#2765

RESIDENTIAL COMBUSTION VENTING FAILURE

A SYSTEMS APPROACH

FINAL TECHNICAL REPORT

PROJECT 6:

CASE STUDIES OF HOUSES WITH COMBUSTION GAS SPILLAGE PROBLEMS:

A FOLLOW-UP TO THE CANADA-WIDE SURVEY

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STATEMENT OF PART V FUNDS

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

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

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

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RESIDENTIAL COMBUSTION VENTING FAILURE - A SYSTEMS APPROACH

PROJECT 6: CASE STUDIES: A FOLLOW-UP TO THE COUNTRY-WIDE SURVEY

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SUMMARY

This report describes the results of 20 problem-house investigations, conducted as a follow-up to a country-wide survey of residential combustion venting failures. Both the country-wide survey and the follow-up investigations comprise part of a larger research project entitled "Residential Combustion Venting Failures - A Systems Approach" completed by the Scanada-Sheltair Consortium Inc. on behalf of CMHC. Details on the country-wide survey results, and the test procedures used during these follow-up investigations, are documented in other reports. In addition, follow-up investigations intended to determine the spillage frequency and duration in problem houses are documented elsewhere.

The sample of 20 problem houses investigated included a mix of gas- and oil-heated houses, of construction dates, and of styles of houses, including some very tight houses and a preponderance of exterior placed chimneys. All 20 houses had shown evidence of excessive combustion gas spillage on at least one occasion over a three-month period during the heating season.

In all but one of the problem houses, chimney safety tests (i.e. diagnostic procedures) were able to establish a reason for spillage with a high degree of confidence. Backdrafting, due to house depressurization, was implicated in 75 percent of the houses investigated. Many houses with backdrafting problems were found to be particularly vulnerable to pressure-induced spillage due to a combination of other problems. The combination of weak draft in chimneys due to leakage, restrictions, undersized liners, and other factors, produced pressure-induced spillage in houses even at marginal levels of house depressurization (2 to 5 Pascals).

In several houses spillage problems were definitely related to extremely tight building envelopes, where even one or two weak exhaust fans could cause major amounts of chimney spillage. In other cases, the backdrafting problem was related to a powerful exhaust fan, and, in still other cases, the problem was a multitude of exhaust fans in an otherwise average house.

It was apparent that converting from oil to gas had increased the potential for combustion gas spillage in some houses, and not just because a gas appliance is inherently more susceptible to pressure-induced problems. Other factors contributing to poor chimney performance following fuel conversion included: longer flue connectors, reduced height of chimney, leakier flue pipes, flue size constriction, increased obstacles, lower flue gas temperatures, and increased holes and gaps in the chimney system.

Field testing during windy days emphasized the value of wind-induced draft, which prevented spillage in chimneys that might otherwise have experienced problems during the tests.

Spillage detectors used in the country-wide survey were shown to be more sensitive to DHW spillage than furnace spillage due to their design and location. Some gas furnace detectors performed poorly because of vanes in the furnace which were re-directing hot gases, extremely low exit temperatures for flue gases, or spillage being re-directed up the interior of the appliance as opposed to out the dilution air inlet.

In two of the problem houses, side-by-side chimneys caused a complex spillage problem. The use of the fireplace resulted in house depressurization, causing flow reversal in the furnace flue, thus drawing wood combustion gases to back into the house through the furnace flue, leading to subsequent air quality problems.

The oil furnace spillage detectors were found to be extremely sensitive to the 15 to 30 second start-up spillage which is common for this type of appliance. It is concluded that use of smoke detectors would be more suitable for identifying oil appliances with major or continuous spillage problems. An evaluation was conducted of the venting systems prior to conducting the test - a diagnostic procedure for characterizing potential problems in houses on the basis of a house description and inspection. Difficulties were encountered in estimating the equivalent leakage area of houses, and an alternative procedure was developed on the basis of these results.

Evaluation of the chimney safety tests emphasized the value of a flue pressure measurement as a way of recognizing houses where the chimney system suffers from exceptional leakage or constriction, and where established HDL's are therefore inappropriate.

Installation of warning devices - as opposed to conducting chimney safety tests - appears to be a good first step for houses with potential spillage problems.

Extensive amounts of indoor air quality monitoring data were collected on each of the problem houses. Ambient measurements in the houses "as found" were confused by the warmer weather and varying occupancy of the problem houses. One house had high indoor CO_2 *levels, but they were unrelated to combustion gas spillage.*

After one or two hours of testing, with the appliance cycled on and off in its failure mode, carbon dioxide levels in the problem houses were commonly in the range of 3000 to 5000 ppm. Estimated steady-state concentrations were not much higher. Grab bag samples of combustion pollutants from other locations in the houses indicated a delay of 10 to

30 minutes in peak concentrations, and showed that levels were always higher at the basement ceiling (return air plenum) than in other rooms.

High levels of carbon monoxide were measured in one case study house only, primarily as a result of a dirty burner and the lack of a forced air distribution system. Boiler rooms are suspected in presenting a special hazard for CO production in problem houses.

Short-term nitrogen dioxide rates in one test house were seen to exceed the proposed acceptable exposure range for short-term periods, and it is concluded that NO_2 may represent a significant health hazard from combustion venting problems.

Health hazards from venting problems will vary depending on the type of failure scenario. Acute, short-term hazards are most likely related to occasional backdrafting in a relatively tight house, or occasional backdrafting in a boiler room. Chronic health hazards are most likely related to continuous spillage, poorly designed, broken, or poorly maintained chimneys, or from regular backdrafting due to massive house depressurization in tighter houses with powerful exhaust fans, or from prolonged spillage at start-up - especially where leaky or constricted flues combine with marginal amounts of house depressurization.

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1.0 INTRODUCTION

This report is part of a larger research project into Residential Combustion Venting Failures, undertaken by the Scanada-Sheltair Consortium Inc. on behalf of the Canada Mortgage and Housing Corporation. The research included a country-wide survey into the extent and severity of combustion venting failures, as well as the development of computer models and field test procedures for diagnosing venting failures, and the evaluation of remedial measures for houses with venting problems. A more thorough description of the overall project can be found in Appendix B.

The Canada-wide survey of residential combustion venting failures involved the installation of spillage detectors in 938 houses. The detectors identified 63 gas-heated houses that appeared to have experienced excessive combustion gas spillage on at least one occasion during the first three months of 1986. Another 111 oil-heated houses appeared to have experienced excessive combustion gas spillage (or had inoperative barometric dampers).

A follow-up to the Canada-wide survey was undertaken, which included site visits to a subset of the 63 gas and 111 oil spillage "problem houses". Four problem houses were visited in each of five regions, or twenty problem houses in total. This report describes the results of these problem house investigations.

The follow-up visits to problem houses had four objectives:

1) to provide more information on the extent of the spillage problem in these houses, and especially to determine the causes of spillage;

2) to allow for a thorough field evaluation of the assessment and test procedures developed for identifying combustion spillage potential;

3) to assess the impact of the combustion gas spillage events on the indoor air quality in the problem houses;

4) to field test and evaluate the most appropriate remedial measures (and associated communications products), developed earlier as part of remedial measures research.

The results of the follow-up investigations into problem houses have been summarized in a case study format. In addition, this report includes a brief review of the procedures that were followed during the investigation (Part 2), and some general comments on the results of the investigation, and the implications for Canadian housing (Part 3).

2.0 PROCEDURES

2.1 Field Testing Procedures

Much of the procedure followed in each of the problem houses was developed previously as part of other projects, including the hazard assessment work, and the checklist refinement. Table 1 provides a brief listing of the steps taken in each house.

In general, the tests required a full day per house. The tests were conducted by two people. Each regional company provided a single research assistant for this purpose. The primary investigator in all cases was Peter Moffatt, a Sheltair employee working and travelling continuously for a period of six weeks.

The participation of one individual in all of the testing was originally proposed as a way of improving consistency and reliability of the test data, and allowing for continued improvement of test technique. It also made possible the use of expensive and specialized equipment in all problem house investigations. In practice, this approach worked well, and allowed for considerably more data to be collected in each problem house than otherwise would have been possible. The regional research assistants were, in most cases, well trained and knowledgeable building technicians who also contributed greatly to the success of the research.

TABLE 1: TEST PROCEDURES, STEP-BY-STEP

1. Inspect the spillage detector, and carbon monoxide alarm.
2. Set up, warm up and calibrate equipment. Set up instrumentation, and take measurements of building systems and components.
3. Examine spillage counters, and record spillage time since installation.
4. Sample indoor and outdoor air quality, as found.
5. Complete a Venting Systems Assessment.

6. Conduct a Comprehensive Safety Inspection.
7. Conduct a Heat Exchanger Leakage Test.
8. Conduct a Venting Systems Test.
9. Measure the Total Flue Pressure at standby, and after 5 minutes of operation.
10. Conduct an airtightness test of the house, and produce a vent pressure profile for determining exhaust fan flows.
11. Complete the FLUESIM Data Forms, and, where time permits, model the vent performance in the house using FLUESIM.
12. Complete the IAQ Data Forms, and, where time permits, model the indoor air quality (worst case scenario) using the IAQ spreadsheet program.
13. Estimate pollutant concentrations in the house for the failure mechanisms that have been identified
14. Use the depressurization fan to purge the house with fresh outdoor air.
15. Begin monitoring of systems performance parameters (e.g., temperatures, flows) and combustion pollutants (e.g., CO_2, CO, NOX).
16. Simulate or provoke a venting failure according to evidence of the dot detectors, counters, or FLUESIM program.
17. Periodically conduct active sampling and grab bag sampling in various locations in the house - particularly living area and bedroom.
18. Cycle appliance in typical fashion, and operate home in accordance with the worst case scenario.
19. Shut down the appliance after two hours of testing and disconnect all of the monitoring equipment (except carbon dioxide), for grab bag measurements.
20. Measure and calibrate air changes per hour using decay of CO_2 (if possible).
21. Conduct an interview with occupant, explaining the nature of the spillage hazard. Ask about system performance history, and health complaints.
22. Investigate or plan appropriate remedial measures.
23. Discuss follow-up actions and possible remedial measures with occupants.
24. Pack up equipment, clean up, and purge house.
25. Check operation of appliance.
26. Compare empirical data with computer modelling results and investigate discrepancies (as time permits).
27. Draft letter to householder.

It was originally planned to complete remedial measures on the problem houses shortly after the site investigations. For a number of reasons this was not possible. The budget did not permit remedial measures to be conducted on all problem houses, and it was necessary to wait for the completion of all testing before priorizing which houses were most suitable for which measures. It was also impossible to give clear directives to regional supervisors for installing remedial measures, when research on remedial measures had not produced clear guidelines of this sort. As a result, a plan for remedial measures research on these problem houses is currently under preparation. Guidelines for installation or application of measures by the trades are also part of the work-in-progress.

Problem house investigations were conducted from west to east across the country. Because of delays in getting equipment operational, a portion of the British Columbia problem houses was investigated after all other houses.

It was originally intended to complete investigations on four houses in each region for a total of twenty houses. In Toronto, however, only three houses were investigated. Two Toronto houses that were visited were not suitable for testing because of an error made in interpreting the numbers of black dots, or in recording these results. The unsuccessful visits to houses resulted in lost time which could not be made up within the tight schedule. As a consequence, an additional house was tested in the Ottawa region, resulting in five problem house case studies for Ottawa.

In Prince Edward Island, the house investigations did not include extensive indoor air quality monitoring, due to difficulty in simulating air quality failures for long periods of time, and to a lack of suitable equipment for monitoring pollutants from oil-fired appliances. The shorter testing time requirements in Prince Edward Island allowed for additional visits to houses, and for more careful evaluation of the checklist procedures. Consequently, five houses were visited in Prince Edward Island (instead of four). Also, the case study format for houses with oil-fired appliances is somewhat different from houses with gas-fired appliances.

2.2 Air Quality Monitoring and Modelling

Plans to monitor NO and NO_2 in all the problem houses were revised at the last minute, due to difficulties encountered with the test equipment. The chemiluminescent NOX meter used in the British Columbia problem house testing was found to be unsuitable for plane travel to the other regions, since its weight and bulk exceeded airport regulations. Consequently, additional testing was completed in the Vancouver test homes, to obtain more information on how NOX concentrations compare to CO_2 concentrations and distributions under various venting conditions. The results of this testing has been presented in a separate report (Project 4).

Modelling of the pollutant concentrations for each problem house was attempted during the on-site investigations. Discrepancies were found between the modelling and monitoring data; which, initially, prevented extensive use of the IAQ model in the field for projecting failure scenarios. After the site investigations work was completed, the bugs were eliminated from the IAQ program and, in the few cases where a comparison was made between modelling values and on-site measurements, a reasonable fit was achieved. This permitted a prediction of long-term, steady-state pollutant concentrations in the problem houses - information that could not have been collected in the field. This type of analysis has been generated for one case study only (House 2053), as an illustration of the technique. Further analysis was not completed.

2.3 Monitoring Spillage Frequency in the Problem Houses

A largely unsuccessful effort was made to monitor spillage frequency in the problem houses, using spillage times recorded with thermistor probes. Because of delays in project commencement, and delays in the survey execution, the heating season was almost gone by the time problem houses had been identified. Ideally, these spillage time recorders (or "spillage counters") would have been installed in all problem houses several months in advance of the site visits, and during the middle of the heating season.

The spillage counters were constructed from a light-weight, metallic box with a self-adhesive, high temperature backing. These boxes were easily stuck to the front of a furnace, or the top of a water heater, or the flue pipe near the barometric damper, in a similar manner to the spillage detectors used in the survey. Illustrations of the spillage counters, installation instructions, and a wiring schematic are presented in Appendix A.

The spillage counters contained a 9-volt alkaline battery, a thermistor probe, a mechanical digital time recorder, and a circuit board. The thermistors were ordered, to specifications, with an average time constant of 10 seconds, and a trigger temperature of 45°C. It was felt that fast response, consistent accuracy, and low power consumption were important design features. For these reasons, a high quality thermistor was used instead of a bi-metallic switch. Thermistors also permitted the control to be adjusted to varying "on" temperatures. Mechanical controls were 5V DC Hecon Impulse Timers. A mechanical device was necessary to avoid loss of data in the event the battery failed. The counter recorded one digit every 15 seconds, and could be wired so as to "remember" partial counts. The circuit board was designed to minimize current drain on the battery, since the thermistors required a constant power supply. A potentiometer was used for fine calibration.

Four spillage counters were supplied to each of the five regions during the telephone survey period. The regional supervisors were requested to install the counters immediately upon identifying problem houses. Due to the very short time period between phone surveying and site visits, this was not always possible.

During the on-site investigations of problem houses, the spillage counters were read and the total spillage time recorded. In some cases, the counters were installed during the site investigations.

During the on-site investigations, the appliances were made to spill hot combustion gases for prolonged periods as a part of the failure event simulations. The spillage counters were observed to function as intended, and provided an accurate record of the total spillage time. The spillage counters were re-labelled at the completion of the investigations, and left in the problem houses. By this time, however, the heating season was over and no useful data could be collected on the frequency of spillage vents.

A separate research project was funded by CMHC to re-install the spillage counters in 20 problem houses over the 1986/87 heating season. The counters were retrofitted for this purpose (to improve the life of the counters, their durability, sensitivity, and precision). Also, the counters will now record both total events and total time. Results of this follow-up work are available in a report titled, "Monitoring the Frequency and Duration of Combustion Gas Spillage in 20 Problem-Prone Houses," March, 1987.

3.0 RESULTS

Characteristics of the problem houses have been summarized in Tables 2 and 3, which separates gas-fired and oil-fired appliances. House numbers refer to the numbers allocated during the Canada-wide survey. The first digit of the house number is the regional code:

1 - Vancouver	(1001-1183)
2 - Winnipeg	(2001-2209)
3 - Toronto	(3001-3124)
4 - Ottawa	(4001-4193)
5 - Prince Edward Island	(5001-5228)

The sample of twenty problem houses includes a mix of construction dates and number of storeys.

The leakage areas of some of these problem houses were very small, especially in the Winnipeg region.

A predominance of exterior chimneys is evident (15 out of 21 houses), although only 53 percent of the entire survey sample had exterior chimneys. This corresponds with the statistics from the Canada-Wide Survey, which showed a significantly greater number of problem houses had exterior chimneys.

The furnace and water heater "spill temperature" refers to the temperature of the dot that turned black on the spillage detector. A black dot of 54°C or higher indicates an excessive spillage event (i.e., continuous spillage in excess of one minute).

Tables 4 and 5, Failure Mechanisms, summarize the reasons for spillage in gas-fired and oil-fired houses, respectively. Tables 4 and 5 also cite, the major contributing factors, and the possible remedial measures, identified during the problem house investigation in each house. Using

Table 2

SUMMARY OF PROBLEM HOUSE CHARACTERISTICS AND TEST DATA
(Gas-Heated Houses)

House #	Const. Date	No. of Storeys	ELA (cm^2)	Chimney Type	Furn. Spill (C)	DHW Spill (C)	HD Limit (Pa)	HD Limit (Pa)	HD Fans (Pa)	HD Fans Plus FP (Pa)	HD Fans Plus Furn. (Pa)	Total Flue Press (Pa)	Comments
2053	Post - 1975	1	415	Interior metal	54	71	6	5	11			12	Furnace back-drafted and f.p. spilled with fans on
2129	Post - 1975	1	250	Exterior metal	38	71	6	5	9	12		11	Furnace back-drafted with fans on
2022	1900-1945	2	472	Exterior masonry	71		5		6			18	Furnace back-drafted with fan on
2138	1945-	1	226	Exterior lined masonry	71	54	5	4	2	4.2	4	8	Flue 1960 restrictions caused major spillage
3056	1900-1945	2	2243	Exterior masonry	54	38	5	4	0	1	0	6.5	Boiler rebuilt improperly - major spillage
3113	1945-1960	1	704	Exterior masonry	121		5		8			16	Kitchen range caused furnace to backdraft
3102	1960-1975	2	1441	Exterior masonry	121		5		6	7.5	3.5	6	Tight furnace room caused furnace to backdraft
4181	1945-1960	1	470	Exterior lined masonry	121	38	5	4	7			10	Fans caused furnace to backdraft - liner restrictions caused furnace to spill
4184	Post-1975	1	857	Exterior metal	54	71	6	5	5		7	9	Fireplace fails in all cases; furnace & DHW fail with furnace room door shut

4004	1945-1960	2	891	Exterior masonry	54	71	4	4	3	6	5	12	Fireplace & fans fail DHW and furnace (heat exchanger cracked)
4002	Post-1975	1	587	Exterior metal	38	71	5	4	4.5	8.5	5.5	6	All appliances fail; smoke in basement
4135	Post-1975	2	512	Exterior masonry	121		5	4	3	6	6	16	Fireplace & fans cause failure; smoke in basement
1076	1945-1960	2	1715	Exterior masonry	71		5		1	2	1	3	Missing ash clean out cover and chimney was dwarfed by trees and houses
1128	1960-1975	1	1259	Interior masonry	71		5		2.5	6	6	17	Restricted chimney and 2 open fire-places caused appliance to spill
1142	1900-1945	1	1520	Interior masonry	54	38	5	4	3.5			17	Cause of spillage was unknown
1057	Post-1975	2	1668	Exterior metal	54	38	5	4	4	6	4	10	Restrictive flue chimney, and many exhaust fans caused appliance to spill and backdraft

The H.D. Limits have been extracted from the table in the venting systems test, and are a reflection of the chimney type, location and height.

