

**Residential Combustion Venting Failure – A Systems Approach**

**Project 5**

**Remedial Measures for Wood-burning Fireplaces:  
A Fireplace Spillage Advisor**

**RESIDENTIAL COMBUSTION VENTING  
FAILURE – A SYSTEMS APPROACH**

**PROJECT 5**

**REMEDIAL MEASURES FOR  
WOOD-BURNING FIREPLACES:  
A FIREPLACE SPILLAGE ADVISOR**

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RESIDENTIAL COMBUSTION VENTING FAILURE

A SYSTEMS APPROACH

FINAL REPORT

PROJECT 5:

REMEDIAL MEASURES FOR WOOD-BURNING FIREPLACES:

A FIREPLACE SPILLAGE ADVISOR

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

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January, 1987

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## STATEMENT OF PART V FUNDS

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

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

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

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

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**PROJECT 5: REMEDIAL MEASURES - A FIREPLACE SPILLAGE ADVISOR**

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*SUMMARY*

*This report describes the development and evaluation of a warning device - referred to as a "spillage advisor" - designed to alert householders when fireplaces spill combustion gases and smoke indoors. This research into spillage advisors is part of a larger project which includes research into a variety of remedial measures for houses with combustion venting hazards.*

*The development of a spillage advisor was felt to be an important first step for addressing fireplace problems, because the advisor promised to be low-cost, accurate, and appropriate for widespread application.*

*Extensive testing of various types of spillage detectors was undertaken in one Vancouver house. Temperatures, particle counts, and CO concentrations were measured in different locations while varying the type of fire and the quantities of spillage. The fire was forced to spill as a result of wind downdrafts, house depressurization, and blockage (a closed damper). Different brands of CO alarms and smoke alarms were tested for sensitivity to the spillage gases.*

*It was concluded that the optimum location for a fireplace spillage warning device is at the centre line of the firebox, attached to the front face of the mantle (or equivalent for fireplaces without mantles), and hung slightly below the lip of the mantle (or out from the wall) so as to catch the gas stream. Locations immediately below the mantle, or at the ceiling, are not recommended.*

*Neither a smoke alarm or a carbon monoxide alarm, on its own, is adequate as a spillage advisor. Spillage from fires at high burn tend to trigger the smoke alarm, where-as low burn (ember) fires trigger the CO alarm. Combining both detector technologies in the same alarm unit is the preferred design objective.*

*Control of the alarm for on/off switching, and for audibility, may be necessary due to the potential for frequent fireplace spillage occurrences.*

*The use of heat-resistant materials is not essential (although such materials could easily be used to house the detectors).*

*Spillage advisors can be hung from the mantle, or mechanically fastened in place. The use of 110 VAC wiring is essential and may complicate installations and dissuade potential users of a spillage advisor.*

*The greatest obstacle to production of a suitable spillage alarm for fireplaces is the cost of CO detectors for residential use (as high as \$175 each). However, new approaches to detecting CO are now being tested*

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*and patented and may provide the means for producing a combined CO and smoke alarm for fireplace use that retails in the \$40 to \$50 range.*

*Follow-up applications of a device designed along the lines of a spillage advisor has taken place during two surveys conducted for other parts of this research project. The surveys confirmed the usefulness and sensitivity of the two-detector system, although no attempt has been made to gauge response by occupants to spillage advisors.*

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## 1.0 INTRODUCTION

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.

The development of such a warning device (or "spillage advisor") was felt to be 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. The advisor is a way of indicating whether a need exists for more costly or difficult remedial measures. A preliminary assessment of alarm technologies indicated that such a device could be produced at a low cost. Initial investigations of ionization-type smoke alarms for detecting fireplace spillage (undertaken as part of the development of survey technology) indicated that 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.

Research on the fireplace spillage advisor has been conducted in parallel with research on a variety of remedial measures for combustion appliances with potential problems from pressure-induced spillage. A description of these other remedial measures, and an overview of the larger research project of which this work forms a part, is provided in the Appendix of this report.

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## 2.0 RESEARCH METHOD

Extensive testing of various types of spillage detectors was undertaken in one of the Vancouver test houses. This house is a typical Vancouver bungalow (ELA = 1480 cm<sup>2</sup>), constructed in 1940, with a full basement and an oil furnace. The house contained an open fireplace, without doors or air supply, the fireplace had an exterior unlined brick chimney, had a firebox of conventional dimensions. The fireplace had been used regularly by the occupant with no reported problems.

