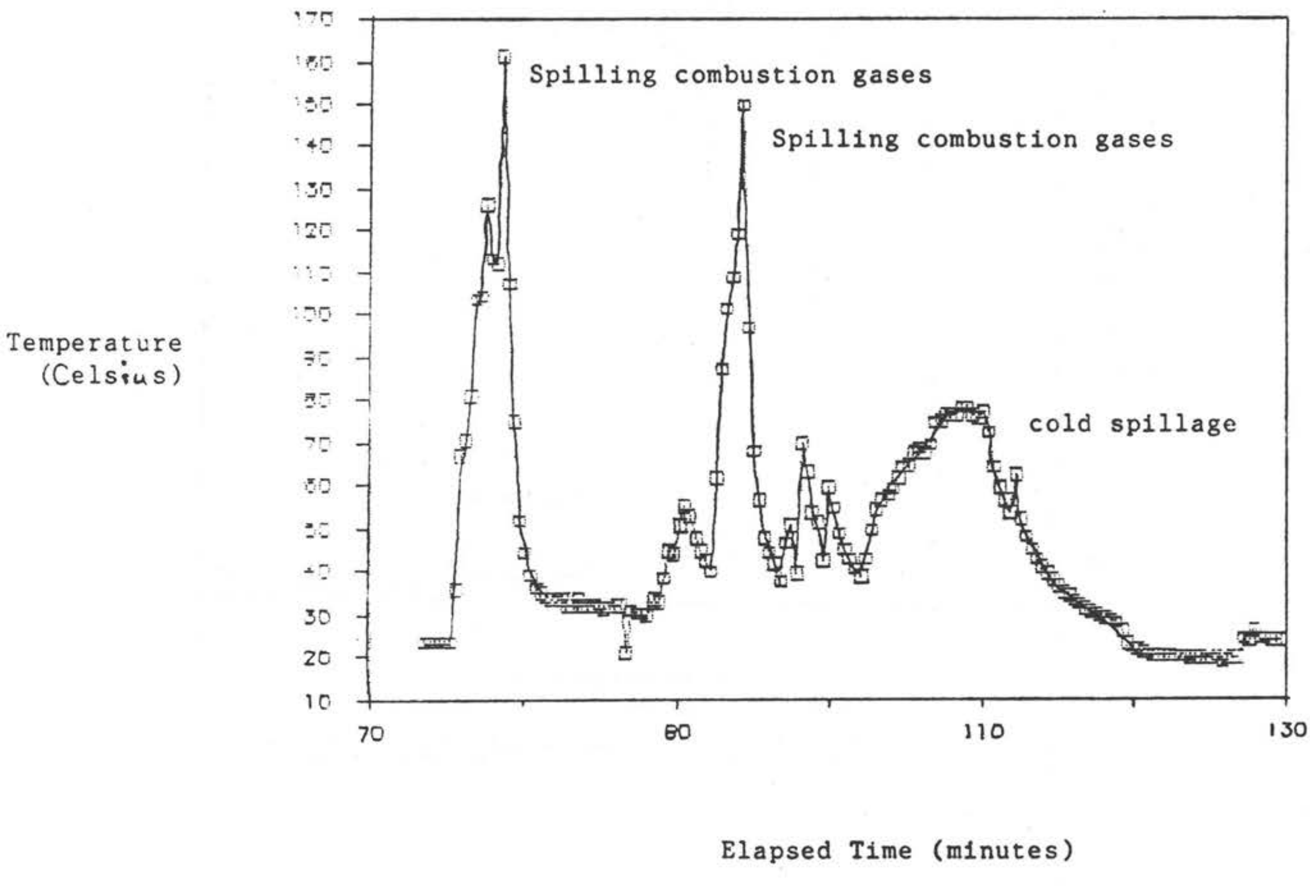


FIGURE 4.4: **Temperature at Furnace Air Inlet During Backdrafting**

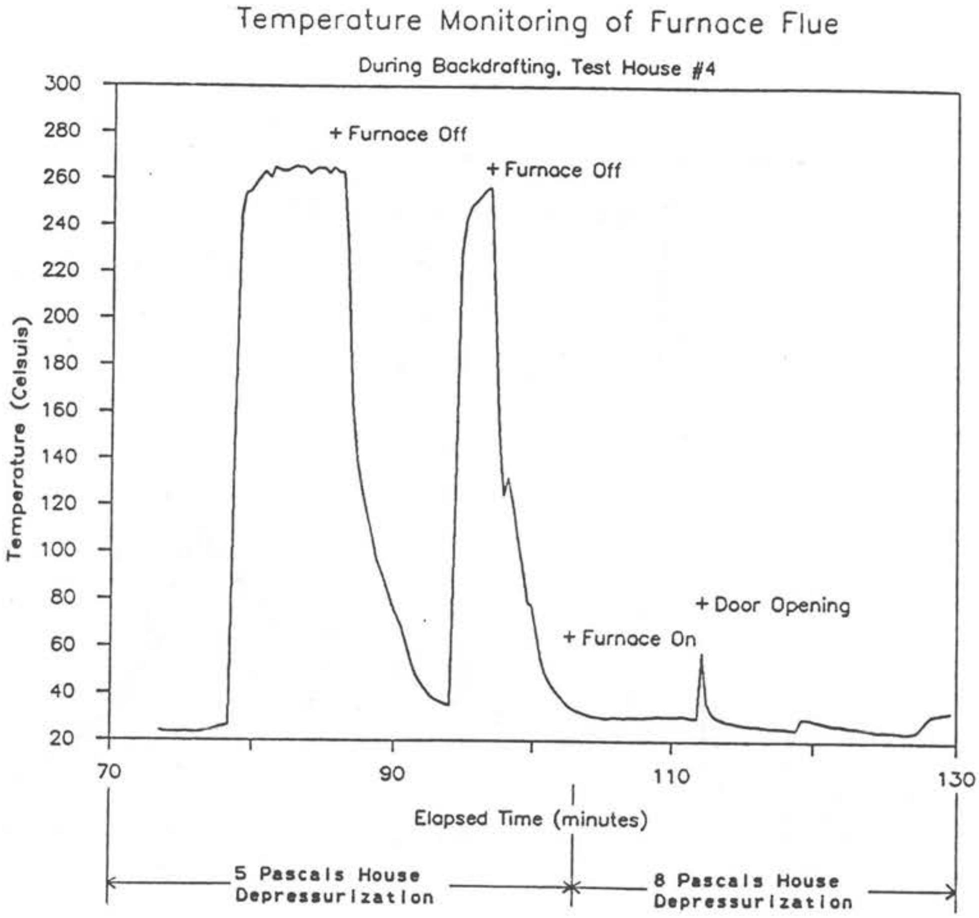
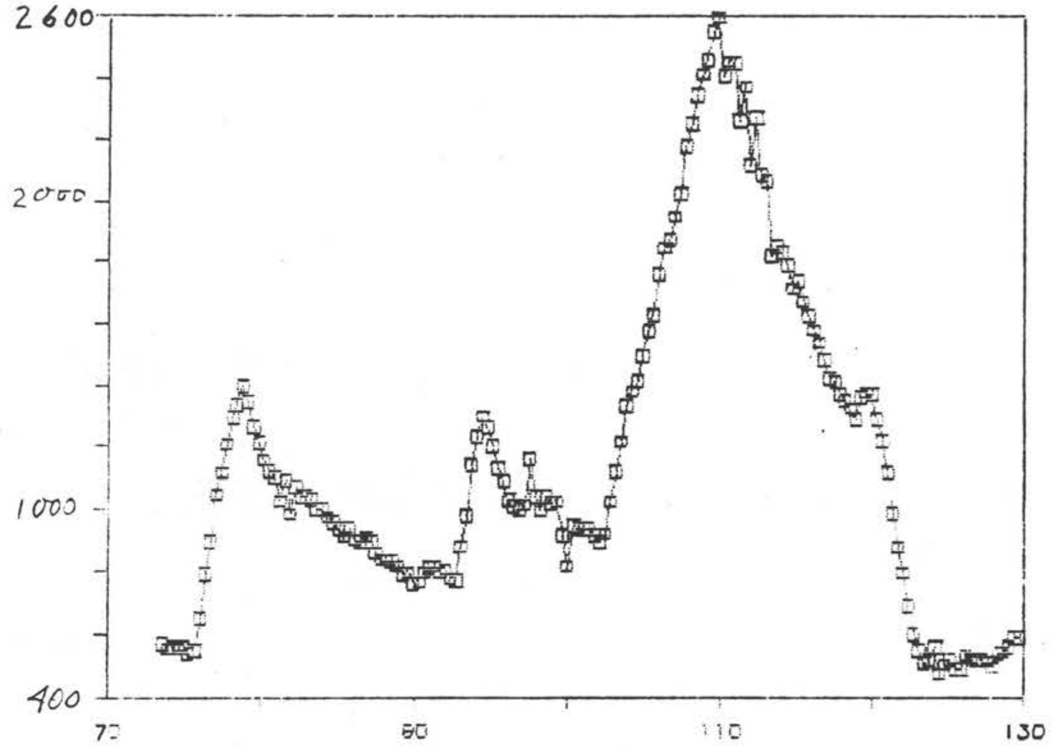


FIGURE 4.5: Temperature Inside Furnace Flue Above Air Inlet During Backdrafting

CO2

Concentrations

(ppm)



Elapsed Time (minutes)

- AT 80 minutes living room grab bag sample showed 950 ppm
- At 80 minutes bed room grab sample showed 700 ppm

- At 112 minutes living room grab bag sample showed 1500 ppm
- At 112 minutes bed room grab bag sample showed 700 ppm