The house depressurization (H.D.) for "fans", "fans-plus-fireplace", and "fans- plus-furnace", are all pressure measurements taken with the manometer while operating these appliances in the problem houses. (In some cases, it was impossible to record house depressurization from "fans-plus-fireplace", since fireplaces often spill when pressures exceed 3 or 4 Pascals.)

The "total flue pressure" refers to the maximum total chimney pressure measured with a plugged chimney after five minutes of appliance operation. Chimneys were plugged just above the dilution air inlet.

Table 3

SUMMARY OF PROBLEM HOUSE CHARACTERISTICS AND TEST DATA
(Oil-Heated Houses)

House #	Const. Date	No. of Storeys	ELA (cm^2)	Chimney Type	Furn. Spill (C)	DHW Spill (C)	HD Limit (Pa)	HD Limit (Pa)	HD Fans (Pa)	HD Fans Plus FP (Pa)	HD Fans Plus Furn. (Pa)	Total Flue Press (Pa)	Comments
5071	1900-1945	2	1510	Interior masonry	121		7		1.5	3.5	35	30	Weak chimney system
5027	1945-1960	1	670	Exterior masonry	121		4	4	0	0	0	8	Bad fuel
5107	1945-1960	1	Not known	Interior masonry	71 oil	93 wood	5					30	Unbalanced barometric
5146	1945-1960	1	800	Interior masonry	121		4		0			30	Down wind in chimney
5007	Post-1975	2	800	Exterior masonry	121		4		4.5			7	Fans failed furnace; also weak chimney

Table 4

FAILURE MECHANISMS AND REMEDIAL MEASURES IDENTIFIED IN GAS-HEATED HOUSES

House #	Reason for Spillage	Major Contributing Factors	Possible Remedial Measures
2053	1. Backdrafting (definite)	1. Tight envelope 2. Many exhaust fans 3. Open fireplace	1. Blast fan 2. CO alarm 3. Fireplace warning label
2129	1. Backdrafting (definite)	1. Tight envelope 2. Many exhaust fans 3. Open fireplace	1. Blast fan 2. CO alarm 3. Fireplace warning label
2022	1. Backdrafting (definite)	1. Tight envelope 2. Powerful exhaust fan	1. Interlock fan and boiler
2138	1. Spillage (definite) 2. Backdrafting (possible)	1. Chimney restriction 2. Tight envelope 3. Open fireplace	1. Replace chimney top 2. CO alarm 3. Fireplace warning label
3056	1. Spillage (definite)	1. Improperly rebuilt boiler	1. New gaskets and plates or new furnace
3113	1. Backdrafting (definite)	1. Tight envelope 2. Powerful exhaust fan in kitchen	1. Backdraft alarm (or) 2. Interlock of fan and and boiler
3102	1. Backdrafting (definite)	1. Leaky ductwork 2. No hot air register in furnace room 3. Down slope on flue connector 4. Leaky return air distribution system 5. Hole in chimney from DHW heater removal	1. Tape and caulk ductwork 2. Install hot air register 3. Correct slope problem 4. Grill in basement door 5. Plug hole in chimney
4181	1. Spillage (definite) 2. Backdrafting (possible)	1. Improperly sized flue liner 2. Restrictive flue top 3. Tight envelope 4. Power kitchen exhaust fan 5. Two fireplaces	1. Replace flue liner and top 2. Downsize system by eliminating appliance or interlocking appliances 3. Interlock kitchen fan 4. CO alarm
4184	1. Backdrafting (definite)	1. Tight furnace room 2. Faulty combustion air damper 3. Faulty defrost damper on air exchanger 4. Depressurization caused by defrost cycle on air exchanger	1. Remove door 2. Repair combustion air damper 3. Repair defrost damper 4. Install defrost on air exchanger exhaust 5. CO alarm and warning label for fireplace

4004	1. Spillage (definite) 2. Backdrafting (possible)	1. Weak chimney 2. Deterioration of tile lining 3. Tight envelope 4. Fans and fireplace 5. Cracked heat exchanger 6. Depressurization of furnace room	1. Replace barometric damper with improved version 2. Replace or re-weld heat exchanger 3. Line chimney and seal flue connector 4. Seal returns 5. Install warm air damper 6. CO alarm and warning label for fireplace
4002	1. Backdrafting (definite)	1. Tight envelope 2. Many exhaust fans 3. Open fireplace	1. Elevate furnace flue 2. CO alarm and warning label for fireplace 3. Induced draft kit
4135	1. Backdrafting (definite)	1. Tight envelope 2. Open fireplace	1. CO alarm and warning label for fireplace 2. Alarm on furnace 3. Extend furnace chimney
1076	1. Spillage (definite) 2. Wind Down Drafting (possible)	1. Missing ash clean-out 2. Chimney dwarfed by trees and houses	1. Extend chimney 2. Tighten chimney
1128	1. Spillage (definite) 2. Backdrafting (possible)	1. Poorly tuned burner 2. Chimney constrictions 3. Large number of exhaust devices	1. Tune furnace 2. Down-size nozzle 3. Tighten flue connector
1142	1. Spillage (possible)	1. Unknown	1. Unknown
1057	1. Spillage (definite) 2. Backdrafting (possible)	1. Poor installation 2. Chimney restrictions 3. Chimney dwarfed by trees and houses 4. Large number of exhaust devices	1. Increase size and slope of flue connector 2. Replace chimney top

Table 5

FAILURE MECHANISMS AND REMEDIAL MEASURES
IDENTIFIED IN OIL-HEATED HOUSES

House #	Reason for Spillage	Major Contributing Factors	Possible Remedial Measures
5027	1. Chimney blockage (definite)	1. Poor installation of energy efficient burner 2. Deterioration of chimney liner and brick 3. Heat exchanger cracked	1. New liner and insulation 2. Downsize and tighten flue pipe 3. Replace furnace (keep burner)
5071	1. Backdrafting (definite)	1. Delivery of impure heating oil with water contamination	1. Nothing
5107	1. No spillage (possible)	1. Barometric dampers not adjusted	1. Service or replace dampers
5146	1. Spillage (possible)	1. Short chimney 2. Chimney dwarfed by tall trees	1. Extend chimney 2. Install aerodynamic chimney top
5007	1. Spillage (definite) 2. Backdrafting (possible)	1. Unlined exterior chimney 2. Tight envelope 3. Powerful exhaust fans	1. Line chimney 2. Tighten flue connector

the Venting Systems Test, and the other diagnostic procedures, it was normally possible to establish a reason for spillage with a high degree of confidence (i.e., "definite"). In one of the houses, however, no definite failure mechanism was identified, and the reason for the black dots on the detectors remains a mystery.

Backdrafting due to house depressurization is implicated in a surprisingly high percentage of the problem houses investigated. This point is best illustrated by a reference to Table 6, which lists the relative importance of various failure mechanisms by means of calculating the percentage of episodes where a particular contributing factor was present. In 75% of the houses investigated, backdrafting was identified as one probable cause of spillage. This contrasts with previous statistics compiled by Hatch Associates Ltd., as part of a report prepared in 1983 for CMHC (Ref.1). The Hatch statistics, also summarized in Table 6, indicated a much lower percentage of houses where backdrafting was implicated as a contributing factor in carbon monoxide poisoning episodes. Because no standardized investigation or reporting procedures had been used for these 293 houses reported by Hatch, it is possible that the backdrafting factor had been overlooked in some cases. It is also possible that spillage caused by backdrafting is less likely to have high carbon monoxide content that other types of spillage.

In several houses (e.g., House Nos. 2053, 4002 and 5007), the spillage problem was definitely related to an extremely tight building envelope. These houses are so tight that even one or two weak exhaust fans are capable of causing major amounts of chimney spillage. In other cases (eg. House Nos. 2022 and 3113), the backdrafting problem was directly related to a powerful exhaust fan like a kitchen barbecue, and the spillage events are probably directly related to the usage of that fan. In still another house (House No. 2129), the backdrafting is a result of multiple exhaust fans, and an average ELA. It is thus impossible to

Table 6

RELATIVE IMPORTANCE OF FAILURE MECHANISMS

Failure Mechanism	20 Case Study Problem Houses With Recorded Combustion Gas Spillage	213 Houses (or Recreational Vehicles) With Recorded CO-Poisoning Episodes*
1. Equipment problems due to poor maintenance damage, defects, fuel problems, cracked heat exchangers.	35%	46%
2. Constricted, collapsed, dislodged, damaged or excessively leaky chimneys, vents and flues.	35%	31%
3. Backdrafting due to house depressurization (often in combination with weak chimneys and wind downdrafts)	75%	25%
4. Improper installation or retrofit of equipment, chimney vents and flues. Lack of understanding of equipment operation, and chimney draft.	35%	24%
5. No definite cause apparent.	5%	(not reported)

* Results of 1983 Survey of Records on co-poisoning incidents across Canada, 1973 to 1983, reported in "Hazardous Heating and Ventilating Conditions in Housing", by Hatch Associates Ltd., prepared for CMHC, November 1983.

finger one housing feature that is responsible for the high number of backdrafting problems.

3.1 Highlights of Problem House Investigations

3.1.1 Failure Mechanisms Identified for Gas-Fired Appliances

Gas Conversions Implicated in Spillage Events:

In a number of the problem house investigations, it was apparent that converting from oil to gas had increased the potential for combustion gas spillage, sometimes in ways which may not be apparent to any particular regulatory or code setting organizations. In addition to replacing a forced draft burner with an atmospheric draft, conversions to gas heating contributed to poor chimney performance as a result of:

1) Longer flue connectors. Both the gas and oil furnace will be situated so as to face away from the chimney or exterior wall. This permits easy access to burner controls and filters, and proper connection with existing plenums. However, the oil furnace has a flue pipe which connects to the back of the furnace. A typical gas appliance, on the other hand, has a flue pipe that emerges from the front of the furnace. The result is quite often an additional 2 metres of flue pipe after conversion from oil to gas. This additional length of flue pipe results in additional cooling and leakage, and contributes to a weaker chimney.

2) Reduced height of chimney. In a similar way to the flue pipe extension, the design of a conventional gas furnace usually results in a shorter chimney elevation. A high boy gas furnace is typically taller than the oil furnace, and the flue pipe leads from the top portion of the furnace (e.g., case studies 4181 and 3102).

3) Leakier flue pipes. The smaller diameter and smaller gauge of metal used for gas flue pipes produces a flimsier connection which, during the problem house investigations, suggested a leakier flue pipe after conversion.

4) Flue size constriction. The installation of a flexible flue liner, recommended often as part of a conversion from oil to gas, was clearly a cause of increased spillage during the field investigations. The reduced diameter of the flue, combined with extremely high resistance of a flexible (corrugated) liner, reduces the flow capacity of a chimney system at a given temperature (e.g., case studies 4181 and 2138).

5) Increased obstacles. Most notably, the converted chimneys incorporate rain and wind caps that represent a major obstruction to flow, and especially increase resistance of the system under low wind conditions (e.g., case studies 4181 and 2138).

6) Lower flue gas temperatures. Many of the downsized gas furnaces operate at much lower temperatures than the oil furnaces they are replacing.

7) Increased holes and gaps. In a number of cases, the thimbles' that have been located on the chimney for connection to the oil furnace or oil hot water heater have been poorly blocked off, or downsized, and represented major leakage areas (e.g., case study 3102).

As a result of the above factors, it was apparent that in a number of houses the chimney system was excessively constricted, cool, or leaky and was that net chimney pressures were inadequate. Under such conditions, it is possible for minor house depressurization (e.g., 2 or 3 Pascals) to provoke prolonged spillage or backdrafting. Although house depressurization may not exceed H.D. Limits, it is still a contributing factor. However, the major problem is the constricted or weak chimney, resulting from faults in the retrofitted chimney design and installation created when converting from oil heating to natural gas.

Wind Pressures Complicated Failure Event Simulations:

Winds would appear to be a significant force in alleviating problems from backdrafting in many houses where high depressurization is common. This was most apparent in the Winnipeg houses, three of which were extremely tight. High levels of house depressurization were sustained for long periods during the air quality monitoring. However, it was difficult to maintain chimney backdrafting due to the winds, which quickly reversed the backdraft in every case (winds were 20 to 30 km/hr during Winnipeg testing). The only way to simulate the presumed backdrafting failure, without generating extreme house depressurization at high air exchange, was to plug the chimney.

Stack Temperature Variations:

Stack temperatures were found to vary considerably for gas appliances. Temperatures ranged from 200-350°C. There was, consequently, major variations in chimney draft and performance for otherwise similar systems (e.g., case studies 4135 and 2129).

DHW Heaters More Susceptible to House Depressurization?

In a number of houses, backdrafting was a definite failure mechanism for both furnaces and water heaters. However, the backdrafting had resulted in a higher temperature of dot detection on the water heaters than on furnaces. Partly, this may be explained by a superior location for the water heater spillage detector, since the detector can span the entire dilution air opening. It may also indicate higher exit temperatures for the water heater, and/or greater frequency and duration of spillage from water heaters (e.g., case studies 4184, 2053, 2129 and 4002).

Poor Performance of Some Gas Furnace Detectors:

In several cases, the detectors on the furnaces continued to indicate a minor or low temperature spillage event, (e.g., 2 dots) despite the prolonged and major spillage induced by the problem house investigation testing. Reasons why detectors sometimes perform poorly include:

- vanes inside the furnace directed hot gases below the location of the spillage detectors;
- extremely low exit temperatures for flue gases;
- spillage up the interior of the inlet box, or around the flue pipe, as opposed to the dilution air inlet.

Side-by-Side Chimneys:

Side-by-side chimneys caused a complex spillage problem in two houses (No. 4002 and No. 4135). The use of a fireplace resulted in house depressurization, causing flow reversal in the furnace flue. Wood combustion gases then re-entered the house through the furnace flue. The hot wood chimney and the cold backdrafting furnace chimney terminate at exactly the same elevation, a few millimeters apart. Even a 300 millimeter extension on either flue would probably avoid this problem.

3.1.2 Failure Mechanisms Identified for Oil-Fired Appliances

Oil Detector Design Problems:

The investigation of problems in the oil-fired appliances revealed a deficiency in the survey techniques. The application of a temperature-based detector to the face plate of a barometric damper, assumes that a damper is operating properly. As the flue heats up, a barometric damper that is operating properly will open slightly (or allow continuous leakage around the perimeter). Incoming air will thus keep the face plate cool.

In one case, it was clear that no attempt had ever been made to properly balance the barometric damper (e.g., House Number 5107). The dampers were stuck closed, and without any dilution air input, the flue pipes reached high temperatures. The heat conduction to the face plate of the damper resulted in dots turning black with only minor amounts of spillage. In retrospect, it would have been better to properly clean, lubricate and balance the barometric dampers at the same time detectors were installed. This approach would have produced slightly more meaningful statistics on the frequency of spillage events from oil furnaces since in a few cases the damper had been simply stuck to its housing.

The problem house investigations showed that, out of seven oil-fired appliances, four experienced combustion gas spillage under worst case conditions, and another had been known to spill during the monitoring period because of water in the fuel. At least in this small sample, the detector performed as intended in at least 70% of the cases. If this percentage held true for the entire sample of houses, the incidence of excess combustion gas spillage events would be 79 houses out of 255, or a failure rate of 31%. It is also possible that the diagnostic techniques used in the field were inappropriate for some oil heated houses. For example, the potential for an oil furnace flue to become very cold during off-cycles, (due to lack of insulation and lack of a pilot), increases the possibility for the house stack to compete with chimney stack, causing backdrafting and start-up spillage. Further use of the FLUE SIMULATOR model may help to clarify the extent of this type of problem.

A second problem with the oil detector design was the lack of an adequate time buffer. Unlike the gas detectors, which were specifically designed to detect the prolonged spillage, the oil detectors could in some cases change colour within 10 or 15 seconds - particularly with the hotter appliances. It is likely that at least a small portion of the 111 oil houses experienced only short-term start-up spillage. This start-up spillage is of interest in oil heated houses because it is suspected that the pollutants are very hazardous. However, an improved detector design for oil furnaces would include several dots mounted on double-sided foam tape, so as to insulate the dots from the damper and delay this response. Alternatively, and at more expense, detectors could be constructed from smoke detectors mounted above the spillage locations.

3.1.3 Results of the Venting Systems Assessment Procedure Used on Problem Houses

The purpose of the Venting Systems Pre-Test is to determine, in advance, or in place of a Venting Systems Test, whether a potential exists for house depressurization in excess of the House Depressurization Limits. The Pre-Test used on the Problem Houses was found to need major revisions. Consequently, the final version of the Pre-Test, as presented in the Chimney Safety Tests Manual, differs in some respects from what was evaluated during the Case Study visits.

The earlier version of the Pre-Test entailed predicting the leakage area of the houses by age, floor area, "Normalized Leakage Area" (in this case, ELA per square meter of floor area), and winter design temperatures. The Pre-Test also entailed estimating the exhaust capacity of exhaust fans and fireplaces in a similar manner to the revised procedures. Refer to the Manual or Chimney Safety Test for details of the Pre-Test.

A Pre-Test was conducted as part of the investigation on each problem house. In addition, the actual leakage area and exhaust fan capacities were measured in these houses. Leakage areas were measured to CGSB CAN2 149.10M using a door fan. Exhaust flow capacities were deduced by measuring the house depressurization with the fans operating, and then reading flow from the air leakage profile for the house.

The table used for predicting ELA is presented as Tables 7 (no longer used for this purpose). Revisions were necessary because of poor correlations between the predicted ELA and the measured ELA. Fine tuning the values in Table 7 did not help to improve accuracy, and this approach was eventually rejected in favour of a single nominal ELA value for all houses.

The results of the Pre-Test procedure are compared with the measured test data for the problem houses in Tables 9, 10, and 11. A review of these tables thus provides some measure of how successfully the Pre-Test predicts "worst case" House Depressurization.