The procedures followed in this house included the preparation of a test fire using kiln-dried maple, and the simulation of different failure mechanisms to cause varying degrees and compositions of spillage. A door fan was installed in the house to simulate precise backdraft pressures at various times in the burn cycle, and blockage was simulated by incrementally closing the fireplace damper. Wind downdrafting was also tested, although no need existed to simulate wind downdrafts. During the day of testing, these were occurring on a regular basis due to gusty south winds impacting on the chimney top in a downward direction, as the air moved over a two-storey neighbouring building. The configuration of the test house and the neighbouring building are illustrated in Figure 1.

Temperatures in and around the fireplace were measured using a digital thermocouple. Particle counts in front and above the fireplace were recorded using a self-calibrating RION 2100 particle counter. The RION 2100 use two photo diodes to count pulses, as particles and air are pumped through an illumination zone. It samples for a 60 second period, and measures particle concentrations (pulses) for diameters of both 0.5  $\mu$ m, and 5  $\mu$ m. Concentrations can vary from 0 to 30,000 particles per litre.

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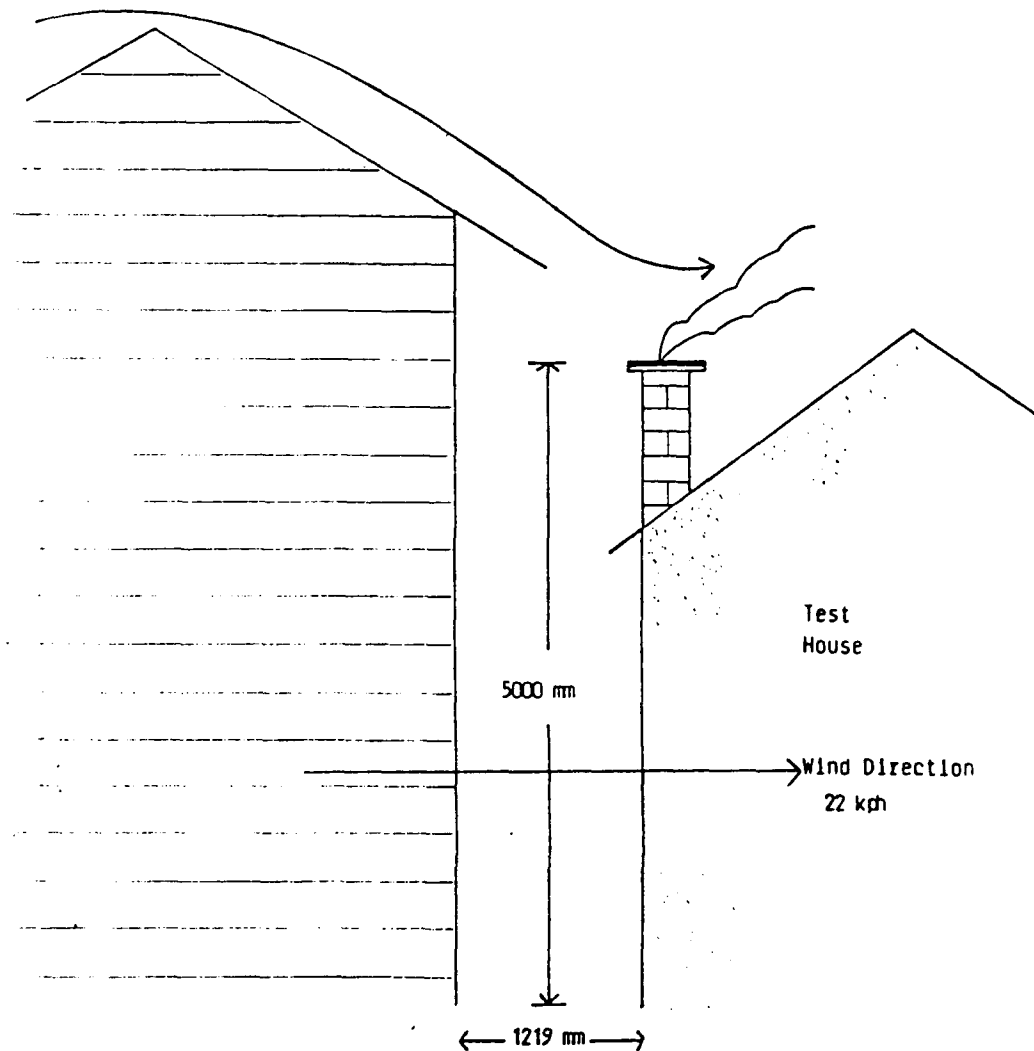


FIGURE 1: Geometry of Fireplace Chimney Clearance

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Carbon monoxide concentrations in the spillage gases were monitored on strip chart, connected to a portable, dual range Nova CO monitor. The Nova CO monitor uses an electrochemical cell. It was pre-calibrated using nitrogen, and a CO span gas.