FIGURE 4.6: CO_2 Concentrations in Return Air During Backdrafting

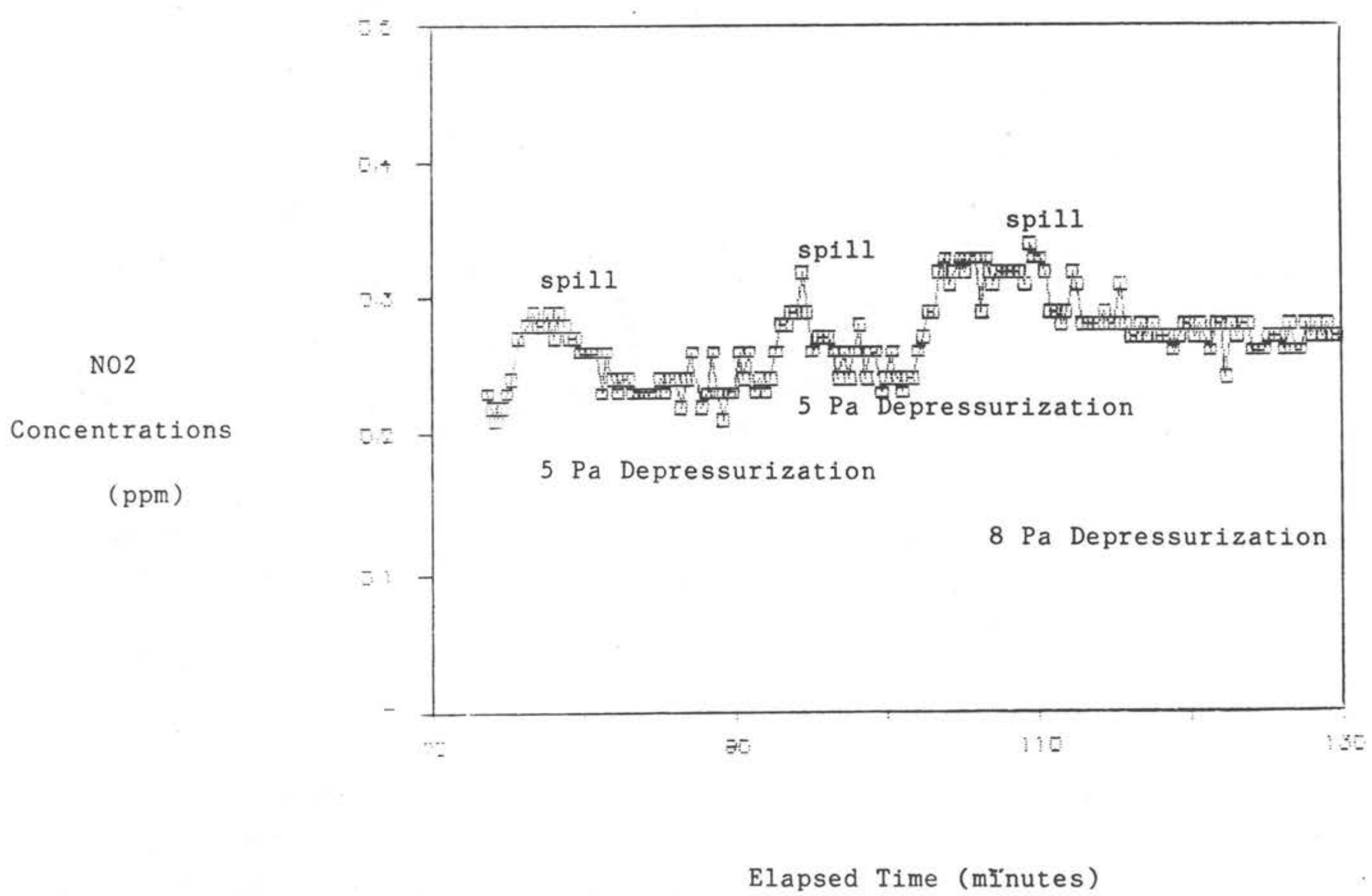


FIGURE 4.7: **NO_2 Concentrations in Return Air During Backdrafting**

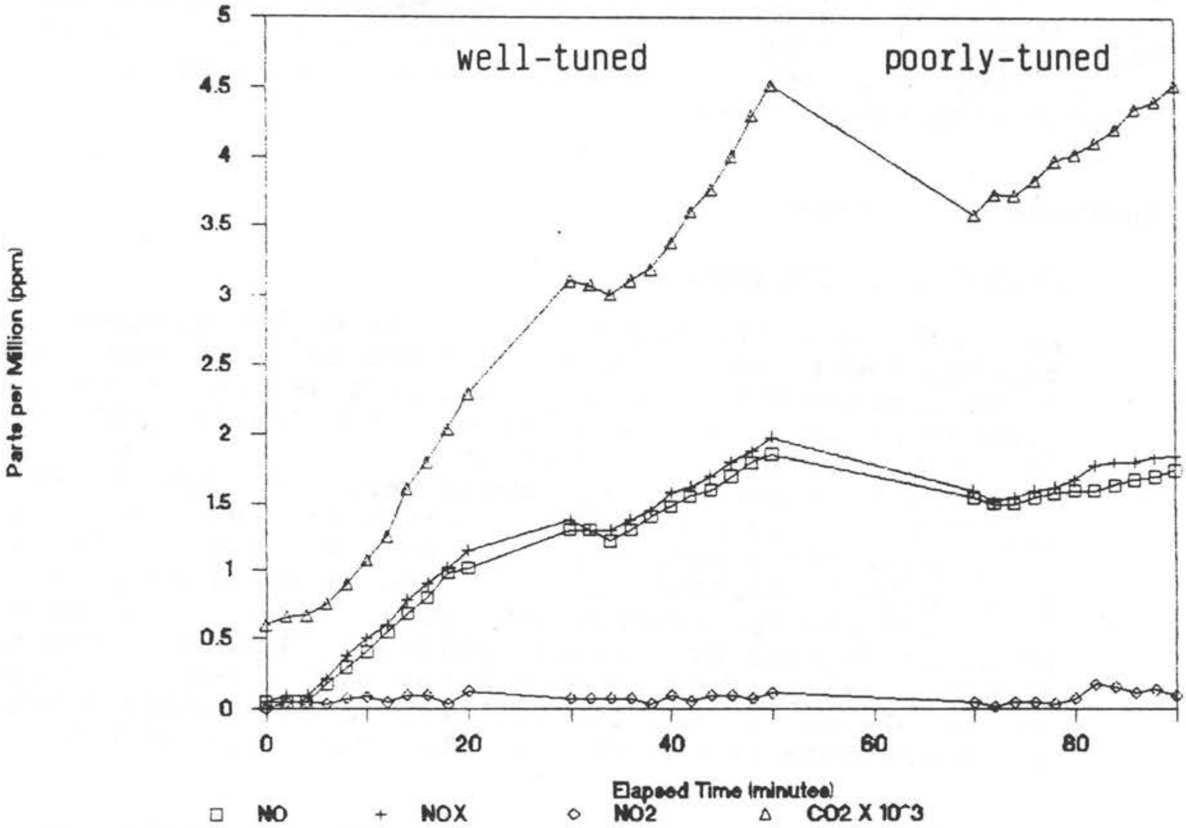


FIGURE 4.8: A Comparison of NO_x Concentrations with CO_2 (Vancouver Test House No. 3)

MONITORING OF POLLUTANT LEVELS IN PROBLEM HOUSES IDENTIFIED IN THE COUNTRY-WIDE SURVEY

Air quality monitoring during simulated failure events in the 21 case study houses produced a lot of information on the impact of combustion venting failures on air quality. Much of the detail on this work is summarized analyzing graphically presented in the Project 6 final technical report. However, the results of the air quality components of this case study investigation are briefly summarized here.

Analysis of Results

Carbon Dioxide Concentrations

As stated earlier, concentrations of carbon dioxide commonly reached levels in the range of 3,000 to 5,000 ppm. Steady state concentrations of CO_2 were modelled using the computer program and were not expected to reach levels much higher than what was achieved after the hour or two of monitoring. However, in a few houses, levels were predicted to reach 10,000 to 15,000 ppm. CO_2 performed well as a surrogate for all combustion gases, illustrating the distribution of pollutants throughout the home, the decay of pollutants over time, and the approximate generation rates of pollutants under conditions of partial spillage. Grab bag samples showed a delay of 10 to 30 minutes in CO_2 peaks for remote rooms. In all cases, the grab bag samples showed lower concentrations of CO_2 than in the return air plenum.

Prior to measuring CO_2 during the failure simulations, the "as found" indoor and outdoor CO_2 concentrations were measured for each case study house. Although concentrations tended to vary from city to city, the indoor and outdoor levels for any one house were not significantly different. As these measurements were made during warm spring weather, the houses were well ventilated and heating systems were seldom in use. The only exception was a house that had been closed up for air conditioning. Its indoor CO_2 concentration was 1025 ppm, compared to the outdoor concentration of 440 ppm.

Carbon Monoxide Concentrations

Carbon monoxide was rarely found in significant concentrations during failure simulations; there was apparently no production of CO as a result of recycling of combustion gases through burners. The hot spillage gases rise and are quickly mixed and distributed throughout the house. The high quantities of CO found in one case study house with a hydronic heating system were primarily the result of a dirty burner and the lack of a forced air distribution system. Forced air distribution systems in most houses were found to produce very rapid mixing of pollutants throughout all rooms.

Occupant Exposure Relative to Failure Mechanisms

A review of the case studies suggests that different types of failure mechanisms result in very different types of exposure to combustion pollutants for the house occupants. The following are brief description of five different failure scenarios commonly found in the case study houses. Each would produce a different mix of pollutant concentrations.

- Pressure induced spillage in a relatively tight house. This is a common failure scenario on the basis of case study research. Tight envelopes mean that exhaust rates do not need to be high to cause problems and thus the house may be inundated with pollutants at times when air change rates are low. The combination of a house that is closed up, a calm day, and the use of particular exhaust fans and/or fireplaces results in occasional backdrafting and relatively high levels of combustion pollutants. Carbon dioxide levels will average or exceed 5000 ppm for an hour or two following each incident, and on occasion may reach 10,000 or 15,000 ppm especially in small houses. Carbon monoxide levels are unpredictable, unless furnace emissions are established.

- Pressure induced spillage in a boiler room. The lack of a forced air distribution system can result in the extremely high levels of combustion pollutants inside the boiler room, and possibly in adjoining rooms. Although the backdrafting events may be infrequent, and may coincide with fan use, the levels of pollutants may be high. This type of failure may be associated with carbon monoxide due to oxygen depletion in a boiler room.

Chronic Failure Scenarios:

- Continuous spillage. Poorly designed, broken, or poorly maintained chimneys and flues can lead to small amounts of spillage on a continuous basis. Whereas a total blockage of the chimney would be noticeable, this type of failure scenario can persist for long periods without householders ever recognizing the source of problems. There is often an increase in the quantities of spillage when the house is depressurized and thus concentrations are unlikely to be lowered through the use of exhaust devices.

- Regular backdrafting due to massive house depressurization. In several houses, a single powerful exhaust fan was capable of depressurizing the house sufficiently to cause flow reversal even in a hot furnace flue. This was also true for houses with badly imbalanced forced air distribution systems which depressurized the furnace room or basement. Under such circumstances, considerable quantities of spillage are likely to be occurring on a frequent basis. Levels of combustion pollutants will ratchet upwards over time, and steady-state concentrations may reach moderately high levels throughout the heating season. The high rate of exhaust during these events helps to reduce pollutant concentrations.

- Prolonged spillage at start-up. A leaky or constricted flue, combined with marginal amounts of house depressurization can produce prolonged spillage at start-up. Spillage is considerable during the first two minutes, and then tapers off as the chimney warms up and draft improves. Concentrations will be highest in houses where the appliance cycle tends to be short, since the spillage period will represent a greater portion of the total on-time. Chronically high levels of combustion pollutants will result in some houses.

Occasional backdrafting in a relatively tight house and occasional backdrafting in a boiler room can produce acute short-term concentrations whereas continuous low volume spillage, or regular backdrafting in a less tight house, or prolonged spillage at start-up are scenarios that may produce low level, long-term chronic exposure.

A COMMENT ON HEALTH HAZARDS OF COMBUSTION VENTING FAILURES

OEEC Consultants was requested to provide an expert commentary on the import of results of failure scenario testing in spillage houses and the well-being of occupants in these spillage houses. It was also hoped that an overall assessment could be made of the health hazards represented by combustion venting failures in the entire Canadian housing stock. Unfortunately, it was felt by OEEC that no assessment is possible until much more data is collected on both the acute and chronic failure scenarios, and on a broader range of combustion pollutants. More information is also required on the frequency of spillage events in each of the spillage houses. Nevertheless, the research completed to date does provide a basis for some comments on the health effects of specific contaminants, namely carbon dioxide, carbon monoxide and nitrogen dioxide.

The finding of 3,000 to 5,000 ppm steady state concentrations of CO_2 does not in itself indicate a significant health hazard, although it is possible that in 10 or 20 per cent of the houses concentrations would reach 10,000 to 15,000 ppm after several hours of repeated failures. This suggests that, in some houses, the other combustion pollutants may also experience extraordinary high concentrations. In general, however, the CO_2 concentrations do not appear to represent a significant health hazard unless maintained over long periods.

The insignificant CO levels in all but one case study house are consistent with previous research by CMHC and Consortium members into venting failures, and suggest that high concentrations of CO in houses during venting failures are the result of the coincidental occurrence of problems with the furnace/venting system other than the problems that caused the venting failures, such as dirty burners or cracked heat exchangers.

Since venting failure appears to be a not uncommon event in Canadian housing, it is fortunate that CO is not a directly related by-product. Nevertheless, even if high CO concentrations occur in only a small percentage of incidents of pressure-induced spillage, if those incidents are increasing, there will be a corresponding absolute increase in cases where CO is a factor. Since the number of venting failures already seems to be significant and seems to be increasing, an argument can be made for increased use of warning devices and improved maintenance procedures for furnaces and water heaters generally. CO sensors, in particular, may be advisable in houses with appliances that are prone to more frequent spillage occurrence or higher pollutant concentrations. These higher risk houses would include those with hydronic heating systems and those with conversion burners.

On the other hand, fireplaces almost always represent a CO hazard and, since the survey indicate fairly frequent spillage from fireplaces, more research and more public awareness are definitely required.

Nitrogen dioxide is a very toxic gas, and the test results do indicate that, with poorly tuned furnaces, the gas can attain steady state concentrations in excess of permissible limits and its distribution parallels that of CO_2. Although firm conclusions can not be made at this time, this pollutant could have a major impact on the health of occupants in spillage houses and should be a primary focus of any further investigations in this area.

The extremely high frequency of spillage from oil-fired furnaces, much of which may be start-up spillage, suggests a need for more detailed investigations of the constituents of combustion gases from oil furnaces, especially during the start-up period.

Further investigations were planned by CMHC during the 1986/87 heating season, to better characterize the impact of combustion gas spillage on indoor air quality. The air quality monitoring procedures and data presented in this report provide a starting point for these further investigations.

PROJECT 5: REMEDIAL MEASURES

There are many possible causes of combustion venting failure. Often the failure is not pressure-induced at all. For example, the chimney might be partially or totally blocked. In such cases, remedial measures are usually available and are usually obvious; e.g. unblock the chimney. However, in the case of pressure-induced spillage, the choice of a remedial measure is seldom so clear. There has been a tendency to fall back on some form of make-up air supply; but there has been little data on the reliability of such measures and little information on how to relate the type and size of make-up air provisions to the cause of the pressure-induced spillage. This project therefore concentrated on research on remedial measures for pressure-induced spillage and included both make-up air supply measures and alternatives to make-up air supply.