Ideally, the assessments should slightly underpredict the ELA, and slightly overpredict the exhaust fan flow, thereby providing a margin of safety. The data in Tables 9 and 10 suggest that the ELA is more difficult to predict than exhaust fan flows. Exhaust flows are fairly consistently overpredicted, but with good approximation of flow quantity.

Table 7

NORMALIZED LEAKAGE AREAS FOR CANADIAN HOUSES

Winter Temperatures	NLA Values (cm^2/m^2)* Old Houses Pre - 1945	Medium-Aged Houses 1945 - 1960	New Houses (but not energy-efficient Post - 1960
Very cold winters (design temp. below -30°C)	6	4	3
Cold winters (design temp. -26 to -30°C)	7	5	4
Moderate winters (design temp. -21 to -25°C)	8	6	5
Warm winters (design temp. -16 to 120°C)	9	7	6
Very mild winters (design temp. above -16°C)	10	8	7

* Based on CGSB/CAN 149.10-M 1986, but normalizing with house floor area rather than envelop area.

HEATING DESIGN TEMPERATURES BY LOCATION

Location	Heating Design Temperatures °C
Vancouver	- 9
Edmonton	-34
Saskatoon	-37
Winnipeg	-35
Toronto	-19
Ottawa	-27
Montreal	-26
Quebec City	-28
Fredericton	-27
Prince Edward Island	-22
St. John	-24

Table 8

ESTIMATED AIR FLOW FOR TYPICAL EXHAUST DEVICES

Exhaust Device	Duct, Flue or Fan Blade Size (mm)	Manufacturer Estimated Flow (L/s)	Corrected for Standard Restrictions (L/s)
Bathroom Fan	75	40	20
	100	50	25
	175	100	50
	200	150	75
Clothes Dryer	100	100	50
	124		
Range Hood	100	50	25
	80 X 250	40	20
	175	100	50
	250	200	100
(Exterior Mount)	250	300	150
Barbecue Fan	250	175	87.5
Exhaust Devices with Chimneys			
Wood Fire Place			80
Open Wood Stove			30
Airtight Wood Stove			15
Operating Gas, Oil, or Propane Appliances	75		10
	100		18
	125		22
	150		34

NOTE: Standard restrictions are 5 mm screen, louvre, one elbow, straight duct, and grease filter

Table 9

EVALUATION OF VENTING SYSTEMS ASSESSMENT
PREDICTED AND MEASURED ELA

House No.	C	n	ELA Measured (cm^2)	Year of Construction	Floor Area (m^2)	NLA* (cm^2/m^2)	ELA Predicted (cm^2)
1057	75.50	0.743	1668	Post - 1975	226	7	1582
1076	108.55	0.595	1715	1900 - 1945	275	10	2750
1128	57.50	0.739	1259	1960 - 1975	160	7	1120
1142	80.30	0.673	1520	1900 - 1945	158	10	1580
2022	20.58	0.757	472	1900 - 1945	231	6	1386
2053	28.51	0.559	415	Post - 1975	156	3	468
2129	13.54	0.662	250	Post - 1975	249	3	747
2138	8.08	0.843	226	1946 - 1960	153	4	612
3056	142.72	0.589	2243	1945 - 1960	191	7	1337
3102	68.23	0.720	1441	1960 - 1975	335	6	2010
3113	39.97	0.638	704	1945 - 1960	248	7	1736
4002	30.11	0.686	587	Post - 1975	332	4	1328
4004	38.29	0.763	891	Post - 1975	269	4	1076
4135	22.24	0.758	512	Post - 1975	198	4	792
4181	24.82	0.812	470	1960 - 1975	164	4	656
4184	42.80	0.698	857	Post - 1975	259	4	1036
5007	45.89	0.630	800	Post - 1975	177	5	885
5071	93.32	0.590	1510	1900 - 1945	136	8	1088
5146	20.64	0.980	800	1945 - 1960	163	6	978

Notes: - Some of these houses are extraordinarily tight.
- NLA values were derived from Table 7: Normalized Leakage AReas for Canadian Houses.

Table 10
EVALUATION OF VENTING SYSTEMS ASSESSMENT - PREDICTED AND MEASURED AIR FLOWS FOR FANS AND FIREPLACES

House No.	Fan H.D. (Pa)	Fan Flow Measured (L/s)	Fan Flow Predicted (L/s)	Fireplace H.D. (Pa)**	Fireplace Flow Measured (L/s)***	Fireplace Flow Predicted (L/s)	Total Predicted Flow (L/s)	Comments
1057	4.0	211.5	150	2.0	126.4	160	310	
1076	1.0	108.6	137.5	1.0	108.6	80	217.5	
1128	2.5	113.2	100	3.5	145.1	160	260	
1142	3.5	186.6	125			80	205	No FP
2022	6.0	79.9	137.5			80	217.5	No FP
2055	11.0	105.9	100			80	180	FP spills
2129	9.0	58.0	150	3.0	28.0	80	230	
2138	2.0	14.5	50	2.2	15.7	80	130	
3056				1.0	142.7	80	80	
3102	1.5	91.4	100	1.0	68.2	80	180	
3113	8.0	150.6	150				150	No Fp
4002	5.0	90.8	100	4.0	77.9	180		
4004	3.0	88.5	100	3.0	88.5	80	180	
4135	3.0	51.1	125	3.0	51.1	80	205	
4181	7.0	120.5	125			95	220	FP spills
4184	5.0	131.6	137.5			80	217.5	FP spills
5007	4.5	118.4	75				75	No FP
5071	1.5	118.5	100	2.0	140.5	80	180	
5146	0.0*	0.0	50				50	No FP

Notes: * Below measurement limits
** Fireplace house depressurization is additional depressurization caused by fireplace
*** Fireplace flows were measured while exhaust fans were operating. Consequently, the flow is reduced by house depressurization.

Table 11

EVALUATION OF VENTING SYSTEMS ASSESSMENT - PREDICTED AND MEASURED HOUSE DEPRESSURIZATION

House No.	ELA Measured (cm^2)	ELA Predicted (cm^2)	Total Measured Flow (L/s)	Total Predicted Flow (L/s)	House Depress. Measured (Pa)	House Depress. Predicted (Pa)
1057	1668	1582	337.6	310	6	7.5
1076	1715	2750	217.1	217.5	2	1
1128	1259	1120	258.3	260	6	9.7
1142	1520	1580	186.6	205	3.5	4
2022	472	1386	79.9	217.5	6	5.8
2053	415	468	108.9	180	11	26.2
2129	250	747	88.0	230	12	16.1
2138	226	612	30.2	130	4.2	8.5
3055	2243	1337	142.7	80	1	1.2
3102	1441	2010	159.6	180	2.5	2.2
3113	704	1736	150.6	150	8	2.1
4002	587	1328	168.8	180	9	4.3
4004	891	1076	177.1	180	6	6.4
4135	512	792	102.3	205	6	13
4181	470	656	120.5	220	7	19.1
4184	857	1036	131.6	217.5	5	8.7
5007	800	885	118.4	75	4.5	2.6
5071	1510	1088	259.0	180	3.5	6.4
5146	800	978	0.0	50	0	1

The ELA predictions, on the other hand, are in some cases a long way from reality. The greatest discrepancies are in the extremely tight older houses in Winnipeg. Some of these problem houses are experiencing spillage solely because they are extraordinarily tight, something that is impossible to predict.

When the measured and predicted house depressurizations are compared in Table 11, it is clear that the assessment is capable of differentiating those houses with such low levels of depressurization that backdrafting is highly unlikely, and those houses with such high levels of depressurization that backdrafting is virtually certain. There is, however, a grey area close to the H.D. Limits (4 to 7 Pascals) where some amount of scatter is evident. It is dangerous to place too much credence on the Pre-Test results, within this range, and for this reason the Pre-Test was revised.

3.1.4 Evaluation of Venting System Test Data

A venting system test was conducted in all problem houses and used to help diagnose spillage problems. In almost all cases the test procedures worked as intended, and the tests were conducted quickly and effectively. However, a few revisions and additions to the tests have been proposed as a result of the field trials:

Value of a Flue Pressure Measurement:

In a number of houses spillage was observed during house depressurization and not during open house conditions. It was concluded, therefore, that prolonged spillage was induced by depressurization of these houses. However, because house depressurization had not, in all cases, exceeded the house depressurization limit, the problem was defined as a combination of a weak chimney, and some house depressurization.

Since this situation was common in our problem houses (No. 1076, 2138, 3056, 3102, 4181, 4004, 4135 and 5007), a standardized diagnostic procedure was needed to determine why the chimney was so weak. This resulted in the development of the Total Flue Pressure Test (described in the Procedures Manuals Progress Report 3.3). Total Flue Pressure Tests were conducted in all of the problem houses.

Value of Pressure Averaging Tubes:

The importance of using pressure averaging and dampening devices to achieve accurate readings from the pressure gauge was emphasized during the Winnipeg testing, since high winds persisted on all test days. The extra tubing was found essential for accuracy.

Fireplace Testing Unnecessary:

The difficulty of including fireplaces in the Venting Systems Test was emphasized by these field trials. In 15 of 19 houses, the house depressurization exceeded the 3 Pascal H.D. Limit for a smoldering fireplace. In three of the 14 houses with operational fireplaces, the fireplace spilled during the testing, despite a hot flame fire.

No clear solution to these fireplace hazards has been revealed. In a large number of Canadian houses, it is likely that fireplaces either cause the house to exceed the House Depressurization Limits, or spill on their own due to house depressurization caused by exhaust fans. Both these situations seem to complicate the test procedure and results, without providing much useful information. Until low cost remedial measures are available for fireplaces, it is not worthwhile to include fireplaces in the Testing. A labelling approach is more appropriate, perhaps in combination with a separate test just for fireplace spillage.

Basement Doors May Cause New Problems:

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. Since these interior doors typically connect the furnace with other operating fans, they are not normally closed during the test. It now appears there is a good argument for testing with basement doors both open and closed.

Diagnostic Procedures Work Well in Conjunction with Warning Devices:

Installation of warning devices prior to conducting Chimney Safety Tests appears to be a good policy. In most cases the detectors identified problems at much less cost and hassle than conducting tests in houses. The tests are essential, however, in properly interpreting the course of spillage once a problem is identified.

3.1.5 Highlights of Indoor Air Quality Monitoring

The indoor air quality monitoring conducted as part of this project was only a small component of the overall budget. At this stage, much of the data has not been organized and analyzed, and generalizations about the impact of combustion gas spillage on indoor air quality are difficult to make. Further work in this area by CMHC is planned for the 1986/87 testing season. The highlights of air quality monitoring presented on the following pages should provide a starting point for these further investigations.

1. Carbon Dioxide Concentrations

Prior to failure simulations, ambient levels of CO_2 were measured indoors and outdoors. A sample of these "as found" CO_2 values is presented in the following table.

TYPICAL CO_2 CONCENTRATIONS AS FOUND

House No.	CO_2 Indoors (ppm)	CO_2 Outdoors (ppm)
1076	790	830
3102	875	416
4004	440	1075
4181	618	880
2022	650	600
4135	1000	868
4002	738	620

Variations in CO_2 was apparent - especially from city to city. However, levels could be considered high only in House 4004, where indoor levels were 1025 ppm, as opposed to outdoor levels of 440 ppm. House 4004 is an oil-heated house in Hull, Quebec, which, on the morning of testing, was closed up tightly. The house had been occupied by a family of five, who had slept all night with an air conditioner operating and the house closed up tightly. Presumably, the high levels of CO_2 reflect the human occupation. The warm spring weather encountered during the site investigations caused most houses to be well ventilated and unheated, which destroys the significance of "as found" pollutant concentrations.

The concentrations of carbon dioxide in the houses during failure event simulations was surprisingly low. After one or two hours of testing, with the appliance cycled on and off in its failure mode, carbon dioxide levels were commonly in the range of 3000 to 5000 ppm. In some cases, the longer term steady-state concentrations of CO_2 in these houses were estimated, using the indoor air quality computer. Steady-state concentrations were not much greater than the levels reached during the hour or two of monitoring.

Some notable exceptions existed in the CO_2 monitoring case studies, including two houses where the levels rose extremely quickly, exceeding the measurement range for the CO_2 analyzer (5000 ppm). Within the first five minutes, estimated steady-state concentrations for these houses are much higher (in the range of 10,000 to 15,000 ppm).

Carbon dioxide was used as a surrogate for other combustion pollutants in the failure houses. It performed well in 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. Carbon dioxide monitoring was especially useful in validating the indoor air quality computer model, which could then be used to more accurately predict concentrations of other pollutants, or concentrations of CO_2 over longer periods of time.

2. Sampling in the Return Air Plenum

Air quality was sampled in the return air plenum as a convenient way of obtaining an average concentration for the house. This approach resulted in a few minor problems. Because the circulating blower of a furnace operated after the furnace had already begun to spill, the return air plenum would often fill with the hot combustion gases rising from the flue pipe. This phenomenon produced a sharp peak in concentrations at the beginning of each on cycle. Although this small peak had little influence on overall results, it resulted in a less than perfect match between the indoor air quality model and the real time monitoring results.

3. Relative Distribution of Carbon Dioxide

Grab bag samples of indoor air from other locations in the houses were collected and compared with the return air sample. In all cases, the grab bag samples showed lower concentrations of CO_2 than the return air plenum. In part, this can be explained by the continuous induction of concentrated combustion gases into the return air plenum through leaks in the ductwork. In far away rooms, the delay of 10 to 30 minutes in CO_2 peaks was common. The best sampling technique is to sample from the centre of the air stream, and from the portion of the return air plenum that is furthest away from the furnace room. Unfortunately, due to types of ductwork design, and finished basement rooms, this was not always possible.

4. Carbon Monoxide Concentrations

In case study houses where carbon monoxide levels were monitored, only one house showed significant levels of CO as a result of the failure event simulation. Since the failure events under investigation in this project appear to be extremely common, it is not surprising that CO is rarely implicated. No production of CO was apparent as a result of recycling of combustion gases through burners, since the combustion gases were quickly mixed and distributed throughout the house.

The CO rise in the one case study house was primarily a result of a dirty burner. An added factor in this one case was the lack of a forced air distribution system. Forced air distribution systems in most houses result in a very rapid mixing of the combustion pollutants throughout all portions of the house. In the case of the high CO levels, the house was heated with a boiler, and the result was extreme rise in the combustion pollutants in the room where the boiler was located. A much longer delay in distribution of these pollutants was noticed. On the basis of this one case study, it is suspected that combustion gas spillage is likely to be much more hazardous in houses that lack forced air distribution systems. Re-ingestion of combustion pollutants by burners in boiler rooms may also be a contributing factor.

5. Nitrogen Oxides and Nitrogen Dioxide Concentrations

Indoor concentrations of NOX, NO and NO_2 were not measured in most of the case study houses due to difficulties in obtaining portable equipment with sufficient accuracy for this project. Instead, a series of failure events were simulated in test houses in Vancouver during which NOX, NO, NO_2, CO and CO_2 were simultaneously measured. The intention of this exercise was to provide a comparison between NOX and NO_2 values, and the CO_2 measurements that were being taken in the case study houses. It was also hoped that the results of this testing would be in agreement with the indoor air quality model predictions. In combination with generation rates available from the scientific literature, this would assist in computer modelling of NOX concentrations in the case study houses. Since the NOX test data is not presented in the case studies, a brief review is presented here.

An example of the NOX data is illustrated in Graph 1, which compares NOX, NO, NO_2 and CO_2 levels in the Vancouver Test House No. 3 during a 90-minute failure simulation. The chimney was blocked during these runs, and indoor air was sampled from the return air plenum. The furnace was cycled on for three 20-minute periods. The furnace was well-tuned during the first two cycles, but during the third cycle the primary air inlets were closed to simulate a "poorly-tuned" furnace. The NOX measurements were taken with a Monitor Labs chemiluminescent NOX monitor.

Graph 1 illustrates a number of features common to the NOX monitoring:

- After the end of the first on-period, concentrations of CO_2 and NOX in the return air plenum continue to rise as pollutants move through the ceiling of the basement into the first floor rooms, and into the return air inlets. There is a 10- to 20-minute "mixing" delay.
- Small peaks in the measured concentrations at the beginning of each cycle show how pollutants collect in the return air plenum until the furnace blower begins to operate.
- NOX levels rise rapidly, and consist primarily of NO during the well-tuned cycles. The volumetric ratio of NO_2/NOX is not constant, since NO_2 is decaying at a more rapid rate.