Investigations of the design possibilities for a spillage advisor included subcontract work by an electrical engineer to develop alternative circuit board for use with smoke detectors. In addition, a visit was made to the head office of Dicon Ltd. in Toronto, Canada's largest manufacturer of smoke alarms. The Dicon facilities were toured, and a meeting was conducted with Dicon research personnel to evaluate the design and cost parameters. Other design features such as controls, portability and attachment mechanisms were explored in the Sheltair B.C. laboratory.

Simultaneously research was conducted into carbon monoxide detection technology, and discussions took place with various CO alarm manufacturers. Three types of CO alarms were obtained for evaluation with the smoke alarms during simulated failures in the test house.

### 3.0 RESULTS

#### 3.1 Optimum Location for the Spillage Advisor

Four different locations were chosen for evaluation purposes. Both smoke alarms and CO alarms were temporarily attached in each location. Figure 2 illustrates the location of the alarms and the dimensions of the tests fireplace.

Initially a hot high flame fire was created with the logs and kindling. This fire was caused to spill in a number of different ways, and at each spillage event the average response time in seconds was recorded for each alarm location. During the test period, puffing and spillage due to wind, downdrafts were occurring on a regular basis. (The householder was surprised to find that this was occurring.) In addition to the wind downdrafts, spillage was artificially created by forcing 3 Pascals of depressurization with the door fan, sufficient to cause marginal spillage. Full backdrafting was simulated by depressurizing the house to 10 Pascals. Spillage due to blockage of the flue was simulated by completely closing the (warped) fireplace damper, which create a blockage equivalent to 90% of the flue area.

Table 1 presents the response times of smoke alarms at each location for each type of spillage. The response times were rapid and consistent in both the centre mantle location, and below the mantle. A location left of centre produced inconsistent response, and the alarm mounted at the ceiling directly above the fireplace opening produced no response.

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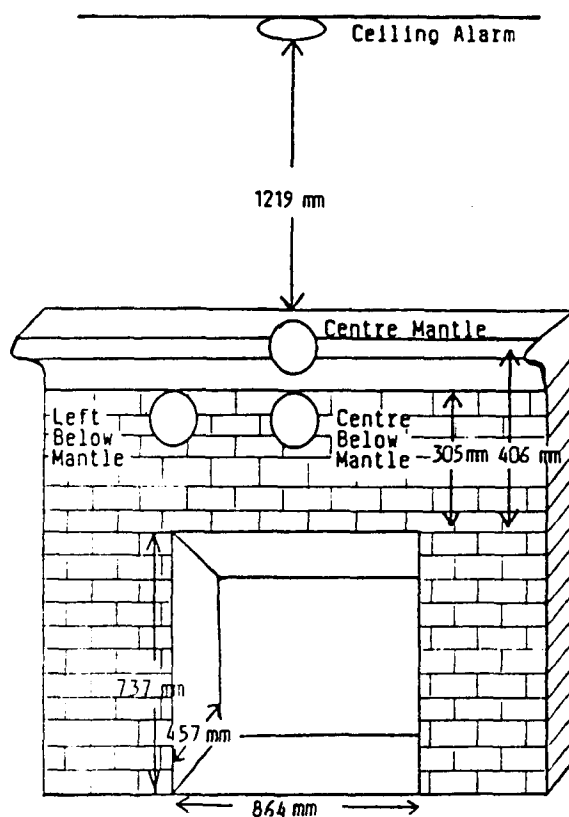


FIGURE 2: Location of Alarms and Dimensions of Test Fireplace

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TABLE 1: Response Times of Smoke Alarms at Different Locations for Spillage from Hot, High Flame Fire\*

<u>Location</u>	<u>Response Time (Seconds)</u>			
	<u>Puffing Due to Wind Downdrafts</u>	<u>Spilling Due to 3 Pa Depressurization</u>	<u>Backdrafting Due to 10 Pa Depressurization</u>	<u>Spillage Due to 90% Blockage</u>
Centre Mantle	3	3	3	3
Centre Below Mantle	10	10	3	4
Left Below Mantle	No Response	50	3	5
Ceiling	No Response	No Response	No Response	No Response

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\* Ember fire was also tested but no response was observed.

The flow characteristics of spillage gases appeared to be very similar for partial spillage, regardless of the reason why the spillage was occurring (wind, blockage, or marginal depressurization). A full backdraft condition, however, produced a markedly different spillage gas flow. Figure 3 illustrates the typical gas flows out of a fireplace.