The work was divided among four research centres in different parts of the country as follows:

Remedial Measures For -	Research Centre
fireplaces	Sheltair Scientific, Vancouver
gas fired appliances	Scanada Consultants, Ottawa
oil furnaces	Solsearch Inc., Charlottetown (with Holland College)
make-up air supply	Saskatchewan Research Council (SRC), Saskatoon

Each research centre was asked to first identify possible remedial measures in their assigned field as well as recent related research. They were then to pick two or three measures which had promise of being ready for commercialization in the near- to mid-term and to conduct the research or development work required to make such commercialization possible.

The research conducted in each of these areas and the results achieved are summarized below.

FIREPLACE REMEDIAL MEASURES

Sheltair looked at two remedial measures for fireplaces subject to pressure-induced spillage:

- the spillage advisor (detector)
- airtight doors with direct air supply

Spillage Advisor

The objective of this research on the spillage advisor was to specify acceptable design parameters and optimum installation procedures for a warning device that can indicate to householders when spillage is occurring from their fireplace.

Although, in the strictest sense, a warning device is not a remedial measure, the development of such a warning device (or "spillage advisor") was felt to have a high priority for several reasons. A spillage advisor was felt to be a good first step for householders concerned about potential health or comfort problems arising from fireplace spillage. When the alarm sounds, the occupants are reminded to operate the fireplace or the house in a safer manner; e.g. close fireplace doors, open a nearby window, or turn off competing exhaust devices. If the alarms sounds frequently despite such efforts, the occupants are forced to recognize that a serious problem exists. In this way, the advisor indicates if a need exists for more costly or difficult remedial measures.

A preliminary assessment of alarm technologies indicated that such a device could be produce at a low cost. Initial investigations of ionization-type smoke alarms for detecting fireplace spillage (undertaken as part of the development of survey technology for Project 1) indicated a high probability of success. Consequently the spillage advisor was considered to have wide applicability to problem houses in Canada and a high probability of successful near- to medium-term application.

The research on the fireplace spillage advisor included the following steps:

- identification of substances likely to be present when fireplace spillage occurs that could be used to detect the spillage

- discussions with smoke alarm and CO detector manufacturers

- tests in a Vancouver test house to map the concentration of the detection substances for various stages of a fire's burn cycle and under various conditions of house depressurization in order to determine the best location for a detector

- design and fabrication of prototype spillage advisors for trial installation and user evaluations in several houses

The results were as follows:

Detection Substances

It was found that detection of smoke particles, using normal smoke alarm technology, was effective when the fire was hot and flaming but was not effective during the smoldering stage of the fire. On the other hand, detection of CO, using the emerging CO detector technology, was not effective during the hot flaming stage but was effective during the smoldering stage. Therefore it is necessary for a fireplace spillage advisor to incorporate both technologies.

Location

The optimum location for a spillage advisor was found to be above the centre of the fireplace and slightly out from the wall, either attached to the front face of the mantle or, if there is no mantle, attached to the wall but tilted slightly outwards at the top.

Design

The final design incorporates the following features:

- both particle detection and CO detection on a common circuit board

- user-adjustable signal volume
- on/off switch (since it may not be possible to stop spillage immediately, once alerted)
- high temperature plastic housing
- 110 VAC power (rather than battery-operated)
- $40 to $50 estimated cost

Trial Installations

An unsuccessful attempt was made to evaluate the spillage advisors in use. An opportunity was recognized during the Canada-wide survey, when fireplace spillage detectors were developed and installed in five houses. These detectors were designed in accordance with the requirements of a "spillage advisor", except for the lack of an alarm. Consequently, the detectors were retrofitted with alarms with variable volume controls and on-off switches. Unfortunately, an early and warm spring in Vancouver prevented their use by householders. Thus the important questions of whether the advisors are acceptable to householders and are capable of reducing the frequency and duration of spillage, remain unanswered.

Airtight Doors With Direct Air Supply

A fireplace is the source of two types of venting failures. First, as a powerful exhaust device it greatly increases the chance of spillage from other chimneys - such as those serving furnaces or DHW heaters. Second, as a combustion appliance, a fireplace often operates with a weak draft at the start and end of a burn and can be caused to spill at back pressures as low as 2 and 3 Pascals. Airtight doors combined with a direct outdoor combustion air supply could be expected to help avoid both these types of venting failures.

The concept to be investigated here was that of truly airtight doors that achieve significant separation of the fireplace from the house indoor pressure regime. A preliminary part of the study was an examination of several brands of commercially-available "airtight" doors to determine to what extent they are likely to achieve such a separation. It was found that these doors are deliberately made leaky to allow room air to cool the glass and to provide for the different rates of thermal expansion of the glass and the frame, and thus to prevent the violent shattering of the doors to help to keep them clean. It was also found that the glass surrounds on many commercially available units are made of light gauge metal and are subject to discoloration and distortion from high fireplace temperatures. The models examined were found to have equivalent leakage areas ranging from 14 cm^2 to 124 cm^2.

Therefore a prototype fireplace door unit was designed and fabricated for testing under this study. It had the following characteristics:

- special heat-resistant glass, referred to as "ceramic" in the industry

- glass tightly gasketed to the steel surround using glass fibre material
- glass surrounds fabricated from steel at least 6 mm thick

- equivalent leakage area, when sealed into fireplace opening with silicone sealant, of less than 2 cm^2.

- integral heat exchanger with centrifugal fan to circulate room air through the heat exchanger and dissipate heat build up in the fireplace

- 75 mm outdoor combustion and draft air supply duct discharging the air through a channel across the entire bottom front of fireplace and incorporating a tightly fitting, manually adjustable damper

The unit is shown in Figure 5.1

The location of the combustion air supply was a contentious issue for the experts and manufacturers consulted during the design phase. The use of an ash-clean-out converter kit was promoted as a simple solution, but was rejected because of interference with the heat exchanger. The eventual choice - providing air along the bottom front of the firebox - was a way to keep doors clear of ash, to cool the glass, to

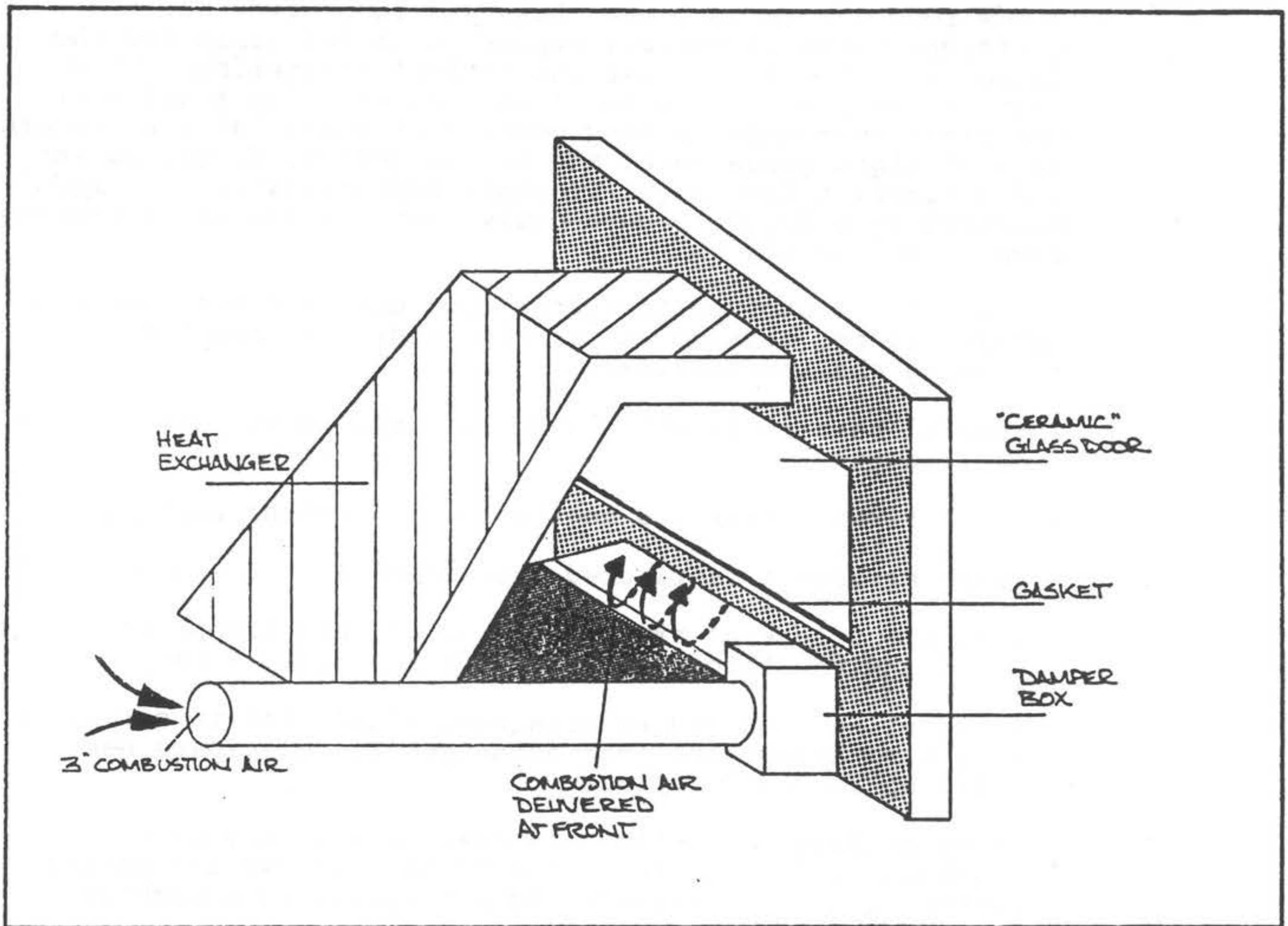


FIGURE 5.1: Glass Door Unit Showing Combustion Air Supply

provide maximum air for combustion, and minimize hazards from blow-back or reverse convection.

A further feature had been suggested by Scanada Consultants - the inclusion of a second outdoor air intake discharging higher in the firebox. This would function much like the draft diverter of a gas furnace, isolating the fire from variations in chimney draft caused by the wind. It would also help to prevent embers from being sucked into the lower air intake by wind-induced negative pressure at its outer end and would reduce temperatures above the fire, thus improving fire safety. However, budget and schedule limitations prevented further exploration of this concept.

The prototype unit was installed in a Vancouver test house and testing was carried out with the following objectives:

- To monitor the installation process in terms of both its cost implications and the difficulties encountered in determining clearances of fireplace and chimney components from combustible building components.

- To measure temperature in and around the fireplace during operation in order to determine the effect of the airtight doors on the safety of the fireplace.

- To determine the effectiveness of the airtight doors in isolating the fireplace from the house indoor pressure regime.

The results were as follows:

<u>Installation</u>

Installation was completed by two men in a period of approximately 3 hours. This time would be reduced (possibly by up to 50%) if the extra work of recording the procedures photographically and checking for clearances from combustibles (see below) were eliminated.

To determine the location of combustibles, the installers of the insert were asked to drill a number of probe holes into the front facing of the masonry fireplace. Drilling holes and noting the change of material that was being drilled through by feel and by examining the bore debris enabled the exact location of various combustible building components to be found. Holes were drilled with an extended 9.5 mm masonry bit on a standard drill. The damage was slight and easily repaired, and the holes were completed quickly. A careful examination of the inside of the chimney collected enough data to be able draw an accurate schematic of the fireplace. It was considered a time consuming and some what demanding task but well within the capabilities of the installers.

The installers used R-20 fiberglass insulation to fill the space between the back of the door frame and the facing brick. This common installation practice was found to be extremely leaky when examined with a smoke pencil when the house was in a depressurized state. Depressurization of the house to 20 Pascals caused heavy smoke spillage around the doors, especially around the bricks and along the lower edge. The door frame was then sealed to the facing brick using a grey masonry silicone. It was impossible to seal a small portion of the door that was unaccessible because of the installation of a recirculating fan on the front of the doors. A better approach appeared to be to apply sealant just before final installation of the unit.

Temperatures and Fire Safety

The drill holes made it possible to insert thermocouples into the masonry to monitor temperatures during typical fires. Figure 5.3 shows temperatures during start-up of the fire. Figure 5.4 shows temperatures when the fire had time to reach peak temperatures. Both Figures can be compared with Figure 5.2, which shows temperatures before the airtight doors were installed. After 3 hours of continuous burning, the temperature of the combustible component nearest the unlined chimney had reached only 30°C.