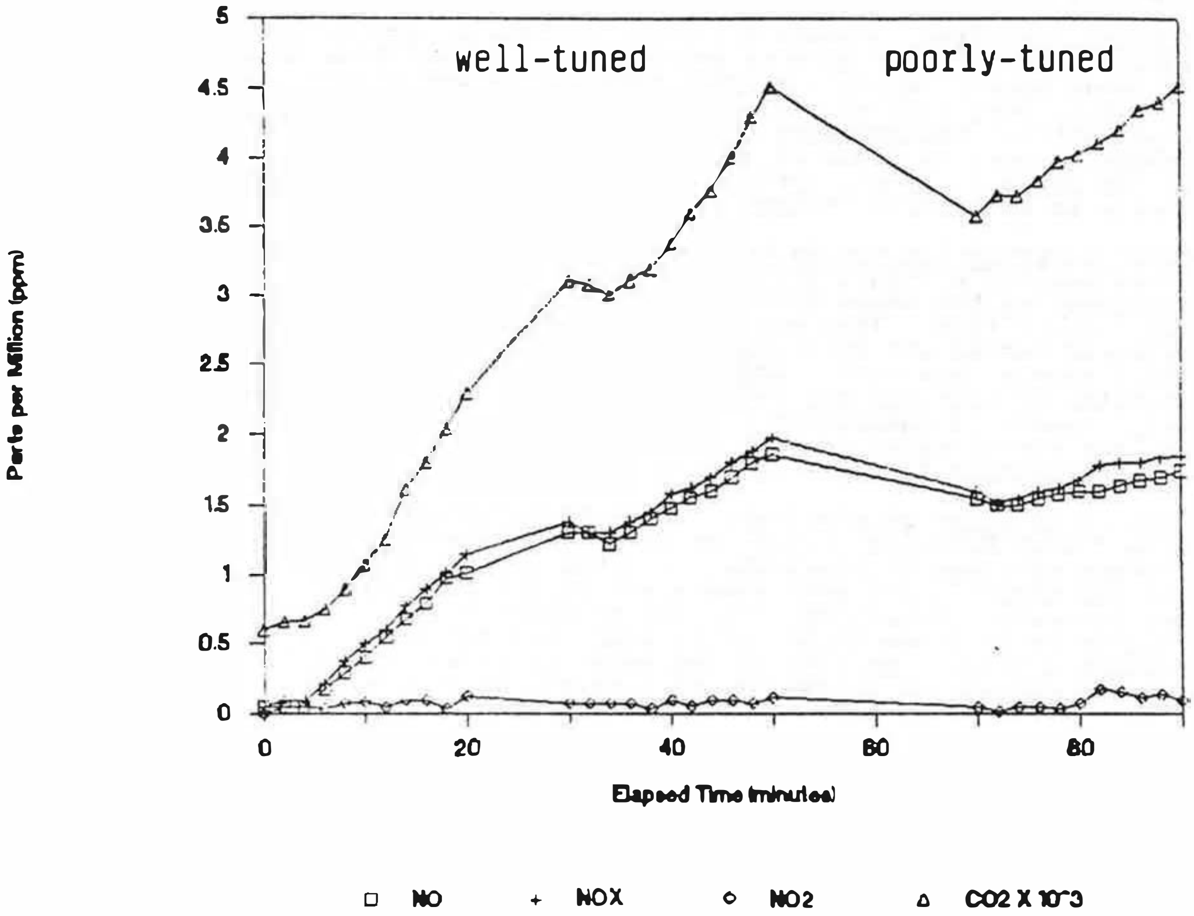
- NOX rises at a slightly lower rate than CO_2, but with a similar pattern and decay.
- CO_2 levels are in the range of 3000 to 5000 ppm after a 90-minute failure scenario, which is typical of a majority of the case study houses.
- The third cycle in the "poorly-tuned" condition, reduces the generation rates of CO_2, NOX and NO, but increases NO_2 generation.
- NO_2 rates are fairly low during the well-tuned cycles, staying below the Canadian ambient outdoor standards of 0.2 ppm. Predicted steady-state concentrations for this house are 0.2 ppm.
- NO_2 rates begin to rise to levels which may be considered a health risk during the third, poorly-tuned cycle (after a 10-minute delay for mixing). Longer term monitoring of the poorly-tuned furnace could generate indoor steady-state NO_2 levels in the range of 0.4 to 0.5 ppm. These levels exceed the proposed acceptable exposure range for short-term periods (residential 1 hour exposure >0.25 ppm) and may represent a significant health hazard from combustion venting problems.

6. 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 failure scenarios can be grouped into two categories, according to whether occupants are exposed to acute, short term concentrations of combustion pollutants, or to low level, long term (chronic) levels.

Acute Failure Scenarios:

- Occasional backdrafting in a relatively tight house. This is a common failure scenario on the basis of case study research. Tight envelopes mean that air change need not be high during a backdraft episode. 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 may reach 10,000 or 15,000 ppm in small houses, but are generally even less. Carbon monoxide levels are unpredictable.
- Occasional backdrafting 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 event itself 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 the boiler room.



GRAPH 1: A Comparison of NOX Concentrations with CO_2 (Vancouver Test House No. 3)

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.

- Prolonged spillage at start-up. Leaky or constricted flues, 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.

7. Using the Indoor Air Quality Model to Estimate the Frequency of Venting Failures, and the Net Exposure to Combustion Pollutants

Further work is required with the indoor air quality computer model before estimates can be made of spillage event frequency, and net long term exposure levels for occupants. The model needs to be revised to incorporate information on the thermal efficiency of the envelope. It would then be possible to allow the appliance to cycle on and off in accordance with the building heat load and climatic data. FLUESIM should be used to bracket the situations under which the particular house and appliance will experience failure events. With these minor changes, the model should be capable of predicting the rise and fall of various combustion pollutants over an entire heating season. In combination with the statistics from the Canada Wide Survey, and the case studies, it would then be possible to generalize about the exposure levels of Canadians to combustion pollutants resulting from combustion venting failures.

The excellent match between the monitoring results during house failure event simulations in the field, and the indoor air quality computer model predictions, suggest that further computer modelling for these purposes would be a worthwhile exercise. Until such an analysis is conducted, it is difficult to comment on the public health risk, especially for the chronic failure scenarios.

8. Additional Time Requirements for Simulating Oil Furnace Failures

A number of difficulties are encountered with trying to monitor air quality in houses during venting failures with oil furnaces. The greatest problem was simulating the failure immediately after testing the furnace, since many of the oil furnaces and chimneys stay warm for long periods and will not repeat the start-up spillage which occurs in a cold flue.

If the spillage duration is short (30 to 60 seconds), longer term monitoring is needed to notice the impact of such an event. If the spillage duration is longer, the air quality can deteriorate very quickly and it becomes an imposition for the occupants. In the pilot tests conducted in Vancouver, backdrafting of an oil furnace for only two or three minutes caused extremely strong, sulphuric odours, and further testing had to be curtailed in the interest of preserving air quality for the occupants.

4.0 CONCLUSIONS

Appendix A of this report presents the case studies of 21 houses investigated during the problem house follow-up visits. The case studies follow a similar format (although the amount of information varies depending on the types of chimney problems encountered).

Each case study presents information as follows:

House Particulars

- Detector Results
- House Type
- Airtightness Test Data (note: "Natural ELA" is the CGSB ELA taken with the flues left unsealed)
- Appliance Type
- Competing Exhaust Systems
- Fireplaces

Results of the Safety Tests

- Preliminary Assessment
- Inspection
- Venting Systems Test
- Total Flue Draft Test
- Spillage Observations
- Heat Exchanger Test
- Questioning of Occupant

Failure Event Simulations (including Graphs)

- Spillage Temperatures
- CO_2 concentrations over time
- CO concentrations over time
- Computer Model Predictions
- CO_2 Decay Rates (for determining air change rates)
- Airtightness Results

Comments and Conclusions

Each Case Study includes comments and conclusions, based on the test results. Because of the extensive information available on each house and the detailed nature of the conclusions, all of the Case Studies have been presented in an Appendix. Readers interested in a thorough analysis of venting failures in houses are encouraged to review this Appendix, especially the Conclusions and Comments sections.

RESIDENTIAL COMBUSTION VENTING FAILURES

A SYSTEMS APPROACH

PROJECT 6

CASE STUDIES OF PROBLEM HOUSES:

A FOLLOW-UP TO THE CANADA WIDE SURVEY

APPENDIX A

CASE STUDIES: 21 PROBLEM HOUSES

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

Prepared by:
Scanada Sheltair Consortium

January, 1987

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

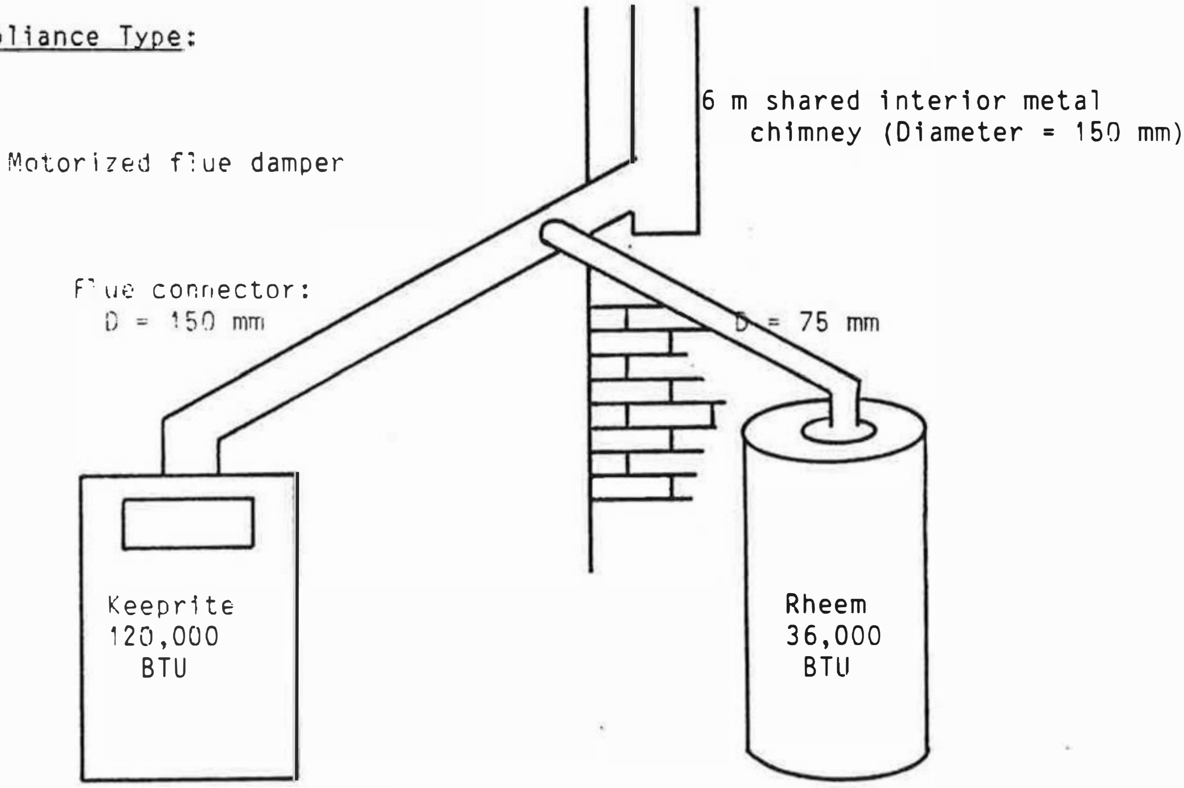
HOUSE NO: 2053 (WINNIPEG)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 54°C exceeded
DHW - 71°C

House Type: One storey with full basement
Post - 1975 construction
Natural ELA @ 10 Pa = 415 cm2
Natural ACPH @ 50 Pa = 1.17

Appliance Type:



Less than 5 years old | Less than 5 years old (serviced within last year)

Competing Exhaust Systems:

1 - Kitchen range hood fan
2 - Bathroom fans
1 - Clothes dryer
1 - Whole house vacuum

(Total measured exhaust = 105 L/s)

Fireplace:

1 - Brick fireplace with doors (no staining of mantle or masonry).

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted H.D. - 26.2 Pa
H.D. Limit - 5 pa
House found to be prone to venting failure.

2) Inspection:

Installation meets all codes and requires no maintenance.

3) Venting Systems Test:

Measured H.D. - [illegible] Pa
H.D. fans = [illegible] Pa
Exhaust fans exceed HD limit for furnace, DHW and fireplace.

4) Total Flue Draft:

Full operation = [illegible] Pa.
Standby = 3 Pa.
A fairly strong chimney, with adequate draft.

5) Spillage Observations:

Spillage duration for depressurized house was more than 30 seconds.
No spillage for open house.
Spillage is primarily a result of house depressurization.

6) Heat Exchanger Test:

No perceptible leakage.

7) Questioning of Occupant:

Occupant unaware of any existing problem.

Failure Event Description and Simulation: House 2053

o It was concluded that excessive spillage had occurred as a result of backdrafting. The major contributing factors were a tight envelope, many exhaust fans, and an open fireplace.

o To simulate backdrafting, all exhaust fans were operated, depressurizing the house to 11 Pascals. To prevent the strong winds from re-establishing draft in the chimney, the door fan was used to increase house depressurization to 20 Pascals. The furnace was then operated continuously for 50 minutes to simulate full backdrafting during cold weather under worst case conditions.

o Graph 1 - 2053, shows operating temperatures of furnace during simulation. The "low" inlet temperature is cool, averaging 95°C, which corresponds with a 54°C dct temperature. Fluctuations are due to constant wind gusting. The inlet temperature was measured at a low location to correspond to detector location.

o Graph 2 - 2053, shows the build-up of carbon dioxide in the return air plenum of the forced air furnace. Maximum CO_2 levels recorded after 50 minutes of backdraft were over 3000+ ppm. (High start levels - 1000 ppm - were due to preliminary firing of furnace during checklist procedures). The slow rise in CO_2 - about 50 ppm/minute - is largely a result of the high air change created by 20 Pascals depressurization. Even without furnace cycling, steady-state concentrations are unlikely to exceed 5000 ppm.

o Graph 3 - 2053, shows the decay rate of CO_2 following the failure event simulation. The air change rate during the test was predicted to be 0.7 ACPH.

No carbon monoxide was produced by this furnace and no CO was recorded during the failure event.

o Graph 4 - 2053, shows a computer model prediction for CO_2 concentrations under conditions similar to the field test. The model matches the field data well.

o Graph 5 - 2053, shows the same computer model prediction for CO_2 combustion as Graph 4, but with a longer time horizon. Steady-state concentrations of CO_2 can be seen to reach approximately 5500 ppm.

Conclusions and Comments: House 2053

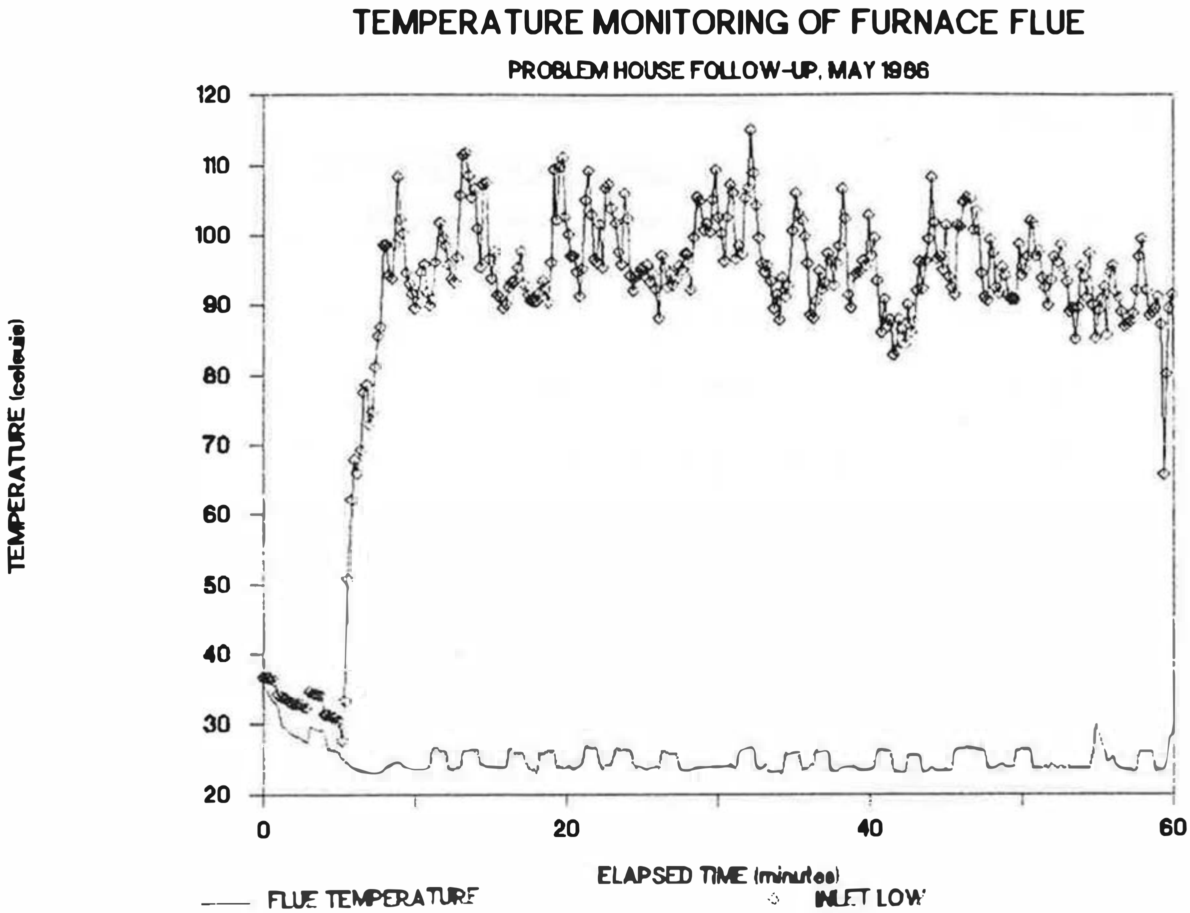
o The range hood fan operating alone in this very tight house is able to exceed the depressurization limits for all combustion equipment and consequently the frequency of combustion gas spillage into the house is certainly high, and is probably a daily event.

o The house did not have a continuous air/vapour barrier and appeared to be of conventional new construction for Winnipeg. It is reasonable to assume that there are whole subdivisions of houses in Winnipeg with identical problems.

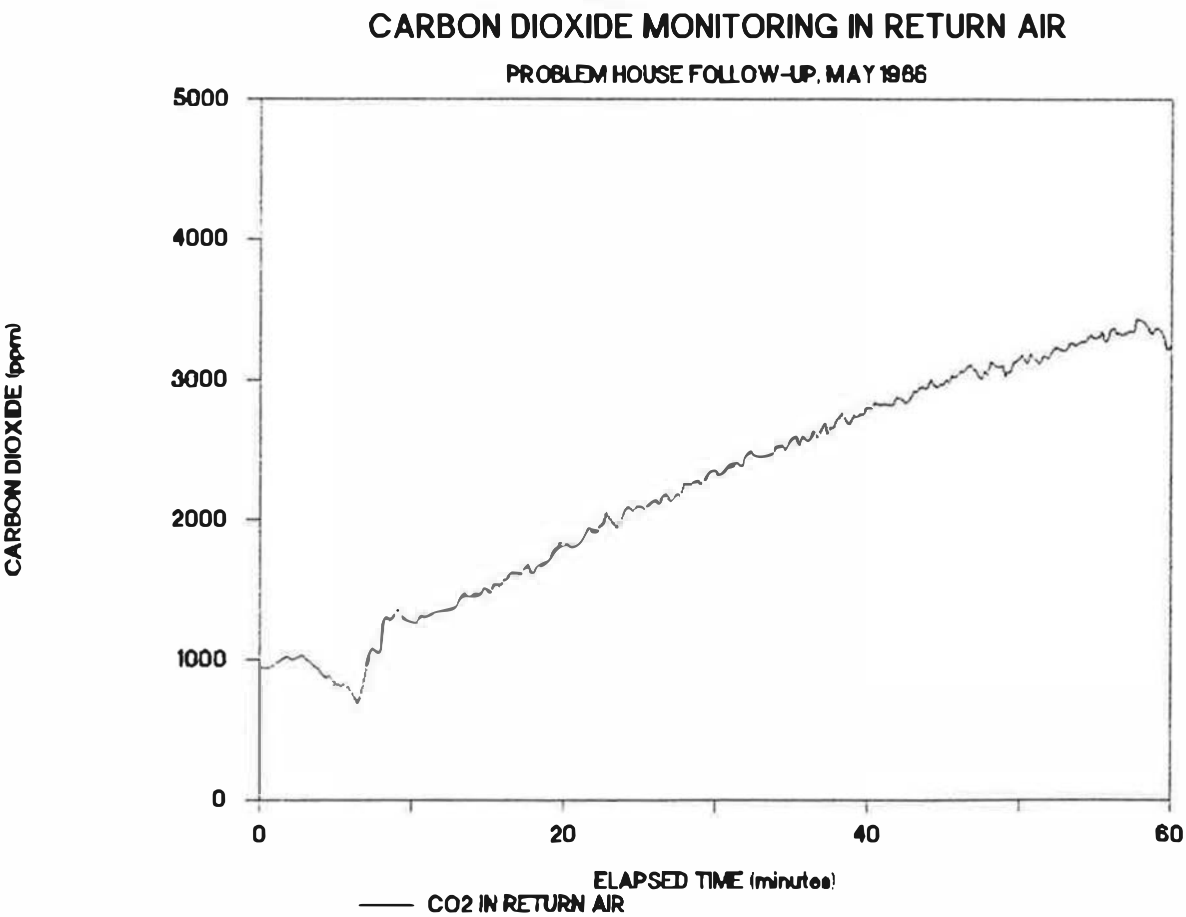
o It is possible that both appliances could spill simultaneously. This event was not tested or modelled, but presumably this scenario would increase pollutant concentrations.

o Although the DHW tank had recorded a high dot temperature, the furnace was more susceptible to backdraft. The detector had been installed on the lower lip of the dilution air inlet because of a motorized flue damper. Consequently, the detector missed the majority of the spillage gases.