There are two features of the gas flows worth noting: the spillage gases tend to rise directly up the face of the wall above the fireplace but a dead spot is created beneath the mantle; and the full backdrafting flows are more horizontal and much more diffuse, with a resulting dead space of greater dimensions.

On the basis of our detailed testing on one fireplace, conclusions were made about what would be the optimum location for the spillage advisor. The optimum location is illustrated in Figure 4. If the fireplace has a mantle, the best location is directly on the front face of the mantle, hung slightly below the lip of the mantle so as to catch the gas stream.

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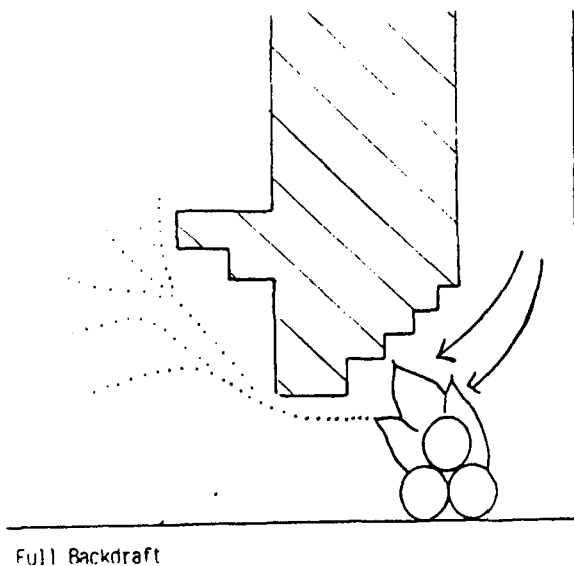
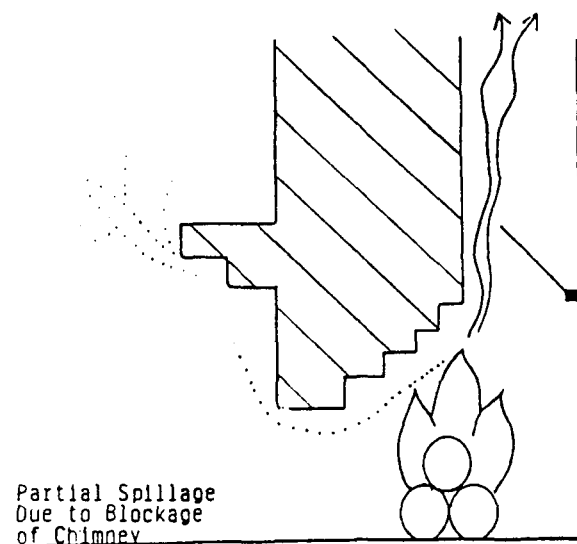


FIGURE 3: Typical Gas Flows Out of Fireplace



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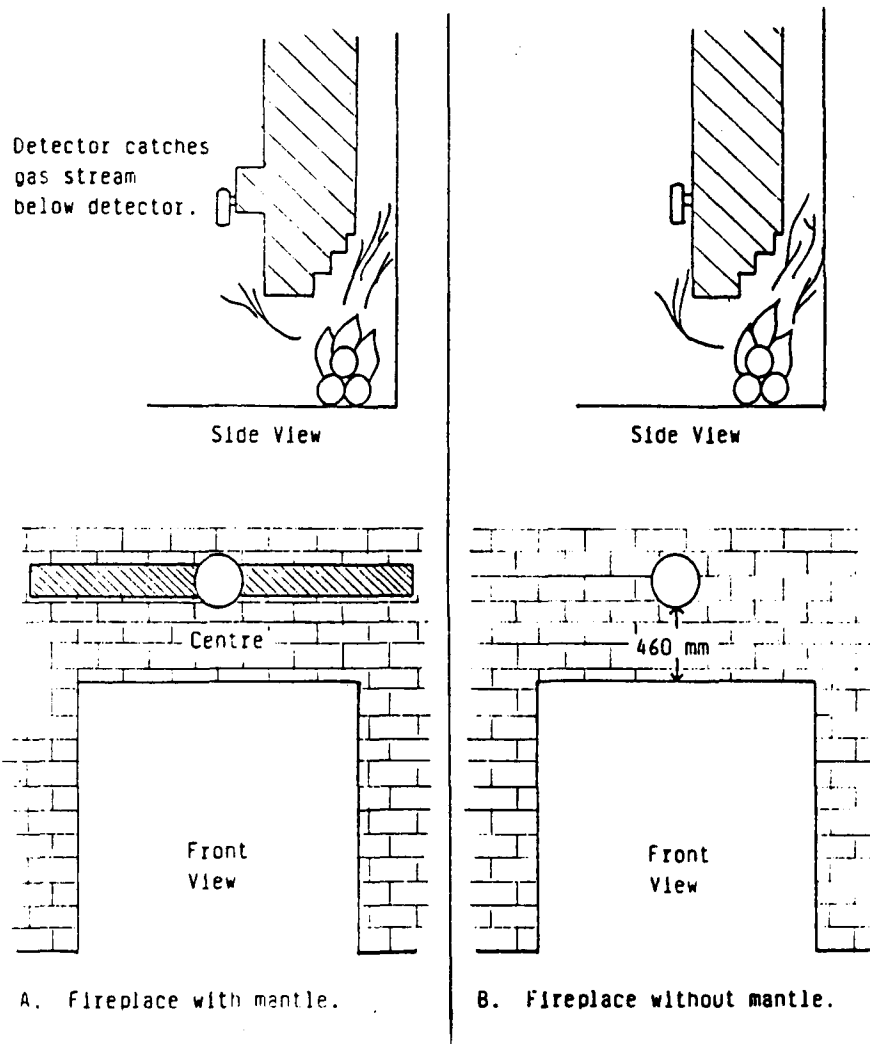