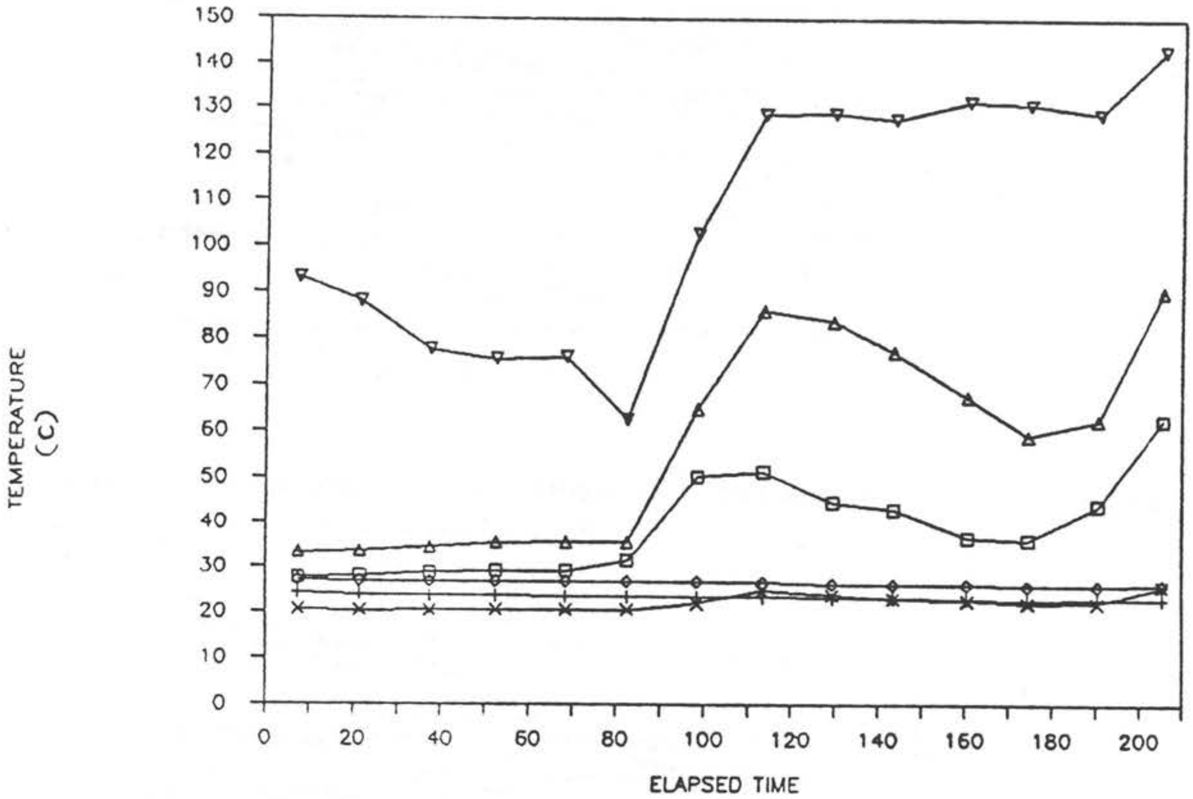
Monitoring of temperatures over a short term (2 to 3 hours) suggested that the potential for fire hazard was not increased by causing the fireplace to backdraft, or by plugging the combustion air intake. Figures 5.5 and 5.6 present temperature profiles for each of the above conditions. In both cases temperatures at the throat of the firebox dropped off radically. The lower temperatures suggest lower risk of fire in the structure surrounding the firebox. On the other hand, the reduced burn rate may lead to increased creosote formation, thus increasing the risk of a chimney fire.

Isolating Effect of the Airtight Doors

To determine the degree to which the fireplace was isolated from the house, a Dwyer inclined manometer was used to measure draft in the hot firebox with the door open and closed. For the same conditions, a door fan was used to depressurize the house and determine the level of depressurization required to cause apparently irreversible spillage. The results are shown in Table 5.1

TABLE 5.1: Measured Pressures in Test House Fireplace

	Measured Draft (Pa)	Depressurization Required to Cause Irreversible Spillage (Pa)
House as Found	3	3
Door Open, Combustion Air Inlet Open	8 - 10	8
Door Closed, Combustion Air Inlet Open	25	22



1. □ At upper lip of fireplace opening.
2. + 6 cm above hearth at fireplace opening.
3. ◇ 15 cm above hearth at fireplace opening.
4. △ Inside upper lip of fireplace brick.
5. X At centre of mantle.
6. ▽ In chimney at throat.

FIGURE 5.2: Temperature Around Fireplace Prior to Installation of Doors

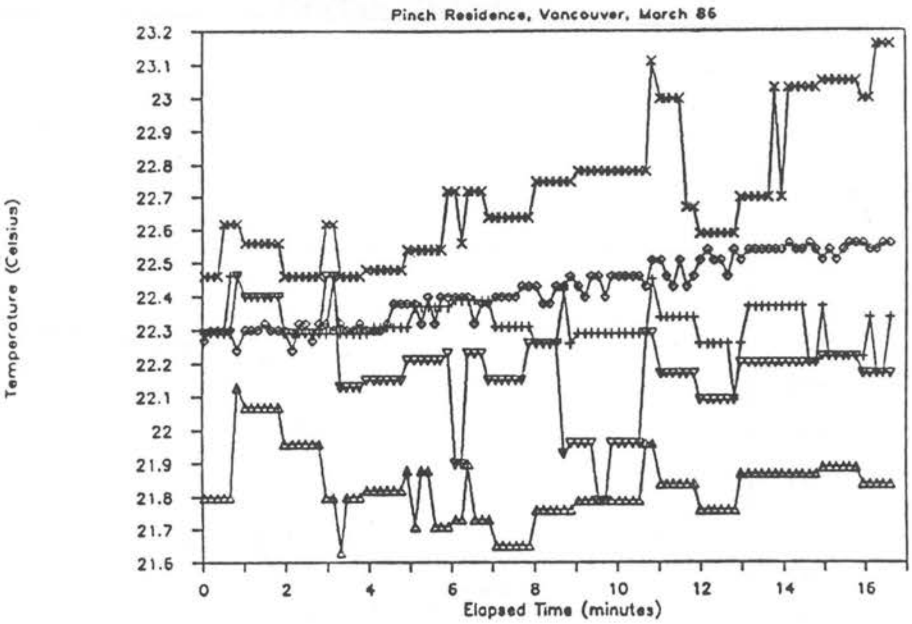
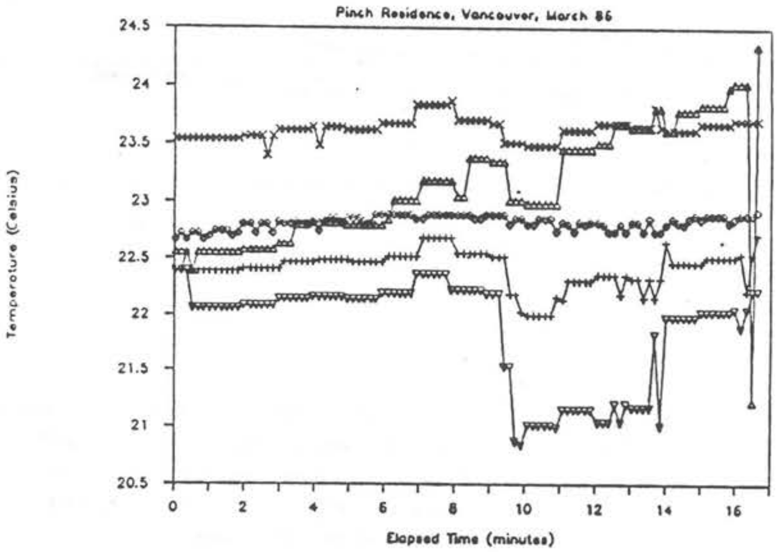


FIGURE 5.3: Temperatures Around Fireplace at Start-up



Legend:
- \+ 57 mm from face of plaster (back of header)
- ◇ 108 mm from face of plaster (back of header)
- △ Room
- X 120 mm from face of plaster through brick base of mantle
- ▽ Angled to face of header at base

FIGURE 5.4: Temperatures Around Fireplace of Hot Fire

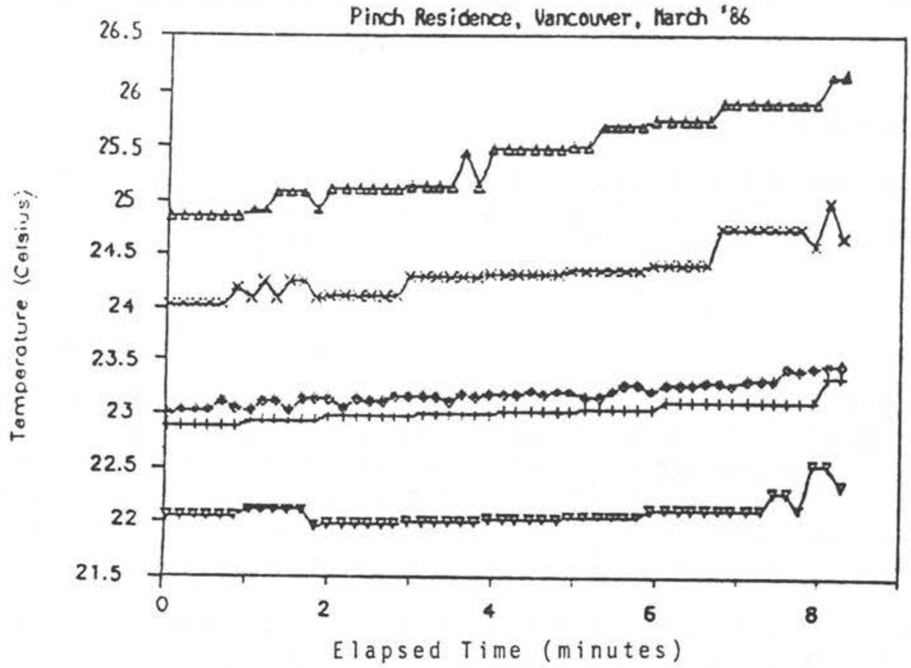
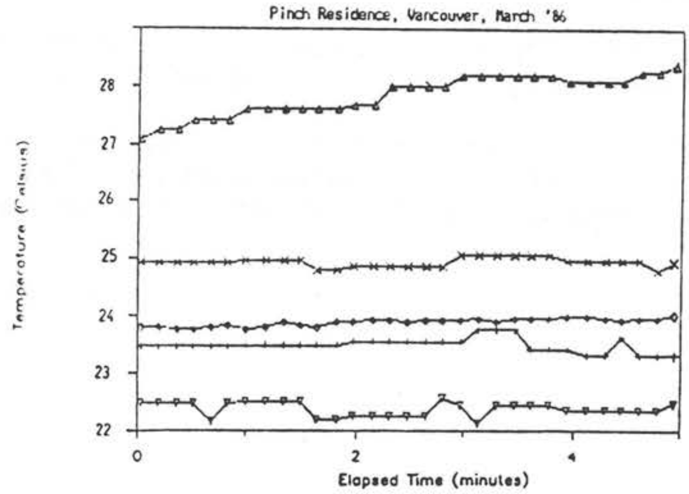


FIGURE 5.5: Temperature Monitoring with Blocked Combustion Air



Legend:
+ 57 mm from face of plaster (back of header)
◇ 108 mm from face of plaster (back of header)
△ Room
X 120 mm from face of plaster through brick base of mantle
▽ Angled to face of header at base

FIGURE 5.6: Temperature Monitoring During Backdraft

Estimated Cost

At an estimated installed cost of $600 (assuming production run quantities), the prototype door would be only marginally more expensive than the better quality doors now available.

Summary

Properly designed, truly airtight doors are effective in isolating fireplaces from the house indoor pressure regime. This remedial measure appears not to affect the fire safety of the fireplace; however, further long term testing is required before it can be recommended unequivocally. Some of the issues that remain to be resolved include the following:

- What is the long term durability of the seal between the door frame and the surrounding masonry?

- Will the additional heat created by the presence of the airtight doors cause discomfort to persons nearby?

- Do airtight doors increase creosote deposits and hence increased potential for chimney fires?

- Can current requirements for clearance between masonry fireplaces and surrounding combustibles be relaxed without undue reduction in safety and thus be made more practicable?