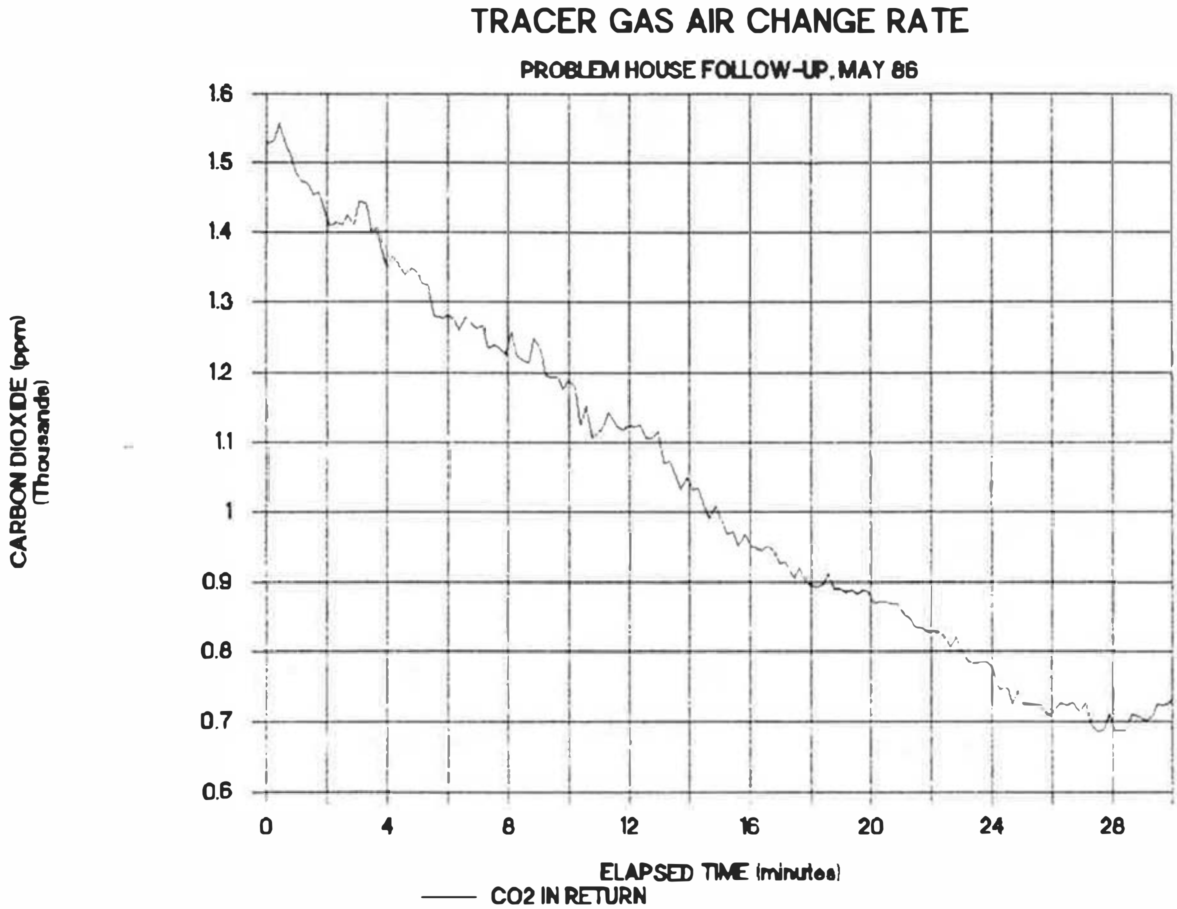
GRAPH 1 - 2053



GRAPH 2 - 2053

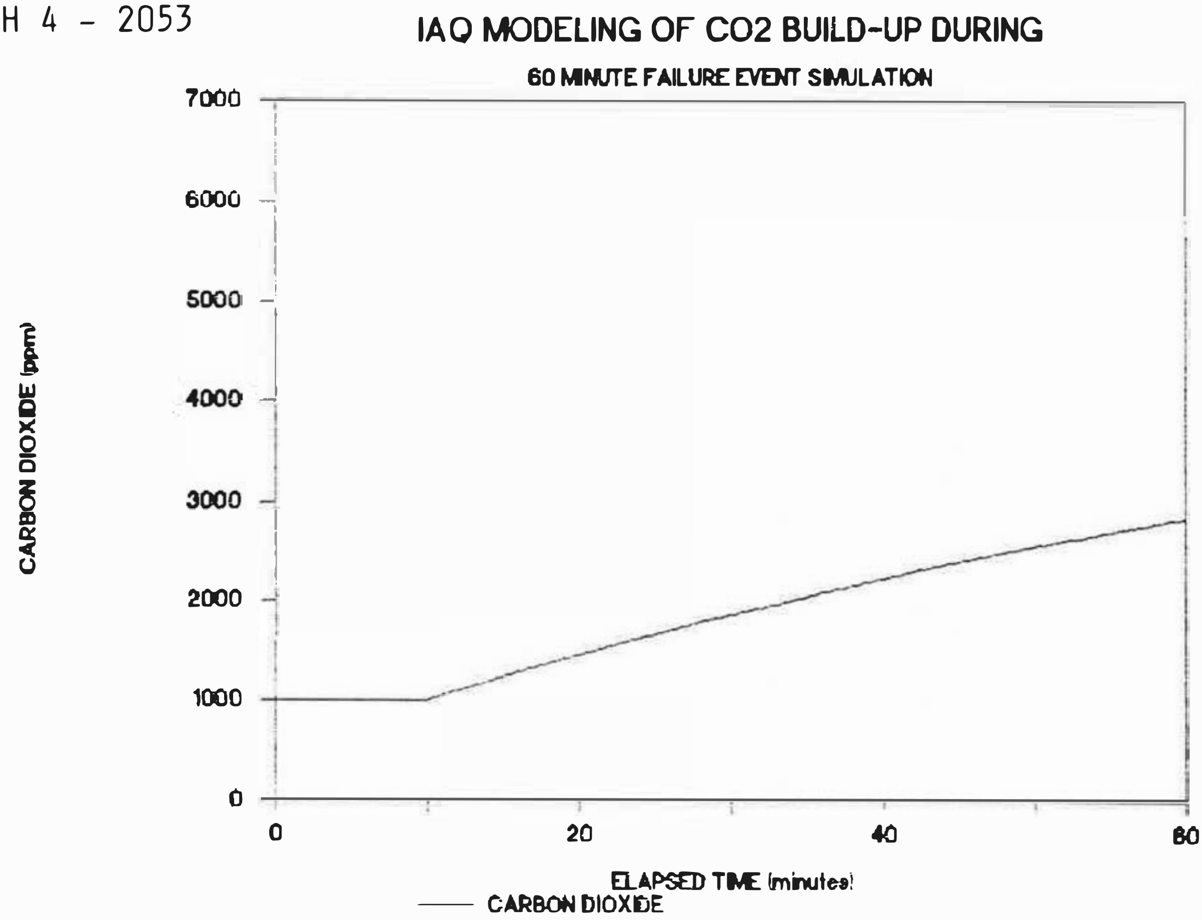


GRAPH 3 - 2053

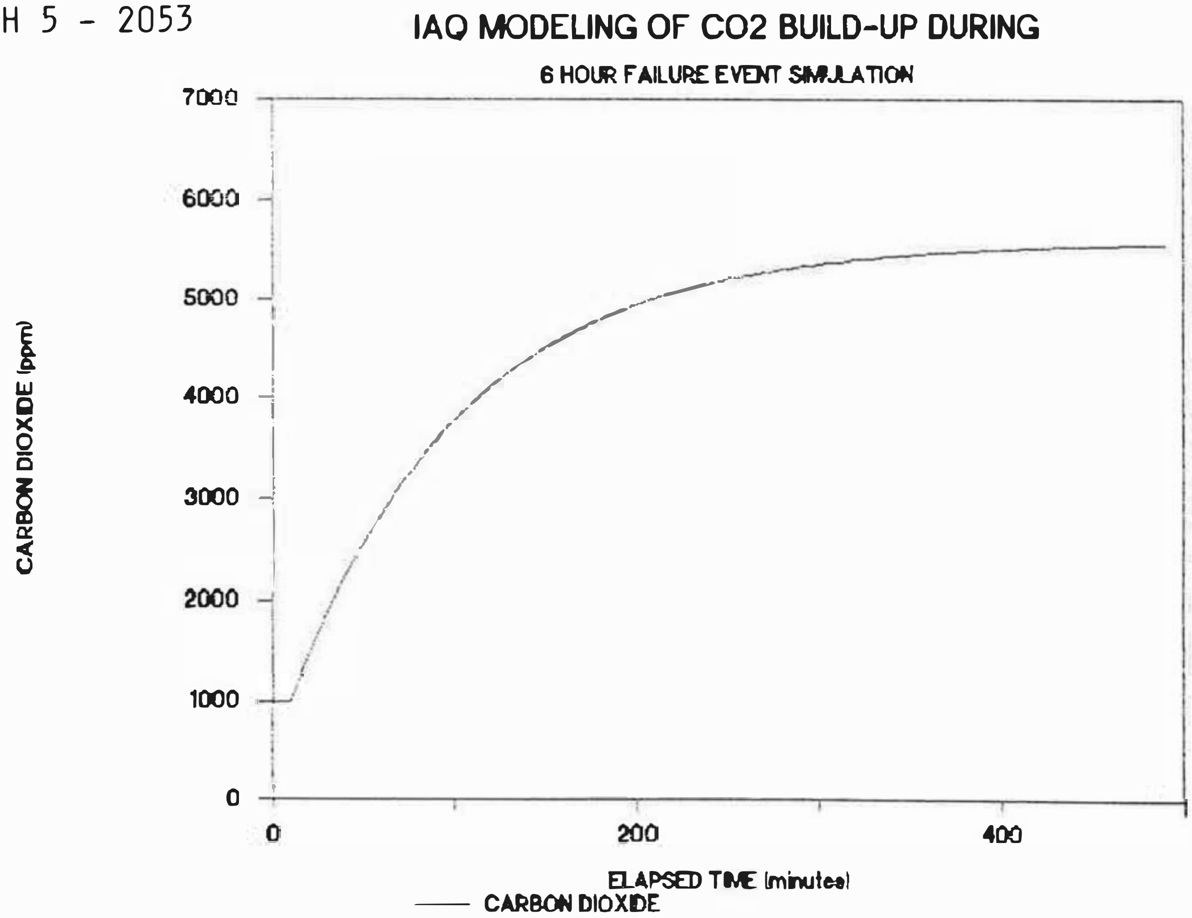


TRACER GAS AIR CHANGE RATE
PROBLEM HOUSE FOLLOW-UP, MAY 86
CARBON DIOXIDE (ppm)
(Thousands)
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0
4
8
12
16
20
24
28
ELAPSED TIME (minutes)
CO2 IN RETURN

GRAPH 4 - 2053



GRAPH 5 - 2053



Model Input Sheet

HOUSE # 2053

House Data		CO2
	Heat Load of house at To - Ti (Kj/hr)	
V	House Volume (m^3)	781
A	Envelope Area (m^2)	332
	Surface Area (m^2)	
ELA	House ELA @ 10 Pa (cm^2)	415
n	Flow Exponent (n)	0.559
k	Mixing Factor (%)	0.85
H	Height of House (m)	3.5

Infiltration model

H1	Height of Wind Measurement (m)	10
fw	Wind Parameter	0.126
C	Shielding Class	0.24
a	Terrain class for house	1
y	Terrain class for house	0.15
a1	Terrain Class for wind measurement	1
y1	Terrain Class for wind measurement	0.15
g	The acceleration of Gravity (m/s^2)	9.8
fs	Stack Parameter	0.139
r	Fraction of Leakage in Floor And Cieling (R)	0.77
x	Fraction of Leakage Imbalance (X)	0.45
Ti	Indoor Temperature (K)	293
L	Effective Leakage Area (m^2)	0.024
q0	Infiltration Rate (M^3/s)	0.158
ACPH	Air Change Per Hour Rate (House Volumes\Hour)	0.729

Appliance Data

		2
Ft	Appliance Type (Oil, Gas, Propane)	gas
Fr	Appliance Firing Rate (btu\hr)	120000
	Appliance Fireing Rate (Kj\hr)	126600
Y	Pollutant as a % of Combustion Gas	
	Fraction of Gas Spilling	1
	Fraction of Cycle that Spills	1
	Fraction of On Time	1
Tc	Time Between Cycles (hr)	0.05

Weather Data

dT	To - Ti at Start	5
To	Temperature Outdoors (K)	288
W	Wind Speed (m/s)	0

Flow Rates, House Depressurization, and Filtration

F0	Make-up Filter Efficiency (%)	0
F1	Recirc Filter Efficiency (%)	0
q0	Make-up Flow Rate (m^3/s)	0
q1	Recirculation Flow Rate (m^3/s)	0
q2	Infiltration Flow Rate (m^3/s)	0.158

c*	Characteristic Flow Rate (Flow/time)	0.134
	Calculated Exhaust Flow (L/s)	
Ex	Default Exhaust Flow (L/s)	150
HDP	House Depressurization (Pa)	20.0

Pollutant Data

		CO2
P	Pollutant	
	Generation Rate Per (mg/kj)	35.000
R	Pollutant Decay Rate	
K1	Inverse Deposition Rate	
Kdep	Deposition Velocity (length/time)	0.000
S	Indoor Source Strength (mg\sec)	1230.833

Steady State Pollutant Data

		CO2
t*	Caharacteristic Time (hrs)	1.614
Css	Steady State Concentration (Css)	9965.881
Cs	Start Concentration (mg\m^3)	1800.000
CO	Outdoor Pollutant Concentration (mg/m^3)	810.000
Ci	Concentration of Pollutants (mg/m^3)	3185.244
	Steady State Concentration (ppm)_	5581

AIRTIGHTNESS TEST RESULTS

HOUSE IDENTIFICATION - 2053 DATE - MAY 28/86

OUTDOOR TEMPERATURE - 19.5 (C) WIND SPEED - 22 KPH

VOLUME - 781 M^3

HOUSE PRESSURE (Pa)	FLOW PRESSURE (Pa)	FLOW MEASURED (L/s)	FLOW CORRECTED (L/s)	FLOW FITTED (L/s)	RELATIVE STANDARD ERROR (%)
60	380	282.30	280.46	281.43	0.35%
55	345	269.05	267.29	268.06	0.29%
50	323	260.37	258.67	254.15	-1.75%
45	272	239.04	237.47	239.61	0.90%
40	238	223.67	222.21	224.34	0.96%
35	212	211.16	209.78	208.19	-0.76%
30	175	191.94	190.69	191.00	0.16%
25	0	0.00	0.00	0.00	0.00%
20	0	0.00	0.00	0.00	0.00%
15	0	0.00	0.00	0.00	0.00%
10	0	0.00	0.00	0.00	0.00%
5	0	0.00	0.00	0.00	0.00%
0	0	0.00	0.00	0.00	0.00%

C = 28.51 n = 0.559

ELA = 415 CM^2

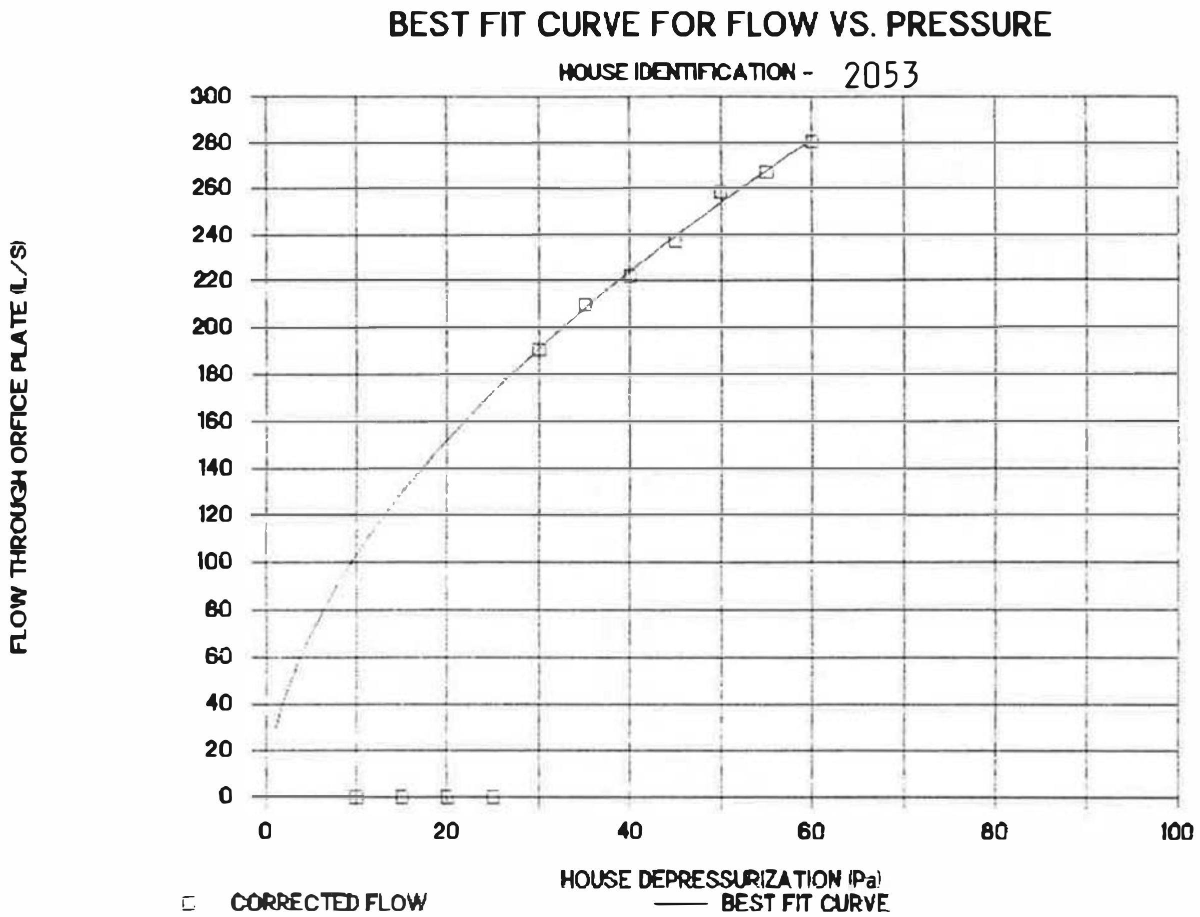
Q @ 50 Pa = 254 Q @ 10 Pa = 103

AIR CHANGE PER HOUR @ 50 Pa = 1.171500633

SXX = 7736675788 SYY = 2433116155

SXY = 4326462567 SYX = 4.85562929

CORRELATION COEFFICIENT = 0.997181770


BEST FIT CURVE FOR FLOW VS. PRESSURE
HOUSE IDENTIFICATION - 2053
FLOW THROUGH ORFICE PLATE (L/S)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
HOUSE DEPRESSURIZATION (Pa)
CORRECTED FLOW
BEST FIT CURVE