FIGURE 4: Optimum Location for Spillage Advisor

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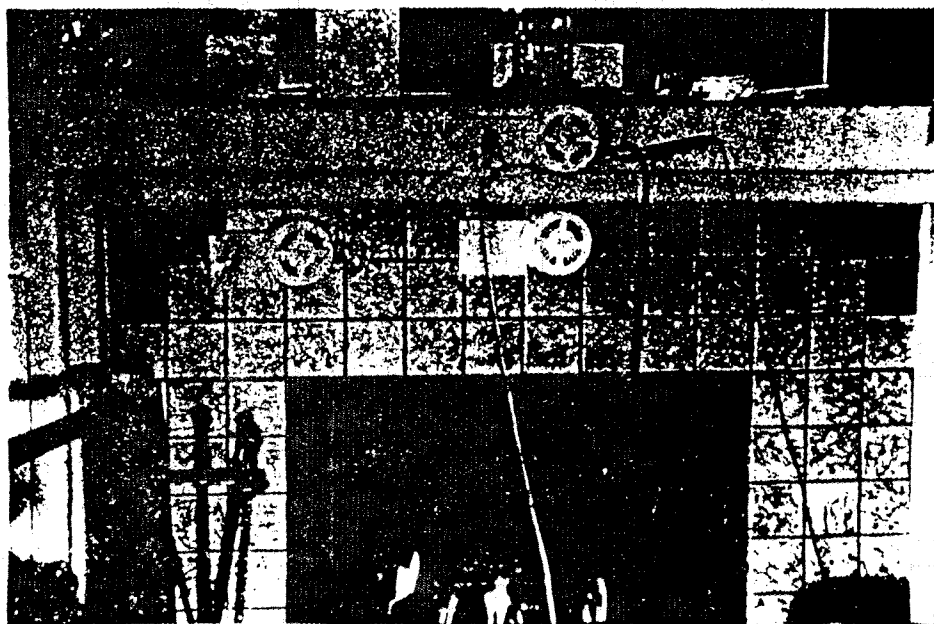


FIGURE 5: Photograph Showing CO Alarm and Smoke Alarms Mounted Above Test Fireplace

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Locations below the mantle might also be effective, but it would be important to avoid the dead spot at the extreme base of the mantle. On a fireplace without a mantle, the optimum location is presumed to be in the same general location, but with the detector artificially tilted out from the face of the wall, so as to extend past the dead air next to the wall.

### 3.2 PARTICLE COUNTS AND CARBON MONOXIDE CONCENTRATIONS

Repeated testing of fireplace spillage events allowed for a correlation between response time of the CO and smoke alarms with the particle counts and the carbon monoxide concentrations of the spillage gases. During this testing the fire was allowed to burn down to an ember fire so as to vary the composition of spillage gases. The results of this testing are presented in Table 2. Particle counts of 0.5 microns, or less, range from a low of 5,917 to a high of 91,117. The particle counts are taken over a 60 second period. Carbon monoxide concentrations range from 1 ppm to 235 ppm. The CO concentrations listed are normally the maximum recorded over the short spillage period.

The greater the quantity of spillage gas observable during the test, the higher the particulate count. However there was no correlation between concentrations of particulates, and the response time of the smoke alarms, or the concentrations of carbon monoxide.

As the fire began to die down and the wood became embers, the concentrations of carbon monoxide increased consistently.

However as soon as the flames were no longer apparent, the smoke alarms failed to respond to the spillage. An inverse relationship therefore existed between the concentrations of CO and the sensitivity of smoke alarms to spillage.