GAS-FIRED APPLIANCE REMEDIAL MEASURES

Scanada looked at three remedial measures for gas-fired appliances subject to pressure-induced spillage:

- the spillage advisor (alarm)
- the retrofit draft-inducing fan
- the draft-assisting chamber

Spillage Advisor

The concept here is not a single device but a range of devices which depend on a temperature-activated switch - a "spill switch" - for triggering. The objective of the testing was to evaluate spill switches with two different trigger temperatures at various locations in the dilution port to determine their effectiveness and consistency in detecting prolonged spillage of combustion products. No attempt was made to measure the effectiveness of any warning or fail-safe devices that the spill switches might be used with, since design of these is a fairly straightforward electric/electronic circuit problem once an effective sensing element has been chosen.

The spill switches selected for testing were based on the "Thermodisc", a commercially available temperature triggered switch used in various appliances as a high-limit or low-limit control. It is available in a number of configurations:

- close on rise
- open on rise
- close on fall
- open on fall

Each is available with a number of different triggering temperatures.

The switches used in the test are based on the Thermodisc 10H Series Controls. These switches are open-on-rise, single-pole/ single-throw linear limit thermostats that provide continuous thermal sensing along a fluid filled copper capillary sensing tube. On temperature rise, the fluid in the capillary tube expands causing a diaphragm in the switch to snap at a pre-calibrated temperature, thereby opening electrical contacts. The capillary tube allows the temperature sensing to be remote from the actual switch location. Automatic reset switches were used in the tests although manual reset is also available.

The switches used in the tests had the following characteristics:

1) Switch 1 - Length: 62 cm. Open on rise at 80.5°C ± 5.5°C. Close at 73.3°C.

2) Switch 2 - Length: 43 cm. Open on rise at 73.3°C ± 8.3°C. Close at 43.3°C.

Tests were carried out on a naturally aspirated gas furnace in an Ottawa test house. The objectives of the tests were to determine the following:

- The conditions which lead to the switches being activated or failing to be activated. This would provide a baseline of data defining what conditions activate the switch upon which more rigorous testing could be based.

- The effect of location on the duration of spillage required to activate the switches. These tests were designed to help optimize the location of the switches.

- If severe backdrafting might delay activation of the switches due to cool outdoor air diluting combustion gases passing over the switches. Thus, only severe backdrafting cases would be considered here.

- The effect of the two different lengths and temperature limits on duration of spillage required to activate the switches. Comparison of the performance of the two switches under identical conditions was sought here.

The tests consisted of the following steps:

- installing the two switches in various positions in the dilution port of the test furnace

- inducing spillage and backdrafting of various intensities and durations by depressurizing the house with a blower door

- recording the duration of spillage required to trigger the switches

- mapping temperatures in the dilution port

The switches were not connected to any warning or control devices, only to a datalogging system which recorded the time, relative to furnace start-up, at which they were triggered and the coincident conditions which resulted in this triggering.

The results can be summarized as follows:

- Neither switch was triggered by short term, reversible spillage and both were eventually triggered by long term, apparently irreversible spillage.

- The time required to trigger a switch varied from 57 seconds to 100 seconds, depending on its triggering temperature, its placement in the dilution port and the level of house depressurization.

- The switch with the lower triggering temperature was consistently triggered sooner at all locations.

- The location that resulted in the shortest triggering times was dead centre in the dilution port.

- Higher levels of house depressurization resulted in longer triggering times due to the fact that cold outside air was drawn down the chimney and out the dilution port, reducing the temperature of the discharge from the dilution port.

- Review of the detailed results for various switch locations and various levels of house depressurization indicates that there may be a location somewhere between the vertical centreline and the bottom of the dilution opening where activation time is independent of the level of depressurization. If one could determine this location, the activation time of the switch would depend on only one variable - the temperature limit of the switch - rather than the three variables of location, depressurization and temperature limit.

The results of these tests indicate that it should be possible to develop a number of different devices to warn of the occurrence of abnormal combustion products spillage from a naturally aspirating gas furnace or to somehow alter the operation of the furnace (e.g. turn it off or activate a draft inducer) when such spillage occurs. These devices could all be triggered by a temperature sensitive switch (spill switch) of the Thermodisc type, which has been shown to react consistently to spillage incidents.

However, these tests were not exhaustive; for example, the effect of extremely cold backdrafts could not be assessed due to the time of year when the tests were carried out (March).

Draft-Inducing Fan (draft inducer)

A number of retrofit draft-inducing fans are commercially available but there is little objective data on their performance and effectiveness in correcting combustion venting problems. The fan chosen for testing was the Model DI-1 manufactured by the Field Controls Company in North Carolina. It is a paddle-wheel type fan which mounts in the side of the vent connector (flue pipe) and extends just over 25 mm into the flow path. There are thus 95 mm of a 120 mm diameter pipe that are not obstructed by the device. It is powered by a 32 Watt, 0.4 Amp. AC motor.

The draft inducer was installed and tested on the same Ottawa furnace/house system as used for testing the spillage sensing switches. The system was first tested as found before installing the draft inducer. The testing, both before and after installation of the draft inducer, consisted of the following steps:

- With the furnace and flue cool and the furnace off, depressurize the house using a blower door.
- Turn on the furnace, observe flow at the dilution port and record how long it takes from furnace start-up to initiate flow into the dilution port.
- Repeat the above at increasing levels of depressurization until a level is reached at which flow out of the dilution port appears to be irreversible.

Figure 5.7 is a plot of duration of spillage versus level of depressurization for the house/furnace system as found and with the draft inducer installed. The following points are apparent:

- For the system as found, depressurization to about 7 Pa was sufficient to cause apparently irreversible spillage.

- With the draft inducer installed and operating, even at 20 Pa depressurization, the spillage was reversible.

Thus the draft inducer increased the level of depressurization required to cause irreversible spillage from 7 Pa to at least 20 Pa. It may have increased it even more, but this was the highest level of depressurization attainable with the blower door used. The draft inducing fan therefore appears to be a very effective remedial measure for use with gas-fired appliances experiencing combustion venting problems. Of course this research was not able to address the issue of durability and reliability.

Draft-Assisting Chamber (DAC)

The "draft-assisting chamber" is a proprietary device that becomes part of the venting system of a naturally aspirating combustion appliance. It fits over the dilution port and, in effect, extends the port so that its entrance is significantly below its normal level. Thus combustion products attempting to escape out the dilution port are forced downward against their natural buoyancy. It is intended to fulfill two functions:

- Contain initial spilled combustion products until proper draft is established.

- Assist in the initiation of proper upward flue flow in a stalled or backdrafting situation yet have no effect during normal flue operation. Thus it is not intended to interfere with the normal combustion process or efficiency.

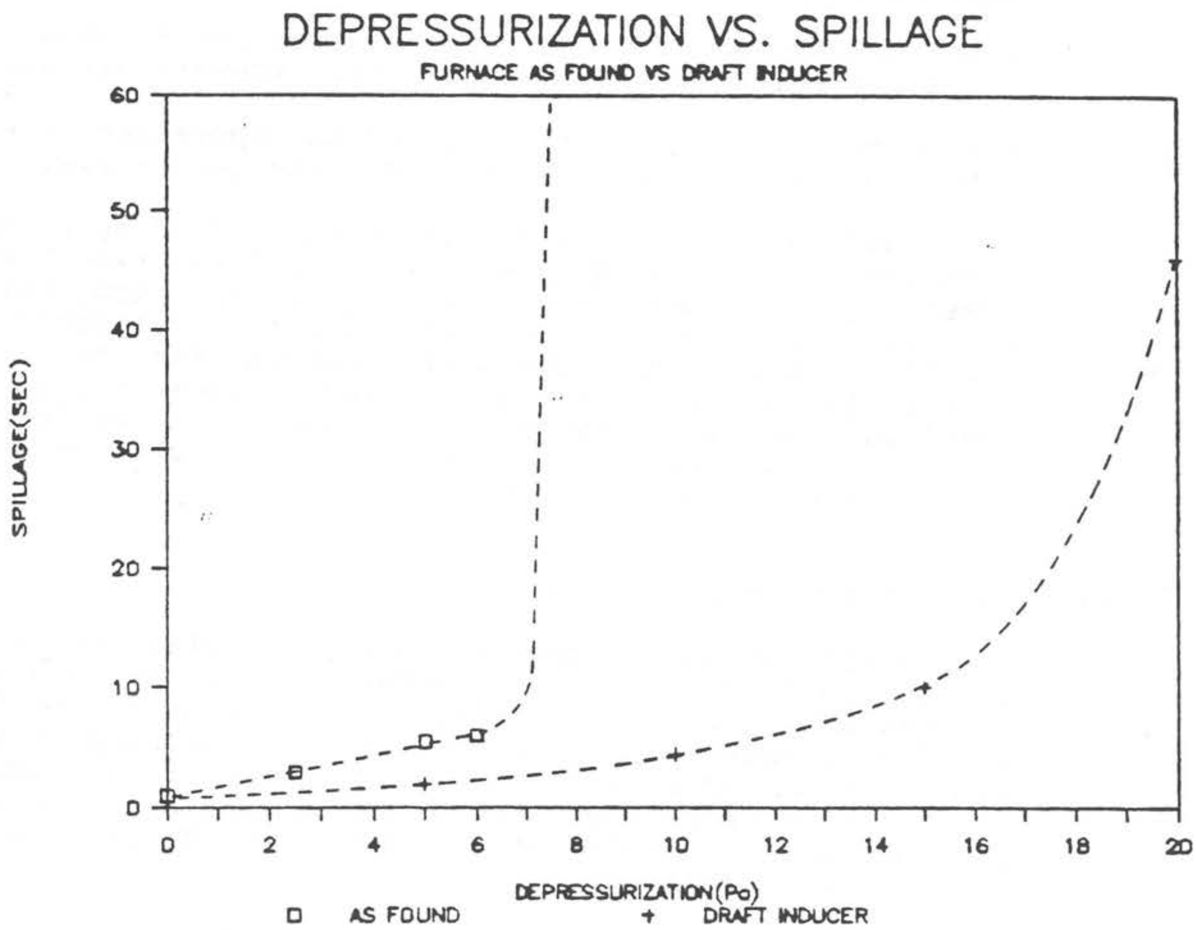


FIGURE 5.7: Depressurization vs. Spillage - Furnace as Found vs. Furnace with Draft Inducer

The proprietary chamber is not yet commercially available but it is easily fabricated without special tooling or equipment, as was the prototype tested.

The DAC was installed and tested on the same Ottawa furnace /house system as used for testing the spillage sensing switches and draft inducing fan. The test procedure was the same as that used for the draft inducing fan; i.e. the effect of the chamber on the duration of spillage from the dilution port at various levels of house depressurization was determined.

Figure 5.8A is a plot of time to establish proper (i.e. upward) flue flow versus level of depressurization for the furnace/house system as found and with the DAC installed. Figure 5.8B is similar except that duration of spillage is plotted rather than time to initiate proper flue flow. The reason for this distinction is explained below.

Evaluation of the performance of the "draft-assisting chamber" in containing and reversing flow out of the dilution port requires a more rigid definition of spillage than that used in describing the performance of the furnace as found. Without the draft-assisting chamber in place, it can be assumed that any flow out the dilution port contains combustion products when the furnace is operating, and thus outward or reverse flow is synonymous with spillage of combustion products. With the "draft-assisting chamber" installed, the interface between the furnace and the room air becomes the bottom opening of the chamber (1 m below the furnace dilution port for the prototype tested) rather than the furnace dilution port. Detection of reverse flow at the bottom opening of the "draft-assisting chamber" does not necessarily imply spillage of combustion products; rather, it may mean displacement of ambient air in the chamber by combustion products accumulating within it. Thus spillage for this configuration is defined as spillage of combustion products out the bottom opening of the "draft-assisting chamber" rather than simply reverse flow at that point. Here, the measurements of temperatures within the chamber provided the additional data needed to distinguish between reverse flow of air and actual spillage of combustion products.