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

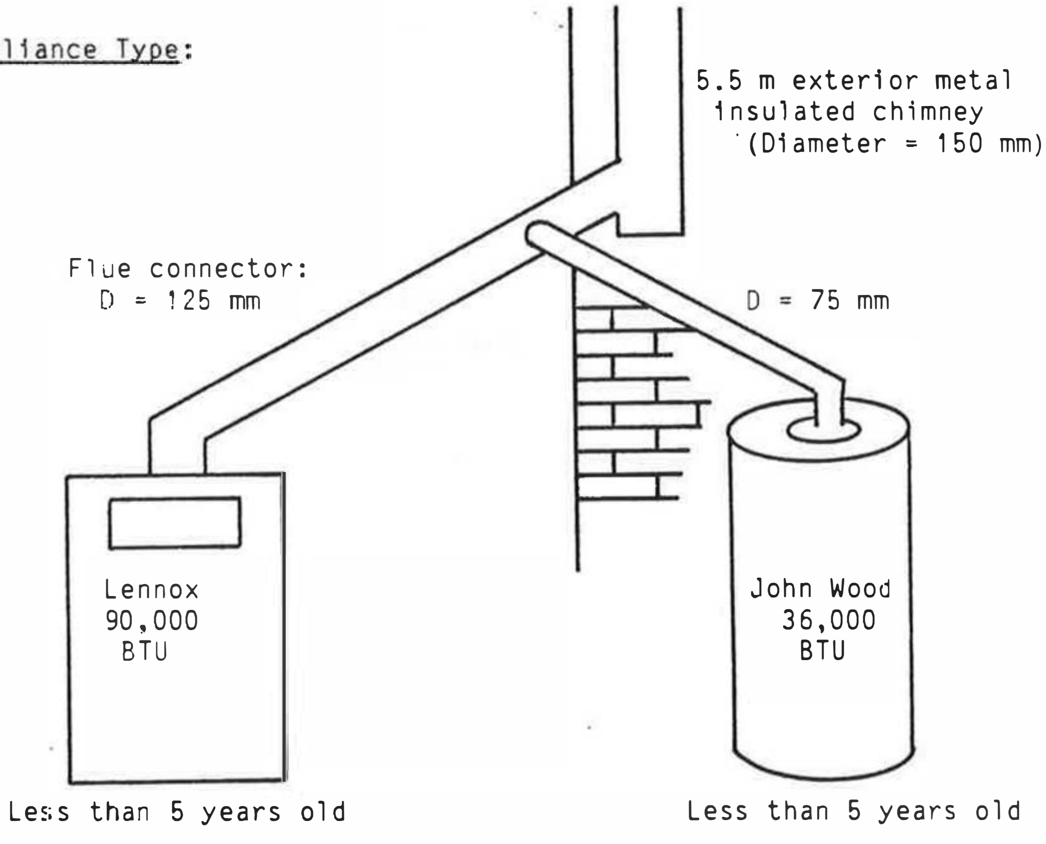
HOUSE NO: 2129 (WINNIPEG)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 38°C
DHW - 71°C

House Type: One storey with full basement
Post - 1975 construction
Natural ELA @ 10 Pa = 250 cm²
Natural ACPH @ 50 Pa = 1.00

Appliance Type:



Competing Exhaust Systems:

1 - Kitchen range hood fan
3 - Bathroom fans
1 - Clothes dryer
Measured total exhaust flow from fans: 58 L/s

Fireplace:

1 - Brick with metal jacket and loose doors
Measured totalexhaust flow from fireplace (at -9 Pa) = 28 L/s

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted H.D. - 16.1 Pa
Furnace H.D. Limit - 6 Pa
House prone to venting failure
(H.D. Limit exceeded by 11.1 Pa)

2) Inspection:

Flue pipe excessively long.
Bent chimney.

3) House Depressurization:

H.D. from fans - 9 Pa
H.D. from fans plus fireplace - 12 Pa
H.D. Limit for furnace - 6 Pa
H.D. Limit for DHW - 5 Pa
H.D. Limit for fireplace - 3 Pa
Exhaust fans exceed H.D. Limit for furnace, DHW and fireplace.

4) Total Flue Draft:

Full operation = 11 Pa.
Standby = 4 Pa.

5) Spillage Observations:

Spillage duration for tight house more than 30 seconds.
No spillage for open house.

6) Heat Exchanger Test:

No perceptible leakage.

7) Questioning of Occupant:

Occupant unaware of any existing problem.

Failure Event Description and Simulation: House 2129

It was concluded that chimney failure was a result of backdrafting. The major contributing factors were a tight envelope, many exhaust fans, and an open fireplace.

To simulate backdrafting, all exhaust fans were operated, creating 9 Pascals of house depressurization. To prevent re-establishment of draft from strong gusty winds, the door fan was used to further depressurize the house to 22 Pascals. The furnace and DHW were then cycled 10 minutes off/20 minutes on, over a 90 minute period.

Graph 1 - 2129, shows temperature monitoring of the furnace flue and dilution air inlet during the simulated backdrafting event.

Graph 2 - 2129, shows the build-up over time of CO_2 in the return air system of the forced air furnace. The maximum level of CO_2 recorded was 4900 ppm. A steady-state concentration of CO_2 is estimated to be 8000 ppm (using the IAQ computer model).

Graph 3 - 2129, shows the decay rate of CO_2 following the failure event simulation, and indicates the air change rate to be 0.8 ACPH when the house is closed and fans are off. This air change rate appears high, and it is suspected that initial poor mixing of CO_2 indoors has accelerated the decay rate of CO_2 at the sampling location.

No measurable levels of carbon monoxide were recorded during the simulation.

Conclusions and Comments: House 2129

o This Winnipeg house was an exceptionally tight house with a large number of fans, none of which was particularly powerful. Different combinations of the fans are capable of creating chimney backdrafting.

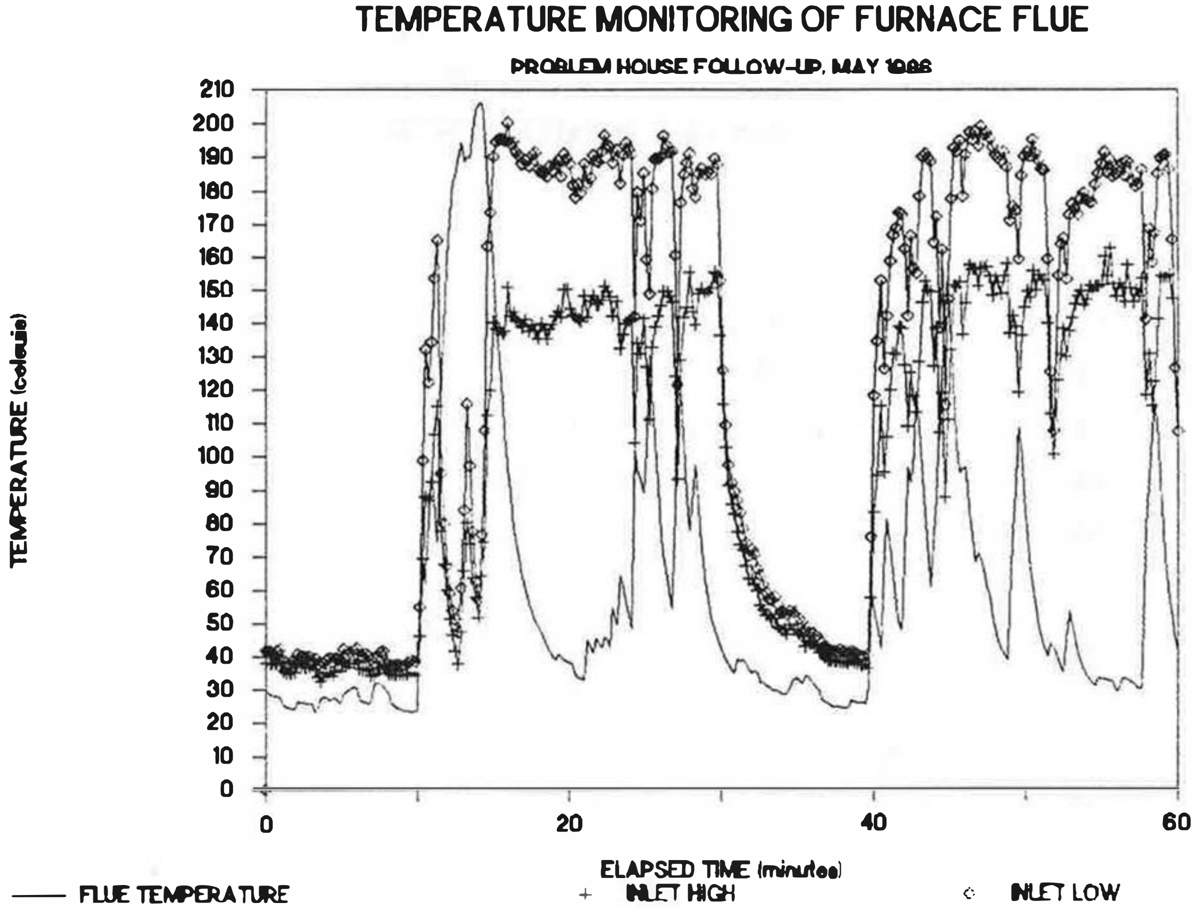
o Although no CO was produced by the appliance during backdrafting, the levels of CO_2 could ratchet up to 8000 ppm over several hours, despite the high air change created by exhaust fan operation.

o Occupant remarked that basement bathroom fan gets left on for days at a time.

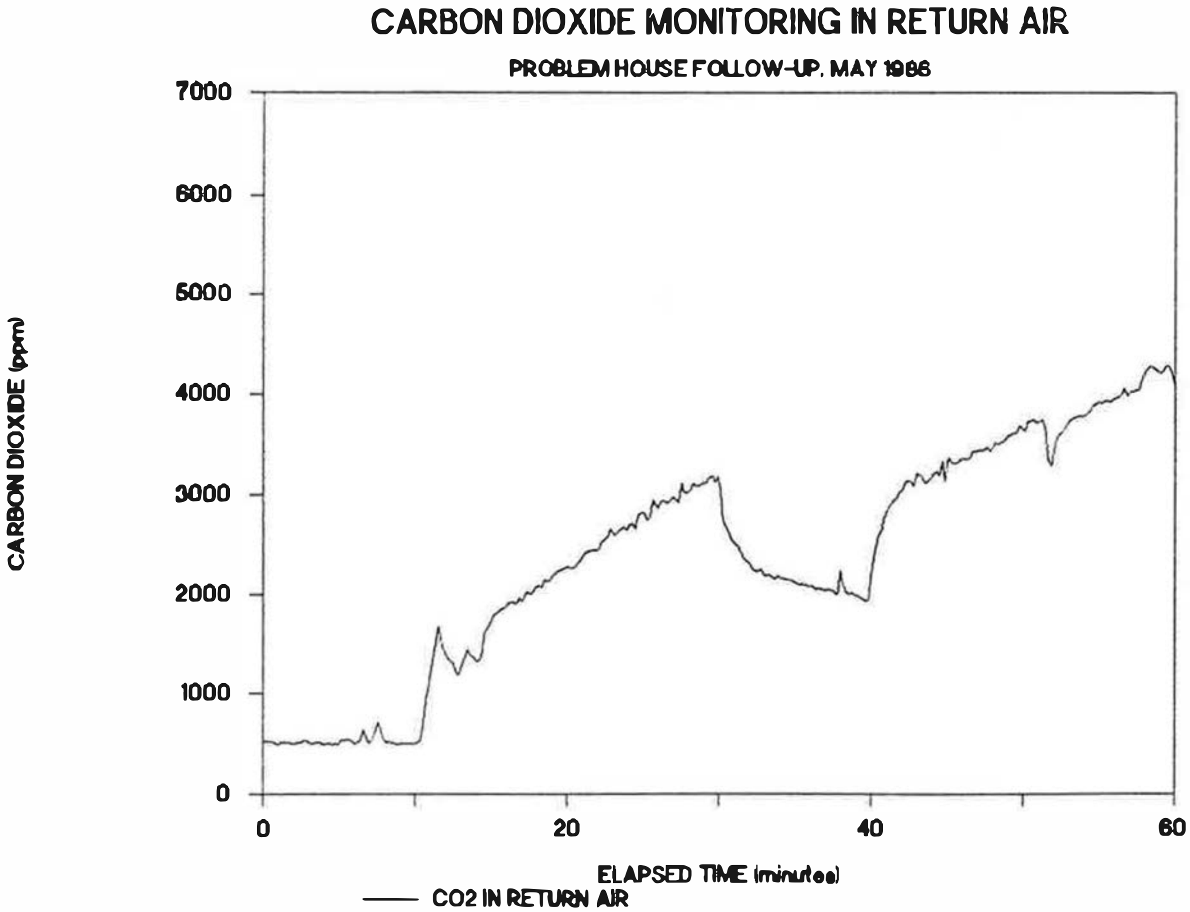
o Occupant fully understood the problem after a verbal explanation.

o A chimney spillage alarm would be a suitable remedial measure for this house. The occupants are prepared to take an active role in avoiding the problem, and the required change in lifestyle is not difficult or inconvenient.