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TABLE 2: Fireplace Test CO and Particulate Data

<u>No.</u>	<u>Time From Start</u>	<u>Cause of Spill and Condition of Fire</u>	<u>CO ppm</u>	<u>Particulate &lt;0.5 um &lt; 5 um</u>
01	4:12	Wind downdrafts	44 max.	2,698 3
02	4:18	3 Pa. depressurization combined with wind downdraft	45 max.	
03	4:19	" "	none recorded	29,547 2
04	4:20	" "		6,998 7
05	4:23	Logs stirred with poker	18 max	6,998 7
06	4:25	" "	57	5,917 1
07	4:27	Fire starting to die out Medium flame	80 max	N.R.
08	4:28	" "	86 max	0,610 4
08	4:29	" "	62 max	9,618 2
09	4:30	Fire starting to die out Medium flame	86 max	7,682 5
10	4:32	Wind downdrafts 3 Pa. depressurization Low flame fire	82	30,979 2
11	4.33	" "		64,592 4
12	4:34	" "	12	40,849 2

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TABLE 2: Continued

13	4:35	"	"	131 max.	91,117 19
15	4:37	"	"	36	10,979 5
16	4:38	"	"	4	20,067 8
17	4:39	"	"	2	7,047 5
18	4:42	Damper intentionally closed		57 max.	80,700 N.R.
20	4:44	Damper opened		1	6,393 2
22	4:49	Full BD at 12 Pa		156 max.	31,018 4
24	4:52	Ember Fire (almost out) 3 Pa. depressurization		235 max.	45,000 N.R.
26	4:54	Ember Fire (almost out) 3 Pa. depressurization		191 max.	39,538
27	4:55	Ember Fire (almost out) 3 Pa. depressurization		260 max.	23,710
28	4:56	Ember Fire (almost out) 3 Pa. depressurization		182 max.	22,185 11
29	4:58	Ember Fire (almost out) 3 Pa. depressurization		186	18,166 6
30	4:59	Ember Fire (almost out) 3 Pa. depressurization		32	12,984 4

END OF TEST

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N.R. Not Recorded

The carbon monoxide alarm, on the other hand, did not respond to spillage from a high flame fire, since CO levels were consistently below the detection limit. Spillage from a low ember fire produced immediate response from the CO alarms, the alarms appeared to operate very close to the manufacturers specifications.

A particularly interesting observation made during the testing of the alarms was the lack of any visible smoke to indicate when spillage was occurring. Under none of the spillage conditions was it possible to visibly determine that spillage was in fact occurring from the test fireplace. Moreover the smell from the spillage gases was of that pleasant woody aroma (kiln-dried maple), and the personnel involved in testing quickly became desensitized to the presence of any spillage gases. For these reasons, it is important that people do not assume -as many experts have - that fireplace spillage is a failure which can be easily recognized by occupants of a house, and that spillage advisor could act as little more than a reminder of what is already rather obvious event. Throughout all of our testing the concentrations of particles and carbon monoxide were such that householders should have been warned but, in most cases, would have been unable to determine that a problem existed at all.

### 3.3 Design Features of a Spillage Advisor

#### 3.3.1 Detection System

Ideally the detection system used for a fireplace spillage advisor should be capable of alerting householders to the existence of both particles and carbon monoxide. Particles from wood fires contain known carcinogens, and therefore represent a definite long-term health risk. Carbon monoxide from fireplaces reaches high levels quickly, and therefore represent a life-threatening hazard.

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The research conducted on the single test fireplace would indicate that neither a smoke alarm or CO alarm, on its own, is adequate as a spillage advisor. Combining both detector technologies, in the same alarm unit, would be a much preferable design objective.

3.3.2 Control Strategies

Since fireplace spillage is a common event, it would be necessary to include on a spillage advisor an on/off or a delay switch for householders who don't want to be reminded of something they already know is occurring. This is particularly important once someone has been educated about their fireplace. They may find themselves in a position where it is hard to put the fire out and a lot easier to turn the alarm off. It may also be worthwhile to consider separate on/off switches for CO and particulate detectors (if the advisor contains both).

3.3.3 Audibility

Both the CO and smoke alarms contained a 65 db or louder alarm. This kind of noise makes talking in the same room impossible. Since the purpose of an advisor may vary from waking people while sleeping, to alerting people in the room to what is occurring, and since the size of houses and rooms vary, a good argument exists for allowing householders to adjust the volume of the alarm.

The smoke alarms manufactured for testing by Sheltair included an additional circuit board which altered the frequency and audibility of the alarm, allowing for a low and higher volume siren. Further fine-tuning of the alarm audibility was accomplished by means of applying silicone to the diaphragm of the siren.