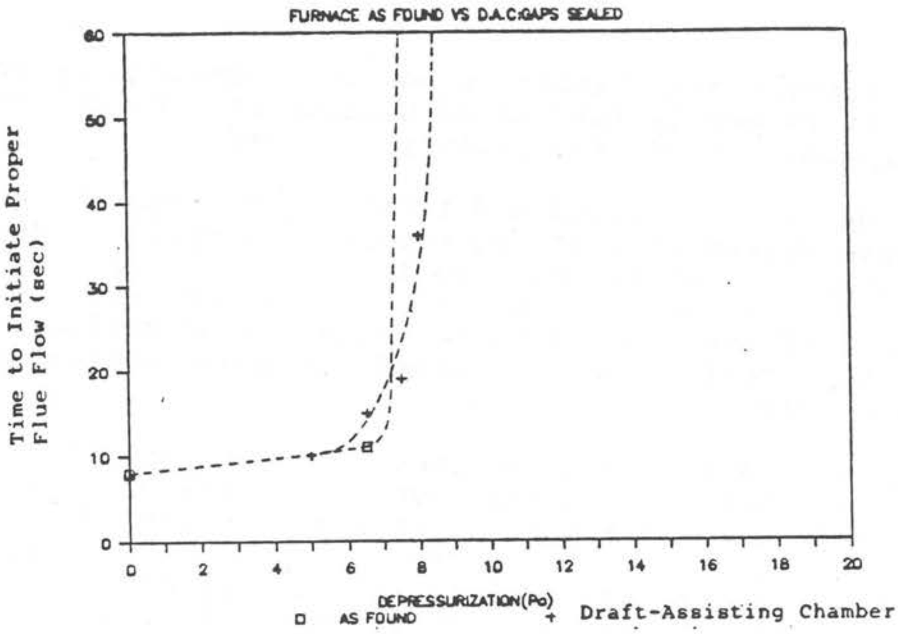


FIGURE 5.8A: Depressurization vs. Time to Initiate Proper Flue Flow - Furnace as Found vs. Furnace with Draft-Assisting Chamber: Gaps Sealed

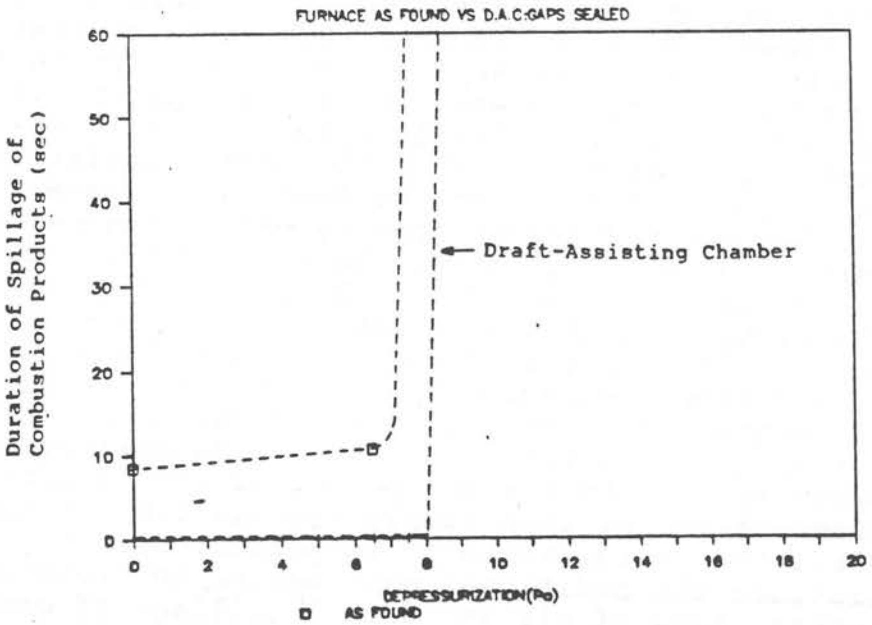


FIGURE 5.8B: Depressurization vs. Spillage of Combustion Products at System Opening - Furnace as Found vs. Furnace with Draft-Assisting Chamber: Gaps Sealed

Therefore, with the "draft-assisting chamber" installed, two events were watched for. These were -

- initiation of upward draft, as indicated by direction of flow at the bottom opening of the draft-assisting chamber, and

- spillage of combustion products as indicated by direction of flow at the bottom opening of the draft-assisting chamber and by temperature of that flow.

It was found that the "time to initiate upward draft" was about the same with or without the "draft-assisting chamber". This is shown in Figure 5.8A.

On examining Figure 5.8A, it is apparent that the incorporation of this particular prototype "draft-assisting chamber" has not significantly improved the time required to initiate proper flue flow compared to results for the furnace as found. At best, it has increased the house depressurization limit by about 1 Pa.

However, the system did, in fact, perform significantly differently with the "draft-assisting chamber" in place in that there was no spillage of combustion products until the house depressurization limit was reached. This is shown by the right-angled duration of spillage line in Figure 5.3B. The vertical separation between this line and the curve for the furnace as found represents the benefit of the chamber in containing the spilled combustion products.

Thus the prototype "draft-assisting chamber" evaluated in these tests has been shown to be an effective remedial measure for containing spillage of combustion products from the dilution opening of naturally aspirating gas furnaces in houses where combustion venting is a minor problem. Unfortunately, the prototype tested does not appear to improve the house depressurization limit significantly.

The reasons for this lack of significant improvement are not clear at this stage, since theoretical modelling showed a potential improvement in system driving pressures of the order of 3 Pa. One explanation can be postulated at this stage: The particular prototype chosen may have allowed the hot portions of the gases to stratify out of the way of the main backdrafting stream, thus losing potential buoyancy in that stream. Another factor may have been the fact that the test house had a rather high depressurization limit (7.5 Pa). The chamber would be expected to have a more pronounced effect in raising the depressurization limit of a house which started at a lower level.

This research has not addressed the issues of code and regulation amendments or waivers which might be required to permit the widespread use of the draft-assisting chamber. However, the results of the before and after heat-up/cool-down tests indicate that the draft-assisting chamber does not affect the normal operation of the furnace/flue system.

OIL-FIRED APPLIANCE REMEDIAL MEASURES

The combustion venting system of an oil furnace is significantly more complex than that of a gas furnace due to the presence of the burner blower and the barometric damper. The blower pressurizes the combustion chamber flue pipe and portions of the flue, thus helping to resist backdrafting but perhaps exacerbating any tendency to spillage. The barometric damper adds higher friction losses to dilution flow than is the case for a gas furnace dilution port but it also provides very strong resistance to spillage flow because it closes and presents very little flow area.

This complexity created problems in the research, resulting in several abortive, exploratory tests in addition to those that produced more tangible output.

Flue Pipe Flow

A very instructive test performed by Solsearch was designed to determine the effect of house depressurization on direction of flow in the flue pipe. This was accomplished by inserting an air flow meter in the flue pipe, approximately 1 m downstream from the furnace breaching, and recording flow while gradually depressurizing the room with a blower door. The burner fan was operating but there was no oil flow and hence no firing. The test was performed on a conventional oil burner (Aero Environmental Model FAFC), with a 1.25 USGPH nozzle and barometric damper, set up in the laboratory of Holland College in Charlottetown. The results are shown in Figure 5.9.

The point to note in Figure 5.9 is that, even without the buoyancy created by a firing burner, flow in the flue was positive (up the chimney) until the house was depressurized to 65 Pa. The significance of this is that we need not be concerned about **backdrafting** with oil furnaces. The burner fan is able to develop sufficient pressure (and the barometric damper closes and thus does not release that pressure) to overcome any level of depressurization likely to be encountered in a house.

Thus we need only be concerned about **spillage** of combustion gases due to an imbalance between the rate of flow through the furnace and the rate of flow up the chimney. When the

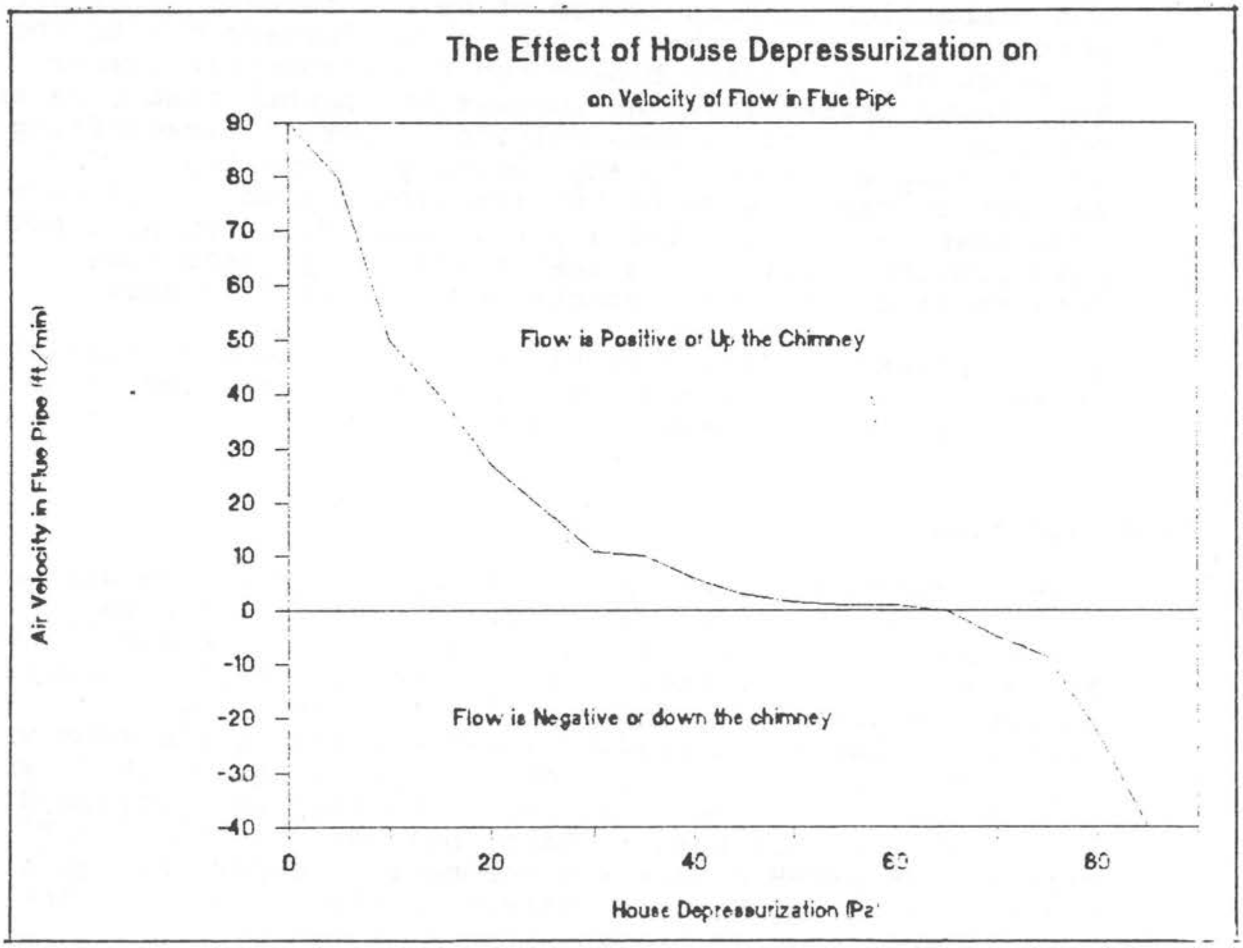


FIGURE 5.9: Effect of Depressurization on Flue Pipe Flows

rate of flow through the furnace exceeds the rate of flow in the chimney, even when the latter is upward, the flue pipe and portions of the flue will be pressurized and flue gases will be spilled into the furnace room through leaks around the barometric damper, along the flue pipe and at the flue pipe's connections to the furnace and the chimney. Such a condition is most likely to occur at furnace start-up, when the chimney is cold, and will continue until hot gases are introduced into the vertical portions of the venting system so that their buoyancy can accelerate flue flow to eventually match the furnace flow.

Solsearch looked at three remedial measures for oil furnaces subject to pressure-induced spillage:

- the solenoid oil flow delay valve
- the retrofit draft-inducing fan
- elimination of the barometric damper combined with a high pressure burner and insulated chimney

Solenoid Delay Valve

A delayed action solenoid valve allows the fan on the oil burner to activate before the oil flow is started. The fan pressurizes the combustion chamber and at least the base of the chimney. The laboratory tests conducted by Solsearch confirmed that this initial pressurization will reverse a backdrafting chimney before the burner fires and combustion products are created. However, because the flue pipe is pressurized, there can still be spillage from the unintentional or intentional holes (e.g. barometric damper perimeter). Thorough sealing of the flue pipe and all connections will reduce this spillage. Also, since proper flow in the chimney is established sooner relative to the burner's first firing, the duration of spillage of combustion products may be reduced; however, no measurements of the effects of this remedial measure on spillage duration were undertaken during these tests.

Draft-Inducing Fan

The induced draft fan, mounted on the flue pipe, draws the products of combustion out of the combustion chamber and then pushes this flow up the chimney. Because the induced draft and burner fans create different pressure regimes in the furnace-flue pipe-chimney system, they were tested both separately and together at the Holland College Energy Systems Technology Laboratory.