GRAPH 1 - 2129



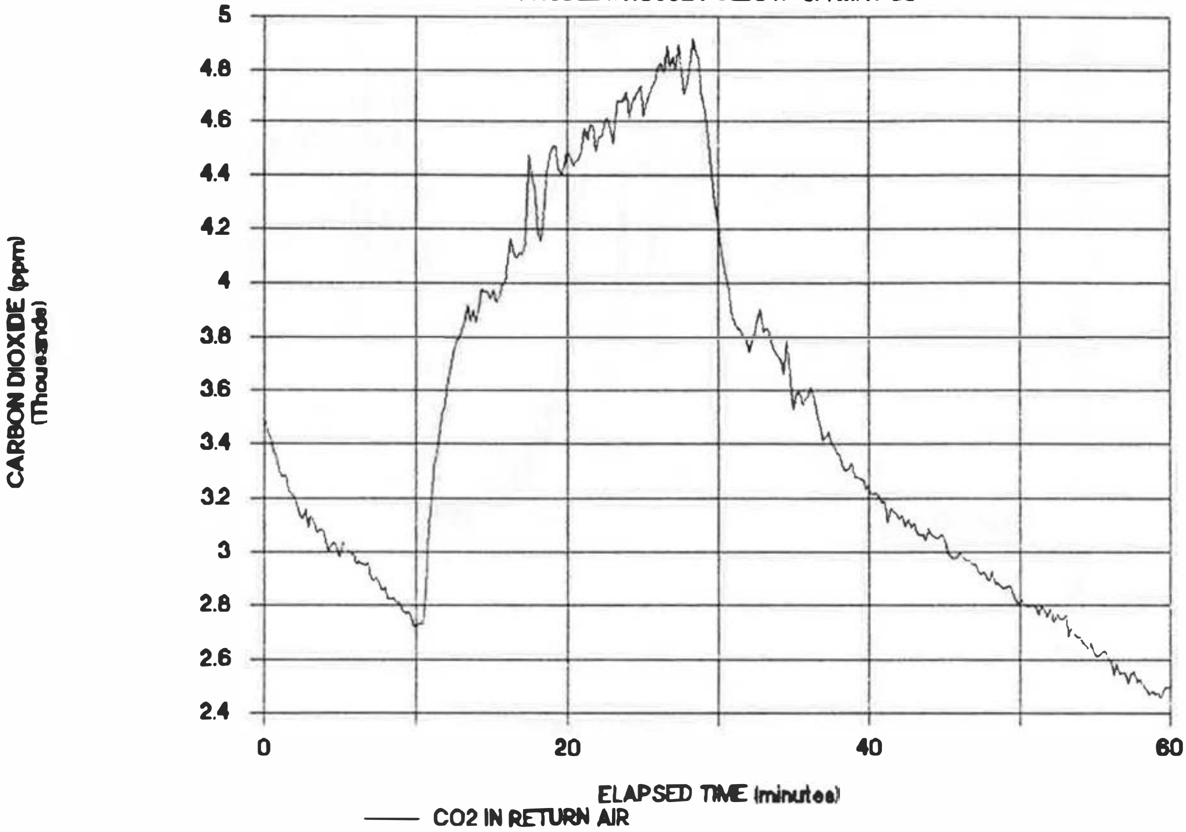
GRAPH 2 - 2129



GRAPH 3 - 2129

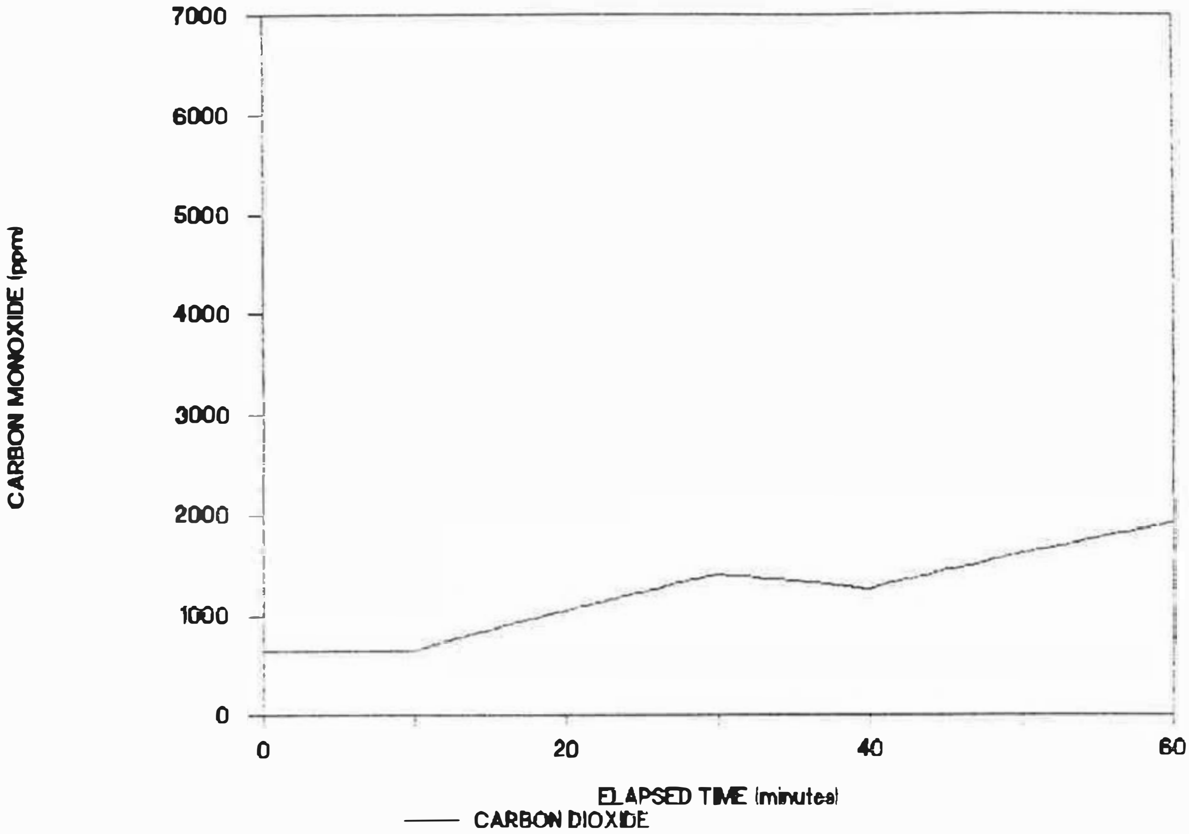
TRACER GAS AIR CHANGE RATE

PROBLEM HOUSE FOLLOW-UP, MAY 86



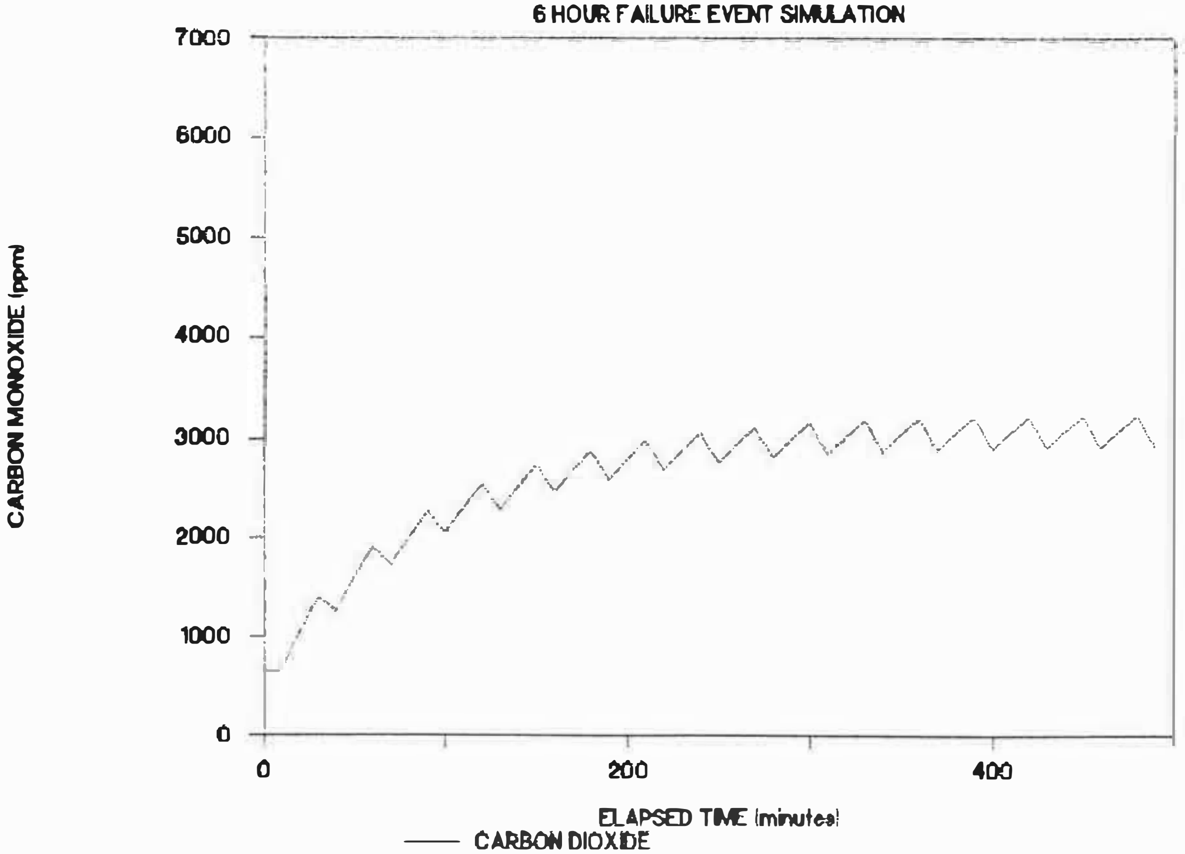
GRAPH 4 - 2129 IAQ MODELING OF CO2 BUILD-UP DURING

60 MINUTE FAILURE EVENT SIMULATION



GRAPH 5 - 2129 IAQ MODELING OF CO2 BUILD-UP DURING

6 HOUR FAILURE EVENT SIMULATION



Model Input Sheet   HOUSE # 2129

House Data   [illegible]

	Heat Load of house at To - Ti (kJ/hr)	
V	House Volume (m^3)	830
A	Envelope Area (m^2)	332
	Surface Area (m^2)	
ELA	House ELA @ 10 Pa (cm^2)	587
n	Flow Exponent (n)	0.686
k	Mixing Factor (%)	0.85
H	Height of House (m)	3.5

Infiltration model

H1	Height of Wind Measurement (m)	10
fw	Wind Parameter	[illegible]
C	Shielding Class	[illegible]
a	Terrain class for house	1
y	Terrain class for house	0.15
a1	Terrain Class for wind measurement	1
y1	Terrain Class for wind measurement	0.15
g	The acceleration of Gravity (m/s^2)	[illegible]
fs	Stack Parameter	[illegible]
r	Fraction of Leakage in Floor And Ceiling (R)	[illegible]
x	Fraction of Leakage Imbalance (X)	[illegible]
Ti	Indoor Temperature (K)	293
L	Effective Leakage Area (m^2)	[illegible]
Q0	Infiltration Rate (M^3/s)	[illegible]
ACPH	Air Change Per Hour Rate (House Volumes\Hour)	[illegible]

Appliance Data

		2
Ft	Appliance Type (Oil, Gas, Propane)	gas
Fr	Appliance Firing Rate (btu\hr)	105000
	Appliance Fireing Rate (kJ\hr)	110775
X	Pollutant as a % of Combustion Gas	
	Fraction of Gas Spilling	1
	Fraction of Cycle that Spills	1
	Fraction of On Time	1
Tc	Time Between Cycles (hr)	0.05

Weather Data

dT	To - Ti at Start	5
To	Temperature Outdoors (K)	288
W	Wind Speed (m/s)	0

Flow Rates, House Depressurization, and Filtration

F0	Make-up Filter Efficiency (%)	0
F1	Recirc Filter Efficiency (%)	0
q0	Make-up Flow Rate (m^3/s)	0
q1	Recirculation Flow Rate (m^3/s)	0
q2	Infiltration Flow Rate (m^3/s)	0.169

q*	Characteristic Flow Rate (Flow/time)	0.144
	Calculated Exhaust Flow (L/s)	
Ex	Default Exhaust Flow (L/s)	168.8
HDP	House Depressurization (Pa)	13.2

Pollutant Data

		CO2
P	Pollutant	
	Generation Rate Per (mg/kj)	35.000
R	Pollutant Decay Rate	
K1	Inverse Deposition Rate	
Kdep	Deposition Velocity (length/time)	0.000
S	Indoor Source Strength (mg\sec)	1076.979

Steady State Pollutant Data

		CO2
t*	Caharacteristic Time (hrs)	1.605
Css	Steady State Concentration (Css)	8305.981
Cs	Start Concentration (mg\m^3)	1170.000
CO	Outdoor Pollutant Concentration (mg/m^3)	810.000
Ci	Concentration of Pollutants (mg/m^3)	2386.783
	Steady State Concentration (ppm)_	4651

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

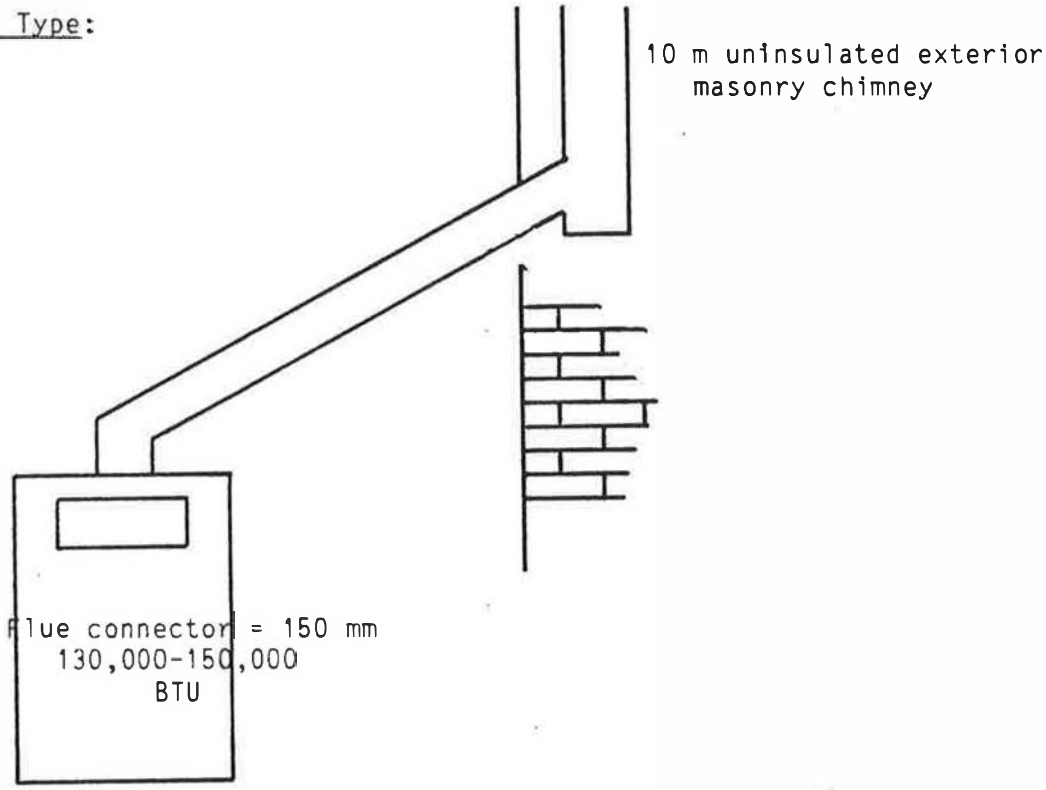
HOUSE NO: 2022 (WINNIPEG)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 71°C
DHW - 0

House Type: Two storey with full basement
1900-1945
Natural ELA @ 10 Pascals = 472 cm2
Natural ACPH @ 50 Pascals = 2.48

Appliance Type:



More than 20 years old

Competing Exhaust Systems:

1 - Stove top barbecue fan
Measured exhaust fan flow: 80 L/s

Fireplace:

1 - Open brick fireplace

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted House Depressurization - 5.8 Pa
H.D. Limit for furnace - 5 Pa
House is a borderline case since the predicted depressurization is roughly equal to H.D. Limit.

2) Inspection:

Burner jets of boiler were covered with grime and rust deposits.

3) Venting Systems Test:

H.D. from fans - 6 Pa
H.D. Limit furnace - 5 Pa
Kitchen barbecue exhaust fan was capable of depressurizing house to 6 Pa.

4) Total Flue Draft:

Full operation = 18 Pa.
Standby = 5 Pa.

5) Spillage Observations:

With the house depressurized, furnace spilled for more than 30 seconds. No spillage was observed for an open house.

6) Heat Exchanger Test:

Not applicable.

7) Questioning of Occupant:

Occupants were aware that there could be a problem. They had noticed backdrafting smells when operating kitchen top barbecue fan. Lacy of house suffers from headaches and allergies and may be hyper-sensitive to air-borne contaminants.

Failure Event Description and Simulation: House 2022

o Chimney backdrafting, due to a powerful kitchen barbecue fan, was the likely failure mechanism in this house. Consequently, the barbecue fan was operated, depressurizing the house to 6 Pa. To prevent strong gusty winds from re-establishing draft during the simulation, the flue connector was plugged. An alternative to plugging the flue would have been to use a door fan to further depressurize the house; however, this approach was rejected because the effect would be to increase air change and air mixing far above normal.

o The first simulation was aborted because carbon monoxide levels rose quickly above 200 ppm, posing a hazard to occupants and researchers. A second simulation was started after relocating the equipment to the floor above the boiler room. Continuous sampling of indoor air was conducted in the basement den area, because pollutant levels in the boiler room were certain to exceed the measurement range of the analyzers.

o The furnace was cycled for only a short time (20 minutes) to avoid hazardous CO levels.

Graph 1 - 2022, shows the temperatures of the boiler flue gases during simulation. The hot inlet temperatures correspond with the brief on-times, before the test was aborted.

Graph 2 - 2022, shows flue gas temperatures during the second simulation. Although flue temperatures rose above 200°C, no combustion gases were observed to escape up the plugged chimney. The inlet temperatures of up to 1[illegible]5°C at the "high" location, correspond well with a dot temperature of 7[illegible]°C.

Graph 3 - 2022, shows the extremely quick build-up of carbon dioxide during the aborted simulation. The levels reached the analyzer limit of 5000 ppm within 2 minutes.

Graph 4 - 2022, shows that carbon dioxide levels in the basement den. Once again CO_2 levels quickly exceed the analyzer.

Graph 5 - 2022, shows the build-up of carbon monoxide in the boiler room during the first (aborted) simulation. Levels rose at a similar rate to CO_2.

Graph 6 - 2022, shows the build-up of CO in the basement den. After the initial jump to 17 ppm, a drop occurs, presumably as CO mixes more thoroughly into the upstairs rooms. Levels then start to rise continuously, at a rate of about 3 ppm per minute, until the boiler is shut off at the 22 minute mark.

Graph 7 - 2022, shows the decay of carbon dioxide immediately following the (second) simulation.

Graph 8 - 2022, is a model simulation of the boiler spilling over a longer period that would be a more likely occurrence during winter months.

Conclusions and Comments: House 2022

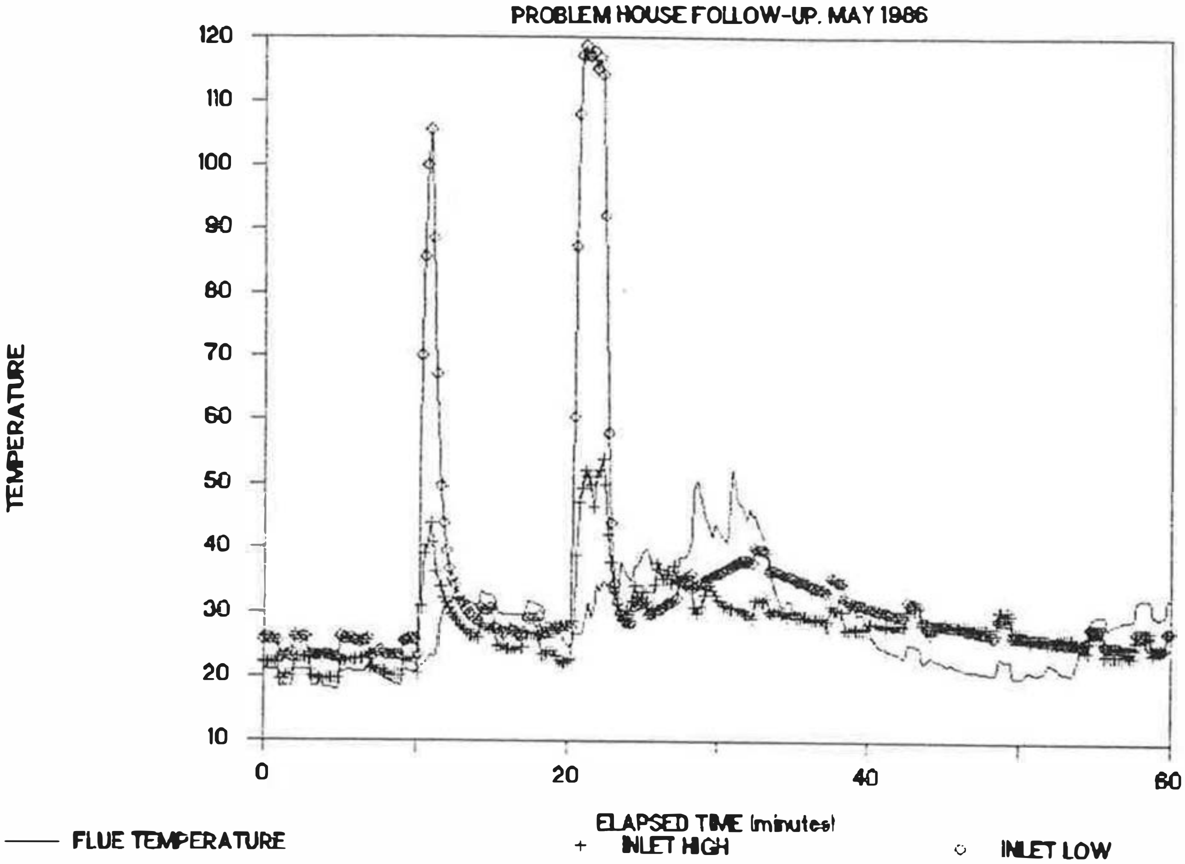
o It was evident that backdrafting from a hot water boiler poses a greater threat to occupant safety than does backdrafting from a forced air furnace. Levels of combustion pollutants quickly build to unacceptable levels if there is no forced air system to distribute and dilute combustion gases. A curious occupant, walking in to this boiler room after smelling backdrafting, could be overcome by CO levels if the boiler had been operating for more than 4 or 5 minutes.

o The boiler had not been maintained while the present occupants have owned the house (more than 3 years). The burners were covered in rust deposits and grime that may have contributed to the high carbon monoxide generation rates.