#### 3.3.4 Materials

The materials used for a fireplace spillage detector must satisfy two criteria: Resistance to high temperatures, and esthetics.

Temperatures were monitored next to the alarms during the spillage simulations. As has been noted in the previous research on spillage detection technology, the temperatures above the fireplace opening are only 1 to 5 degrees in excess of room temperatures, even under major spillage conditions. It is assumed that as long the spillage advisor is located at the mantle, or above, the use of flammable materials is unlikely to cause problems, and is acceptable to the building authorities. However, tests done on the housings of typical smoke alarms revealed that these units are easily malformed at temperatures above 50 degrees C. Discussion with research personnel at Dicon Canada indicated that use of high temperature plastics would not be a problem when mass producing fireplace spillage advisors, and would prevent distortions from temperatures up to 200°C.

The esthetics of a fireplace spillage advisor is an issue that has not been explored. Because the advisor would be mounted in such a central and visible location, its appearance would either have to be camouflaged, or artistic. Since the response times of the detectors is rapid, it is expected that performance of the device will not present obstacles to developing a molding with an attractive appearance.

#### 3.3.5 Cost

It was initially hoped that the fireplace spillage advisors could be manufactured and sold in a similar price range to smoke alarms (\$10 - \$20). However if the spillage advisor must include a sensor for both CO and for particles, the cost will naturally be higher. CO sensors require more complex circuitry, and operate on 110 VAC.



The added cost of adding a smoke ionization chamber to a CO alarm is minimal, since the cost of components currently represent a small fraction of the final retail price. The greatest cost issue is the price of CO alarms, ranging from \$35 to \$175. Currently the low cost CO sensors are not adequate to detect carbon monoxide concentrations in the range measured during the fireplace spills (20 to 250 ppm). However discussions with a Vancouver manufacturer of CO alarms, Newtec Industries, have indicated to Sheltair that soon a major breakthrough can be expected in the sensitivity of conventional CO alarms, and that there may be a corresponding reduction in price. Unfortunately, prototypes of the new CO detector system could not be provided in time for evaluation as part of this report. Nevertheless the technology looks extremely promising, and it may be possible to produce a combined CO and particle detector for use with fireplaces that retails in a range of \$40 to \$50.

#### 3.3.6 Attachment

Various attachment mechanisms were explored for attaching the spillage advisors to the mantle or to the face of the wall above the fireplace opening. The easiest and most effective attachment is to screw the flange of the alarm directly into the wood of the mantle or the mortar of the brickwork. Since this may not be acceptable to the householder, and since this was not appropriate for our temporary installations, an alternative technique was developed. A flexible cord was attached to both sides of the detector and the detector was hung from the cord. The cord was attached to a tack or a nail affixed anywhere on the wall of the fireplace, usually at the very back of the mantle in a location that was not easily visible. This approach resulted in no permanent or obvious cosmetic damage to the mantle or fireplace wall. The adjustment of the location of the alarm could then be accomplished by altering the length of the cord.

Use of a CO alarm for a fireplace was initially felt to be problematic due to the added complexity of running 110 VAC wiring to a location directly

above the fireplace. Even if a mantle is present, the wiring is likely to be an eyesore as it drops to the floor at one end of the mantle. Whether this problem is likely to prevent widespread use of spillage advisors is not known.

The use of 110 VAC wiring does offer an advantage, however. Fire marshals have stated that battery-operated smoke alarms are frequently abused or misused and can quickly become non-functional due to missing or dead batteries. Thus, the installation of an alarm with the more costly 110 VAC power provides compensations in terms of long-term durability and ease of operation.

### 3.4 User Evaluations and Follow-Up Research Using Spillage Detectors

User evaluations of spillage advisors were attempted in the Vancouver area, although results could not be finalized due to an inadequate trial period, late in the season.

The approach taken was to alter the fireplace spillage detectors used in the Canada-wide survey. Ten detectors were manufactured by Sheltair for use as spillage monitors in survey houses where fireplaces were being used three (3) or more times per week. The detectors consisted of conventional smoke alarms with additional circuit boards containing mechanical event counters and time totalizers, and an on/off control on the alarm component.

After a month of spillage monitoring in the survey house, it was planned to request that householders turn on the alarms (high or low volume) and use the detectors as if they were spillage advisors.

A comparison of spillage events (if any) between the initial monitoring period, and the period between the alarm is operational, could have provided a basis for evaluating the effectiveness of the spillage advisor

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as a modifier of behaviour. When the alarms were removed from the houses, the householders could then be interviewed to solicit typical consumer responses to the concept of a spillage advisor.