The results of these tests showed that the induced draft fan, especially if used in conjunction with a solenoid delay on the burner, can reverse backdrafts and minimize spillage under any likely house depressurization. Downstream of the fan there may be some start-up spillage at flue pipe joints, unless these are properly sealed. The key advantage of the induced draft fan over other oil remedial measures is that it depressurizes the flue pipe upstream of the device, thereby eliminating spillage through the barometric damper, flue pipe leaks and breech connection leaks. However, this device may also depressurize the combustion chamber possibly altering flame patterns. There was no investigation of the effect of the fan on furnace/boiler burner performance.

Elimination of Barometric Damper

The "high pressure burner/insulated flue combination" recommended by ESSO Canada was evaluated in this project. This retrofit system consists of three elements:

- replacement of the existing oil burner with a high pressure burner
- sealing of the flue pipe, including elimination of the barometric damper
- installation of a seamless, insulated flue liner in the existing masonry chimney, complete with wind-diverting cap

To test the improvement of draft due to this system, two houses were retrofitted with it. Tests before and after the installations showed a 4 to 7 Pa improvement in draft. The possible reduction in condensation due to the chimney insulation was not investigated.

The system does create improved chimney draft and results in fewer holes at which flue gas spillage can occur. The margin of improvement is not as great as with the induced draft fan and the cost of this retrofit is quite high. However, it may be a good option for homeowners with a furnace/boiler in good condition and a chimney in need of repair (e.g suffering from condensation problems). In many cases it may also provide energy savings due to improved efficiency and thus the cost can be offset against this benefit as well as its benefit to combustion venting.

MAKE-UP AIR SUPPLY REMEDIAL MEASURES

SRC's work was not oriented only toward specific measures, as was the other research centres', but also included investigation into general air supply issues. Thus their work could be classified as follows:

- general air supply issues
- effectiveness of air supply openings
- effectiveness of air supply fans

The work consisted of a large number of detailed tests. It could be said that the various tests were designed to arrive at what was already fairly standard engineering knowledge. However, as this knowledge has been largely overlooked or ignored in the context of regulating combustion venting, there was significant value in conducting tests which -

- placed this knowledge in a residential combustion venting context, and
- were done very carefully so as to eliminate extraneous variables and thus make the results convincing.

All tests were conducted in a 1960's vintage Saskatoon bungalow owned by SRC. It is of typical wood frame construction and has an equivalent leakage area of 520 cm^2 (as determined by testing in accordance with CGSB Standard CAN/CGSB-149.10-M87, "Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method". For the purposes of this project, the house was equipped with the following:

- a range top barbeque with integral exhaust fan rated at 165 L/s
- a range hood exhaust system rated at 130 L/s
- a clothes dryer, tested at 58 L/s exhaust capacity (cold) and 52 L/s (hot) at 0 Pa
- an air supply fan rated at 118 L/s
- various means of creating and closing air supply openings in various places in the building envelope.

The different pieces of exhaust equipment were operated singly and in a number of combinations with each other and in a number of combinations with the air supply fan and the air supply openings. The tests are too numerous to detail here; however, the more significant results can be summarized as follows:

Pressure Distribution

With the interior doors open and the furnace circulation fan not operating, any pressurizing or depressurizing effect of an exhaust or supply fan or supply air opening was felt uniformly throughout the house on a virtually instantaneous basis. Thus, the location of supply air provisions and the final point of delivery of the supply air appears to be not critical. Therefore, it need not be near either the exhaust equipment or the combustion equipment and its location can be governed by other considerations such as thermal comfort. This, of course, would not apply to houses with isolated or sealed furnace rooms.

Effectiveness of Air Supply Openings

With the 165 L/s range-top barbeque exhaust fan operating, opening a 152 mm diameter air supply opening (a 29% increase in the equivalent leakage area), either a simple opening or ducted, had no significant effect on the level of depressurization in the house. The same was true with the 52 L/s (hot) dryer exhaust operating.

Effectiveness of Air Supply Fan

Operation of the 118 L/s air supply fan was effective in overcoming the depressurizing effect of the 58 L/s (cold) dryer exhaust but could only partially offset the depressurizing effect of the 165 L/s range-top barbeque exhaust, leaving a level of depressurization great enough to be of concern from a combustion venting point of view. This residual depressurization would have been even greater in a more nearly airtight house.

Conclusions

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 a building 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.

SRC Project Manager David Eyre also gave considerable thought to the strategy that would be best suited to controlling a supply air fan and concluded that -

- start-up should be triggered by a latching pressure switch sensing the indoor/outdoor pressure difference and

- shut-off should be controlled by a timer which would run the fan for several minutes after start-up.

THE REMEDIAL MEASURES GUIDE

The knowledge generated in the remedial measures research and already available to Consortium members was synthesized into 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.

The Guide is not comprehensive, and in some cases describes procedures which have not been thoroughly field tested. It is hope the Guide will stimulate thought and discussion, and improve current trade practices.

The Guide briefly outlines the most simple solutions such as labelling or disconnecting exhaust devices, and replacing the heating appliance with induced draft, or sealed combustion systems. The Guide then describes seven different remedial measures that should be considered when selecting a strategy for problem houses. The measures are described primarily in terms of how they work and where they are most likely to succeed. "How-to-do-it" information is not included. The seven measures described in this Guide are:

1. Make-up air duct

   Make-up air can simply be ducted through a hole in the wall of a house. Increasing the supply of air to a house reduces the house depressurization at least to a small degree. This is a common approach to combustion venting problems and is required by many codes. Unfortunately, make-up air openings of the sizes required by many codes do not usually solve pressure-induced spillage problems. Without the assistance of a make-up air fan, a simple make-up air opening is usually inadequate to offset the effect of powerful exhaust devices.

   Make-up air ducts are most suitable for very tight houses. Design of make-up air ducts must consider inlet locations, suitable materials (particularly to eliminate resistance to air flow), and the best procedure for delivering air indoors (particularly for tempering the air).

2. Warning devices

These devices alert householders when combustion gas spillage is occurring, or after it has occurred. Audible alarms triggered by detectors which sense excess heat around the dilution air inlet are recommended for gas-fired furnaces and water heaters. For oil furnaces, a smoke alarm can be used above the barometric damper. For fireplaces, a combination of smoke alarm and carbon monoxide alarm can be mounted at the mantle above the centre of the fireplace. An alternative for gas and propane appliances is a dot detector, which leaves black dots as evidence that a prolonged spillage event occurred on at least one occasion.

3. Induced draft fan

An induced draft fan is a small fan shaped like a paddle wheel which penetrates part way into the vent connector (flue pipe) of a furnace and/or water heater. These fans can successfully overcome cold backdrafts at pressures of 15 to 25 Pa, and shorten the time period required for the chimney to warm and create sufficient natural draft. Induced draft fans can be installed as retrofit kits on existing appliances, but have traditionally been too expensive for widespread application because they have usually been installed with their controls interlocked with the furnace controls. Connecting the controls to water heaters has also proven very expensive. Alternative control devices, using heat detection instead of interlocking controls, may greatly reduce costs and make this a suitable remedial measure for many problem houses.

4. A blast fan

A blast fan is a powerful air supply fan installed in a house and used to temporarily pressurize a house whenever house depressurization might be causing chimney spillage. Blast fans (or other strategies relying on forced air supply) may have potential for remedying problems in many houses where problems exist due to powerful exhaust devices. This approach has not been widely field tested. It may offer some cost advantage over the induced draft fan due to simpler control strategies (e.g. tie-in to exhaust fan rather than furnace). Design considerations include noise, vibration, ease of installation, a suitable control strategy, and means of tempering of the outdoor air.

fireplace in the venting systems test complicates the test procedure and reporting without providing much useful information. Until low cost remedial measures are available for fireplaces, it may not be worthwhile to include fireplaces in the test.

In several cases, major depressurization of the furnace room was caused by closing of the furnace room door, or the basement door, while the furnace blower was operating. It now appears that there is a good argument for testing with the basement doors both open and closed.

Indoor Air Quality Monitoring Results

The case study reports contain a wealth of data on pollutant concentrations during failure event scenarios, and on the distribution and decay of pollutant concentrations following venting failures. Full summarization and analysis of this data was beyond the scope of this project; however, further detail is reported in the detailed technical report on Project 4.

PROJECT 7: COMMUNICATIONS STRATEGY

In developing a communications strategy, one objective was kept firmly in mind:

> To encourage and facilitate action, appropriate to the problem incidence and severity identified in Projects 1 and 5, on the part of those individuals and agencies in a position to take action to avoid or alleviate venting failures of combustion appliances in Canadian homes; i.e. to ensure the research results are put to use.

The key phrase in the above is "appropriate to the problem incidence and severity". CMHC wanted to ensure that no great effort went into developing an elaborate, wide-reaching communications strategy until it was clear that such a strategy was warranted. This meant that most of the work on developing the communication strategy had to be delayed until near the end of the overall project when the results of the Canada-wide Survey were known. As things turned out, the wisdom of this approach is apparent as the survey revealed that the problem, while substantial, is not epidemic in proportion and thus there is no need to create widespread alarm in the general public.

PREPARATORY WORK

Prior to the availability of the survey results, it was possible to do some preparatory work. This included the following:

- efforts to ensure that the final outputs of the individual projects were clear and suitable for their intended audience; e.g. that the chimney safety tests documentation is understandable by those who might be called upon to carry out the tests

- development of a network of individuals and agencies interested in following the results of the project and in a position to use those results

- development and pilot implementation of training courses for potential users of the chimney safety tests and the FLUE SIMULATOR model

The latter two of these are expanded on below.

DEVELOPMENT OF A NETWORK OF INTERESTED AGENCIES

The interdisciplinary nature of the chimney venting problem means that a broad range of groups have a role to play in transferring appropriate solutions. A basic communications requirement is simply to generate awareness of the study results amongst all such groups. Three broad target categories have been identified:

- government
- industry
- householders

To generate initial awareness of the study within the government and industry target groups, an information package describing the study was sent to about 160 organizations across Canada as part of a "networking" exercise.

The information package included a feedback form, which permitted respondents to order the summary report for the study as well as to order various background reports on venting failure topics. To gauge general interest in the FLUESIM and chimney safety test products, respondents were invited to indicate if they would be interested in attending pilot training workshops on FLUESIM and the chimney safety tests. General comments were also solicited.

Feedback forms were received from about 80 respondents. Most of these used the form to order a summary report and various background publications. Interest in the pilot workshops was high with about 55% of respondents expressing such interest.

No activities have been undertaken as yet to make householders aware of the project or its results.

PILOT FLUE SIMULATOR TRAINING WORKSHOP

A pilot training workshop on the use of FLUE SIMULATOR was held on September 19, 1986. The workshop was intended to convey to the participants:

- the capabilities of the program
- how to provide the necessary inputs
- how to understand the outputs

It was attended by seven persons from various federal and provincial government agencies and from energy utilities and heating equipment manufacturers. Each participant had use of a computer and a copy of the program and draft manual. Thus hands-on use of the program was combined with demonstration and instruction by the principal author of the program, Michael Swinton of Scanada. Participants were asked to fill in evaluation forms and their response was generally quite favourable. The workshop was an important first step in making the industry aware of the program's potential and also provided an opportunity for some initial feedback from industry, which has already resulted in some last minute detail refinements to the model.

PILOT CHIMNEY SAFETY TESTS TRAINING WORKSHOP

In September 1986, a one-day pilot training course was held to introduce the chimney safety tests to members of the heating trades, utilities and government inspectors. The course was designed to train the participants in the use of the various tests/procedures for determining whether a house may experience a venting failure, and if so, how to remedy the situation. Although the workshop content is intended for a two day workshop, time constraints required that the pilot workshop be condensed to one day.

In the morning, there was a lecture session utilizing two manuals developed for the workshop, a slide show and the tests, all designed to involve the participants and get them thinking about the materials being presented. The afternoon session involved an on-site walk-through of the checklist procedure, involving each participant in at least one step of the procedure. A follow-up discussion was held to discuss the findings in general and review remedial measures developed as part of the CMHC project.

The workshop was very well received, the only criticism being that not enough time was allowed to cover all the material. The industry representatives considered that such a course would be a valuable tool in the upgrading of their service departments. The 12 attendees were supportive of the program presented by the workshop and felt there was an immediate need and use for it in the industry. Contractors appeared to learn from the discussion and appreciated the usefulness of the tests, although there was some doubt as to whether they would use the tests in daily operations -

unless such tests were requested by the householder or required by regulations.

The draft manuals need further refinement, but provide a strong basis for any training program.