The plan to evaluate spillage advisors was modified because of the late installation of the fireplace monitors, and an early spring. Warm weather prevented fires after the initial country-wide survey had been completed. CMHC and EMR undertook two subsequent surveys of fireplace spillage, as part of the larger research project of which this forms a part. These surveys used smoke detectors and CO detectors to monitor the frequency and duration of fireplace spillage under normal use. The detectors were connected to recorders - as opposed to alarms - and did not provide feedback on how householders might respond to a spillage advisor. However, the detectors were shown to be very effective at identifying spillage and confirmed the value of a two-detector system. Spillage occurrences were found to be a common event. Readers who are interested in how a spillage advisor might perform in a typical house environment are encouraged to refer to the reports on these surveys.<sup>1</sup>

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<sup>1</sup> Refer to: FINAL REPORT, PROJECT 1, PHASE 2: COUNTRY-WIDE SURVEY RESULTS; prepared for CMHC by Sheltair Scientific Ltd. and the Scanada-Sheltair Consortium Inc.; January, 1987. And to: A SURVEY OF FIREPLACE SPILLAGE INCIDENTS IN TWENTY-FOUR HOUSES; prepared for CMHC by Sheltair Scientific Ltd. and the Scanada-Sheltair Consortium Inc.; March, 1987.

#### 4.0 CONCLUSIONS

On the basis of detailed testing on one fireplace, the optimum location for a fireplace spillage warning device is at the centre line of the firebox, attached to the front face of the mantle (or equivalent for fireplaces without mantles), and hung slightly below the lip of the mantle (or out from the wall) so as to catch the gas stream. Locations immediately below the mantle, or at the ceiling, are not recommended.

Neither a smoke alarm or a carbon monoxide alarm, on its own, is adequate as a spillage advisor. Spillage from fires at high burn tend to trigger the smoke alarm, whereas low burn (ember) fires trigger the CO alarm. Combining both detector technologies in the same alarm unit is the preferred design objective.

Control of the alarm for on/off switching, and for audibility, may be necessary due to the potential for frequent fireplace spillage occurrences.

The use of heat-resistant materials is not essential (although such materials could easily be used to house the detectors).

Spillage advisors can be hung from the mantle, or mechanically fastened in place. The use of 110 VAC wiring is essential and may complicate installations and dissuade potential users of a spillage advisor.

The greatest obstacle to production of a suitable spillage alarm for fireplaces is the cost of CO detectors for residential use (as high as \$175 each). However, new approaches to detecting CO are now being tested and patented and may provide the means for producing a combined CO and smoke alarm for fireplace use that retails in the \$40 to \$50 range.

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RESIDENTIAL COMBUSTION VENTING FAILURE  
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APPENDIX "A"

OVERALL PROJECT SUMMARY

Prepared for:

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

Prepared by:

Scanada Sheltair Consortium

January, 1987

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

#### PROJECT 1 COUNTRY-WIDE SURVEY

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

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

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

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

#### PROJECT 2 MODIFICATIONS AND REFINEMENTS TO THE FLUE SIMULATOR MODEL

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

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

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

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

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

#### PROJECT 3 REFINEMENT OF THE CHECKLISTS

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

##### Venting Systems Pre-test

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

##### Venting Systems Test

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

##### Chimney Performance Test

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

Heat Exchanger Leakage Test

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

Chimney Safety Inspection

- a visual check for maintenance problems in the chimney system

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

PROJECT 4 HAZARD ASSESSMENT

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

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

The results indicate that, in most houses, one would rarely encounter acute, immediately life-threatening concentrations of pollutants as a result of combustion spillage from furnaces or water heaters. However, chronic health risk due to low level, long term exposure to pollutants, particularly NO<sub>2</sub>, may be a more significant problem which requires further investigation. High levels of CO do not seem to be caused by the problems which cause spillage and thus occur in spillage events only as a result of coincidence.



#### PROJECT 5 REMEDIAL MEASURES

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

The remedial measures identified for FIREPLACES were:

##### Spillage Advisor

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

##### Airtight Glass Doors Combined With An Exterior Combustion Air Supply Duct

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

The remedial measures identified for GAS-FIRED APPLIANCES were:

##### Spillage Advisor

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

##### Draft-inducing Fan

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

##### Draft-assisting Chamber

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

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

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

Solenoid Valve

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

Draft-inducing Fan

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

Elimination of the Barometric Damper

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

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

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

#### PROJECT 6 PROBLEM HOUSE FOLLOW-UP

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

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

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

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

#### PROJECT 7 COMMUNICATIONS STRATEGY

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

#### OVERALL PROJECT SUMMARY AND CONCLUSIONS

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

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

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

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