FOLLOW-UP COMMUNICATIONS STRATEGY

The results of our field research indicate that undesirable combustion gas spillage events may be occurring in up to ten per cent of Canadian homes. However, the precise nature of the health and safety risk posed by such spillage events cannot be defined without further study (see Project 4 - Hazard Assessment). Consequently, there is insufficient evidence to warrant the major communications initiative which would be required if a serious and widespread health and safety risk had been identified. Nevertheless, there is a need for a moderately-paced communications strategy which would ensure that the results of the study are disseminated and acted on. The objective of such a "follow-up" communications strategy would be to establish broader awareness of the venting safety issue and to encourage the use of the diagnostic and remedial techniques that have emerged from our work. Implementation of training programs for the chimney safety tests and associated remedial measures would be a key element of the follow-up program.

The strong interest in the study expressed during the networking process and the fact that most Federal and Provincial energy conservation programs have already begun to warn consumers about the "backdrafting" problem indicates that (1) there is broad consensus that a venting failure problem exists and (2) that there is a growing demand for information on how to avoid or correct such failures. This, in itself, suggests that a follow-up communications program would be desirable. Furthermore, it is the Consortium's view that, if adequate communications initiatives are not taken, there is a significant risk that the "spillage" problem will encompass a growing number of Canadian houses with detrimental effects on health and safety. The number of affected houses is likely to grow due to current trends towards tighter houses, greater use of exhaust fans and supplementary wood heaters, and widespread fuel conversions and furnace modifications. Each of these factors creates adverse operating conditions for chimneys and hence greater potential for chimney failure and resulting combustion gas spillage.

As noted, the health and safety risks associated with such spillage events cannot be clearly defined at this time. Fortunately, our research does indicate that life-threatening incidents due to spillage-related carbon monoxide build-up are likely to be rare. However, the longer-term health risk, especially from corrosive gases such as NO_2 and SO_2 may be of greater concern, especially in view of the potentially large number of "spillage" houses noted above. Therefore, until the precise nature of the risk is clarified through future research, it would appear to be advisable to develop a communications strategy aimed at providing both tradesmen and the public with information on how to minimize exposures to spillage gases.

Summary Of Key Elements of the Communications Strategy

In view of the above considerations, we believe that a follow-up communications strategy should be developed. In our view, the communications strategy should involve the following key elements:

(1) direct distribution of the summary report to key government and industry officials to raise awareness of the venting safety issue and to encourage appropriate action

(2) distribution of the summary report to key media outlets serving the industry and the general public to broaden awareness of the venting safety issue

(3) distribution of the FLUESIM model, with appropriate technical support, to appropriate users so that the model can be put to use in research and design applications

(4) refinement of the draft training packages for the chimney safety tests to facilitate transfer of the test procedures to new users

(5) development of awareness and training programs on appropriate remedial measures for use in association with the chimney safety tests

(6) development of arrangements to transfer the chimney safety tests to the appropriate industry groups via training arrangements with key trades organizations such as HRAI, NECA and CHBA

(7) consideration of pilot programs to test the delivery of the chimney safety test procedures by tradesmen in a non-research environment

(8) distribution of the Householder Venting Safety Check-list and development of supporting consumer information materials which would raise awareness of the venting failures problem without generating undue concern

(9) liaison with relevant government programs, standard-setting agencies, and code authorities to encourage information-sharing and coordinated action on venting safety issues

(10) development of a longer-term communications strategy to promote full implementation of the chimney safety tests and remedials after industry training programs have been completed

All of these elements are discussed in detail in the Project 7 Final Report.

Longer-term Communication Strategy Development

The technical development focus in the short-term will be on clarifying the extent of the hazard, training tradesmen in the chimney safety test procedures, establishment of standards for the use of the chimney safety tests, and finalizing proven and approved remedial measures. The thrust of the follow-up communications strategy is to facilitate this development through effective information exchange arrangements.

Once the short-term development work has been accomplished, there will be a requirement for a communications program designed to achieve full implementation of appropriate measures to prevent combustion venting failures. This would include:

(1) widespread use of the Venting Systems Test to check all residential modifications which could affect combustion venting

(2) widespread use of the all of the chimney safety tests to diagnose problem houses or suspected houses

(3) improved sensitivity of the heating service trades to the venting safety issue during normal furnace maintenance

(4) implementation of better alarms and advisers to warn occupants of venting failures

(5) use of a proven set of remedial measures

(6) improved consideration of venting safety in the design and installation of all new fan, fireplace, DHW and furnace appliances

OVERALL PROJECT SUMMARY AND CONCLUSIONS

This project was undertaken to meet the following broad objectives:

- to improve understanding of the combustion venting problem
- to determine its severity and occurrence in Canada
- to develop improved techniques for identification and diagnosis of the problem
- to develop appropriate preventative and remedial measures
- to identify ways to encourage and facilitate the implementation of these preventative and remedial measures

The project went a long way towards meeting these objectives and significantly advanced the state-of-the-art in this field.

Problem Understanding

Significant strides where made in developing improved understanding of the combustion venting problem. The survey and field testing (Projects 1 and 6) highlighted a number of combinations of causes of venting failure that had not been fully appreciated previously. For instance, some chimneys produce such low draft that even small depressurizations of the house can produce prolonged spillage and/or backdrafting. The combination of a weak chimney with a retrofit-airtightened building envelope is now thought to be an important cause of the relatively high incidence of venting problems in pre-1945 housing stock found in the survey - a portion of the stock that was presumed to be relatively free of venting problems before the survey. Some chimney retrofit work in the older stock may also be problematic in that restriction of the flue as a result of retrofitting a liner without also reducing the firing rate of the appliance may more than counteract the improvement in thermal properties the liner creates, resulting in prolonged combustion gas spillage.

Project 6 confirmed the "systems" nature of the problem in that most case study houses had **several** factors that contributed to their combustion venting problems. Modelling in Project 2 also highlighted the "systems" nature of the problem by showing that the venting performance of a chimney depends not only on its own characteristics and location but also on the circumstances in which it is required to operate. For example, one group of simulations showed that, with moderate house depressurization, interior and exterior B-vents would perform similarly if standby times between furnace firings were less than about 16 minutes, but would perform dramatically differently if the standby times were longer than that. (The exterior B-vent backdrafts.) Similarly, both B-vents would perform significantly better than an exterior masonry chimney if the standby times were shorter than 16 minutes but the performance of the exterior B-vent would fall to that of the masonry chimney (i.e. backdrafting) if the standby times were longer.

The survey, the field case studies and the modelling work all confirmed that exterior chimneys will be more **likely** to experience venting failure than interior chimneys, although this will not manifest itself in all cases - the difference in performance of the exterior chimney may be dramatic or subtle. Leaky exterior chimneys produce very low draft due to the cooling action of cold exterior air leaking into the flue. Against even modest house depressurizations, such chimneys have no net driving pressure at all, and backdraft. In addition, exterior masonry chimneys without metal liners have a high potential for condensation, leading to probable long term structural deterioration. On the other hand, a tight, lined or insulated exterior masonry chimney may not perform significantly worse than an interior chimney in a similar house if the furnace standby times are not too long. It can be concluded that a poorly designed and/or constructed exterior chimney is less forgiving than a similar interior chimney if it must operate in a problematic venting environment (i.e. depressurized house and long standby times).

Severity and Occurrence of the Problem

The country-wide survey (Project 1), the follow-up inspections (Project 6), and the hazard assessment (Project 4) have yielded a first indication that the occurrence of combustion gas spillage in houses is widespread, but the consequence of these episodes is not immediately severe in most cases. This conclusion is based on the fact that problem houses identified in the survey - at least 10% of the gas heated houses sampled and approximately half of the oil heated houses - were shown to have definite weaknesses in their venting system which, if uncorrected, could be expected to cause venting failures on a regular basis. On the other hand, they also had, for the most part, either clean burning appliances or venting systems that vented enough of the potentially harmful combustion products enough of the time that none of the occupants in the survey were perceived to be at immediate high risk. However, one installation was found to be generating higher-than-expected levels of carbon monoxide.

The survey results, the modelling, the remedial measures research and the case studies all indicate that spillage from conventional fireplaces is virtually certain in all but the leakiest houses and that conventional glass doors provide no additional protection against this spillage.

Because the potential for combustion gas spillage is estimated to be high in a significant portion of the Canadian housing stock, there is a responsibility placed on the housing and heating industries to improve the margin of safety against life- or health-threatening combustion venting failures. There are two approaches by which this can be accomplished, both of which should be pursued with equal vigour -

- designing, installing and maintaining heating appliances to burn as cleanly as possible, and
- reducing the factors in the interfacing of heating appliances, venting systems and houses which lead to combustion venting failure.

Techniques for Identification and Diagnosis

A staged approach to identifying and diagnosing venting problems was developed, tested and refined over the course of Project 3, with contributions from Projects 1, 2 and 6. The products of this work are a set of test and procedures - the chimney safety tests - that have been tailored to the various needs of the industry and homeowners, and a number of tested devices that can be used to identify houses for survey purposes and/or for warning the occupants of combustion venting problems.

The tests and procedures were designed to provide a reliable approach to finding and diagnosing the causes of combustion venting failures accurately and cost-effectively for individual installations. They have been recorded as detailed, step-by-step checklists in a draft Chimney Safety Tests Manual.

The chimney safety tests are in an advanced stage of refinement. The procedures and manuals have been tried with trades personnel in pilot courses (Project 7), and are ready for transfer to industry.

The spillage detection devices/alarms were developed to a point where they could be used for the purposes of this project, and have potential commercial value outside of this project.

Preventative and Remedial Measures

A variety of preventative and remedial measures has emerged from the project.

Perhaps the most fundamental preventative measure is the improved understanding of the combustion venting process which has resulted from the project. Once disseminated, both the qualitative understanding that the research has provided and the ability to quantify that understanding which FLUE SIMULATOR allows will help designers, practitioners and officials in the housing and heating industries avoid many of the mistakes in appliance design and appliance/house interfacing that lead to combustion venting failure. This will primarily involve designing venting systems which can generate significant draft and avoiding house depressurization.

Although they will not prevent combustion venting problems, the detection devices investigated, when connected to alarms or warning devices, can prevent a venting problem from becoming a health problem.

This project has hopefully made it clear that simply putting a hole in the building envelope to supply make-up air is often not sufficient to prevent or remedy venting problems unless the area of the hole is a significant fraction of the envelope leakage area - a size that, in many cases, will be impractically large. The make-up air fan offers more promise, but it too can not be sized indiscriminantly - the required capacity is dependent on the capacities of the exhaust devices for which it is intended to compensate.

A number of other promising remedial measures were identified and researched. This research was not as comprehensive or conclusive as was (perhaps naively) hoped at the outset. In some instances, the research identified as many questions as it answered. Nevertheless, the draft inducer for gas and oil furnaces, the high pressure burner and solenoid for oil furnaces and the truly airtight doors for fireplaces can now be added, with a fair degree of confidence, to the repertoire of previously known remedial measures. All are now recorded, in a manner useable by trades persons, in the draft Remedial Measures Manual.

Encouraging and Facilitating Implementation

The final products of much of this work have been designed with implementation in mind. Thus:

- FLUE SIMULATOR is unusually user-friendly for a program of this type and has an extensive user manual.
- The chimney safety tests are recorded in simple language in a comprehensive manual.
- A trades-person-oriented Remedial Measures Manual has been drafted.

All of these have been presented to the industry and have been found to be generally suitable for their intended purposes.

The work of disseminating the project's results has already begun:

- o The chimney safety tests have been incorporated in two courses (for air sealing contractors and insulation contractors) being developed by the National Energy Conservation Association.

- o The venting systems test has been incorporated in a draft CGSB standard which, if implemented, would require the test to be performed on any house on which retrofit work had been performed which could affect the performance of the venting system (e.g. air sealing).

- o A paper* describing the project and its results was presented at a major building industry technical conference in the U.S. in December of 1986.

Further efforts to disseminate the results and encourage implementation of the preventative and remedial measures developed in the project are required. These efforts should be in keeping with the magnitude and severity of the problem as identified in Projects 1 and 4; that is; dissemination and implementation should be pursued with vigour and a sense of urgency, but there is no need to create widespread public alarm. A multi-faceted communication strategy along these lines has been drafted.

In summary then, the project has served a very useful purpose and has advanced the science and technology of combustion venting to the point where the heating and housing industries are now in an excellent position to take action to reduce the number of incidences of combustion venting failures in the Canadian housing stock.

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* Residential Combustion Venting Failures - A Systems Approach Michael C. Swinton, Sebastian Moffatt, Jim H. White
- presented to the Symposium on Air Infiltration, Ventilation and Moisture Transfer organized in Fort Worth, Texas in December, 1986 by the Building Thermal Envelope Coordinating Council

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