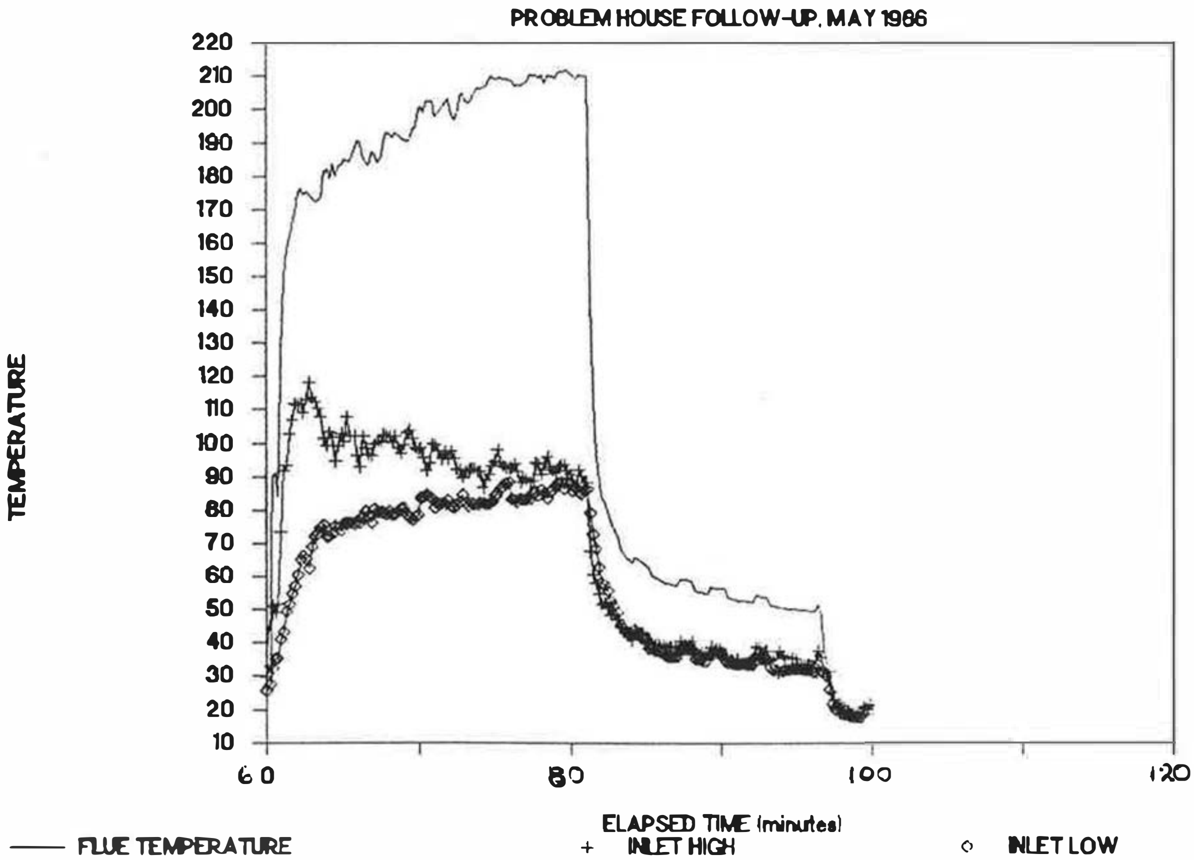
o It is interesting to note that this appliance could also pose a threat to any persons carrying out a safty check on the house. A carbon monoxide sample taken from the combustion gases may be worthwhile, especially when testing boilers. A CO sample of the boiler flue gas showed 47 ppm. Alternately, a tester could carry a CO alarm, or a personal CO dossimeter.

o The distribution of pollutants from the boiler room to other portions of the house was very slow, relative to houses with forced air systems.

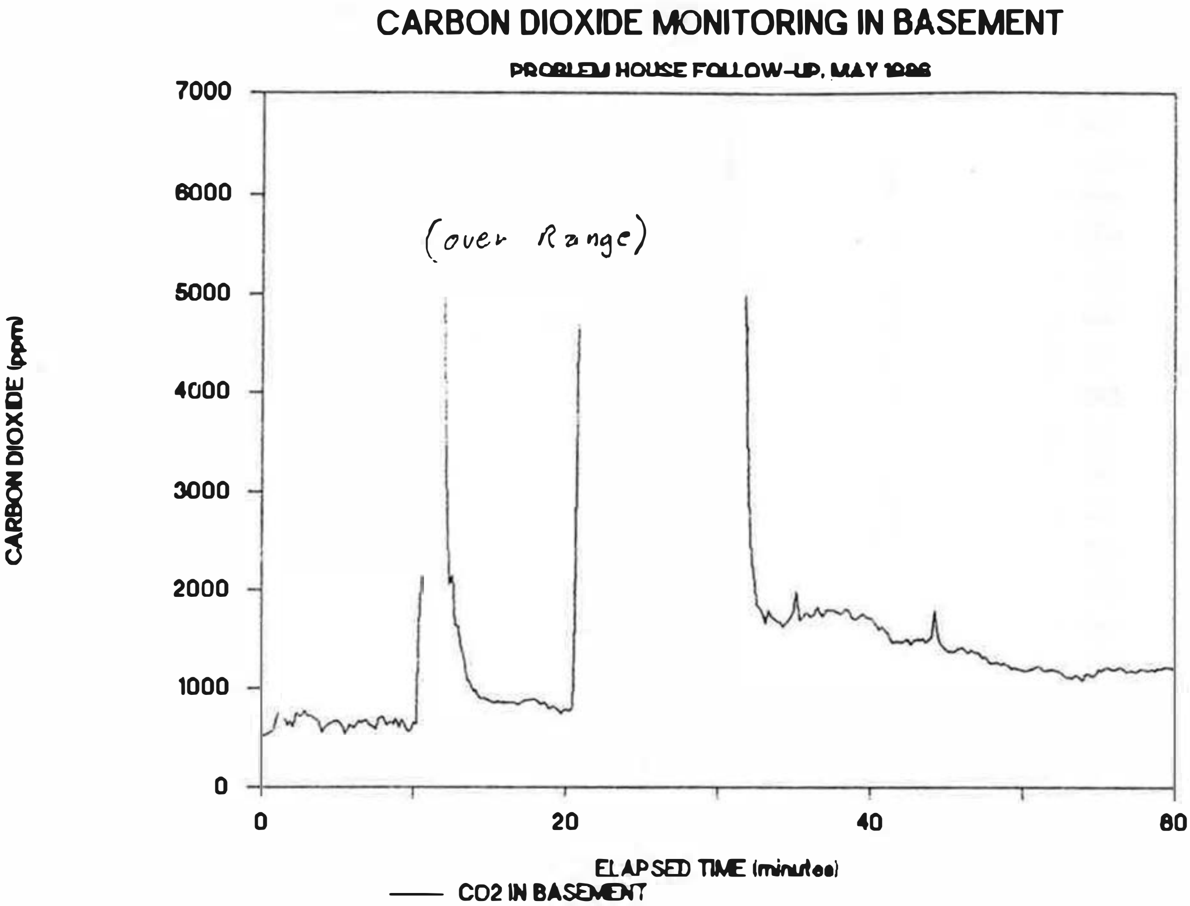
GRAPH 1 - 2022 TEMPERATURE MONITORING OF FURNACE FLUE



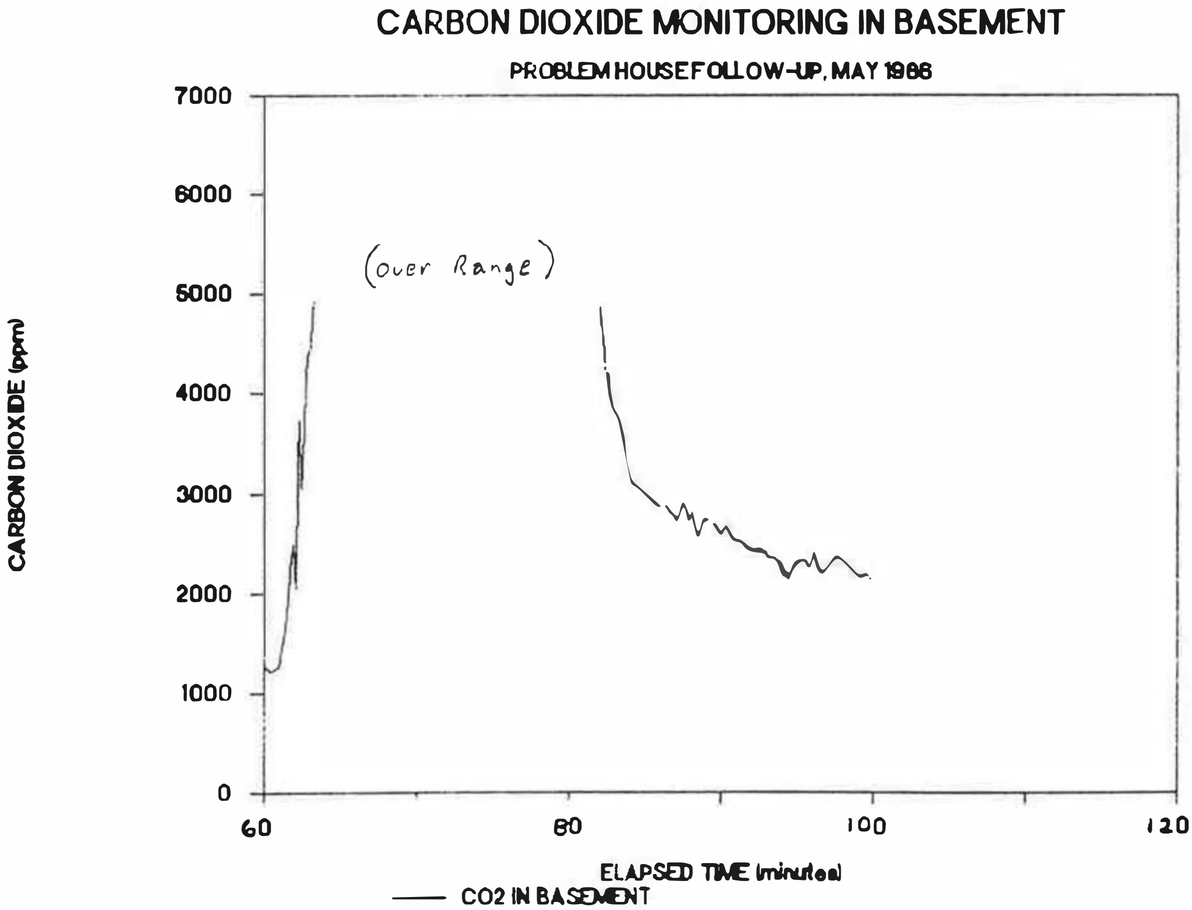
GRAPH 2 - 2022 TEMPERATURE MONITORING OF FURNACE FLUE



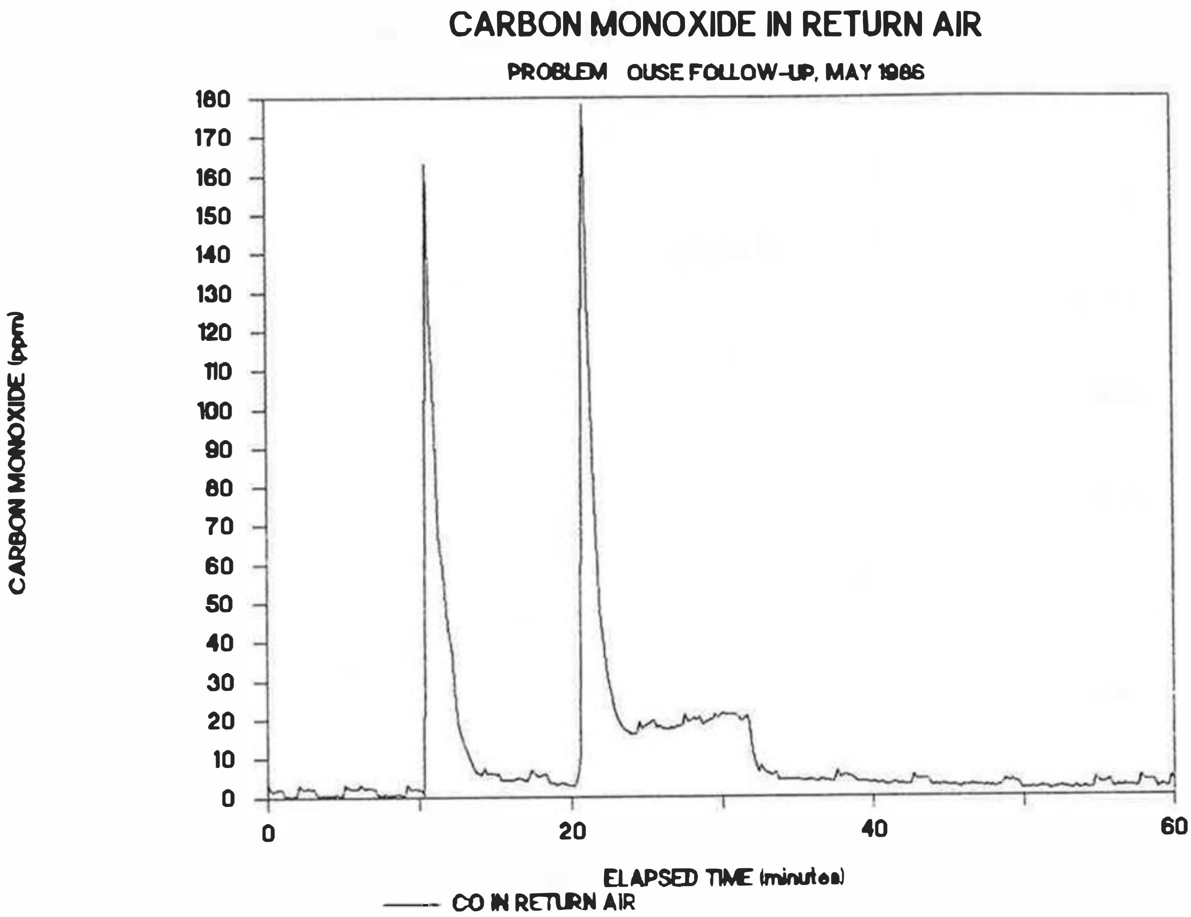
GRAPH 3 - 2022



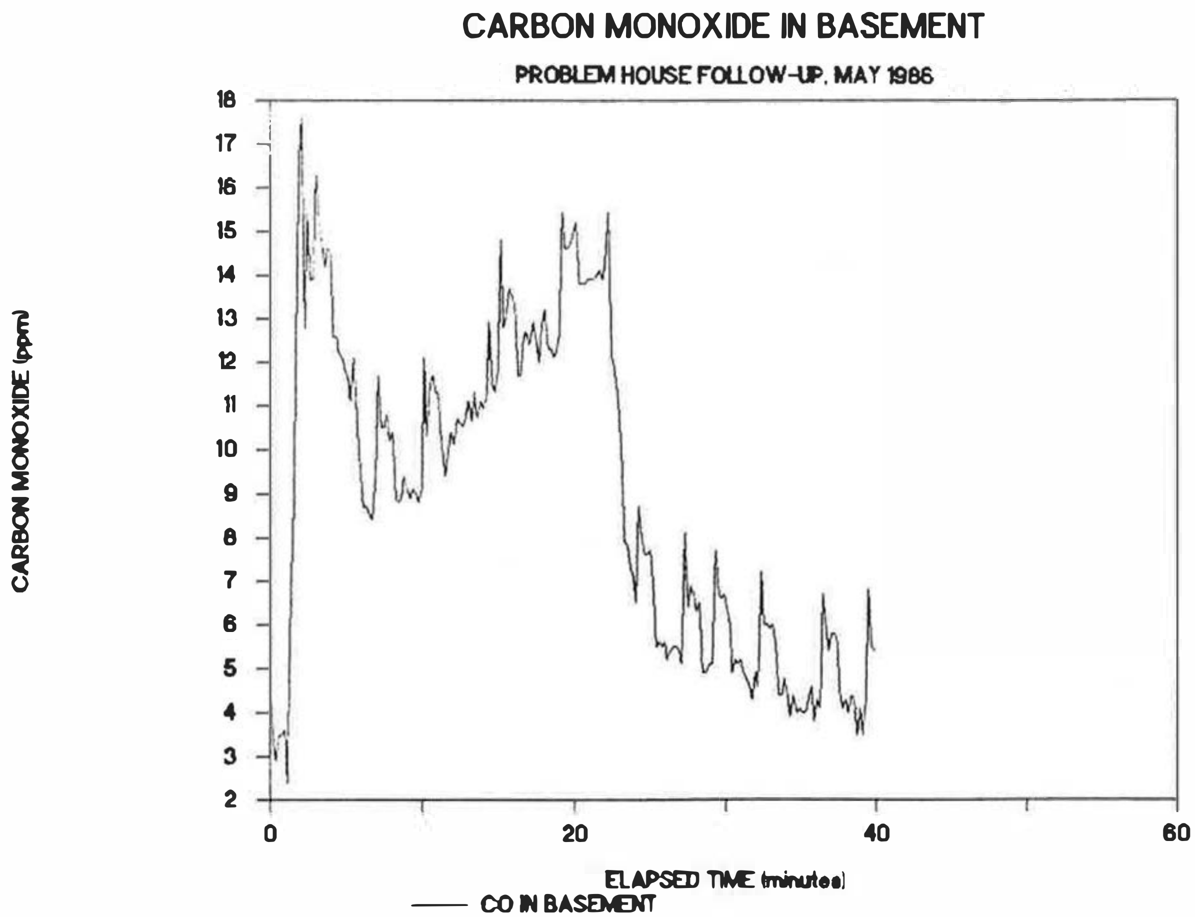
GRAPH 4 - 2022



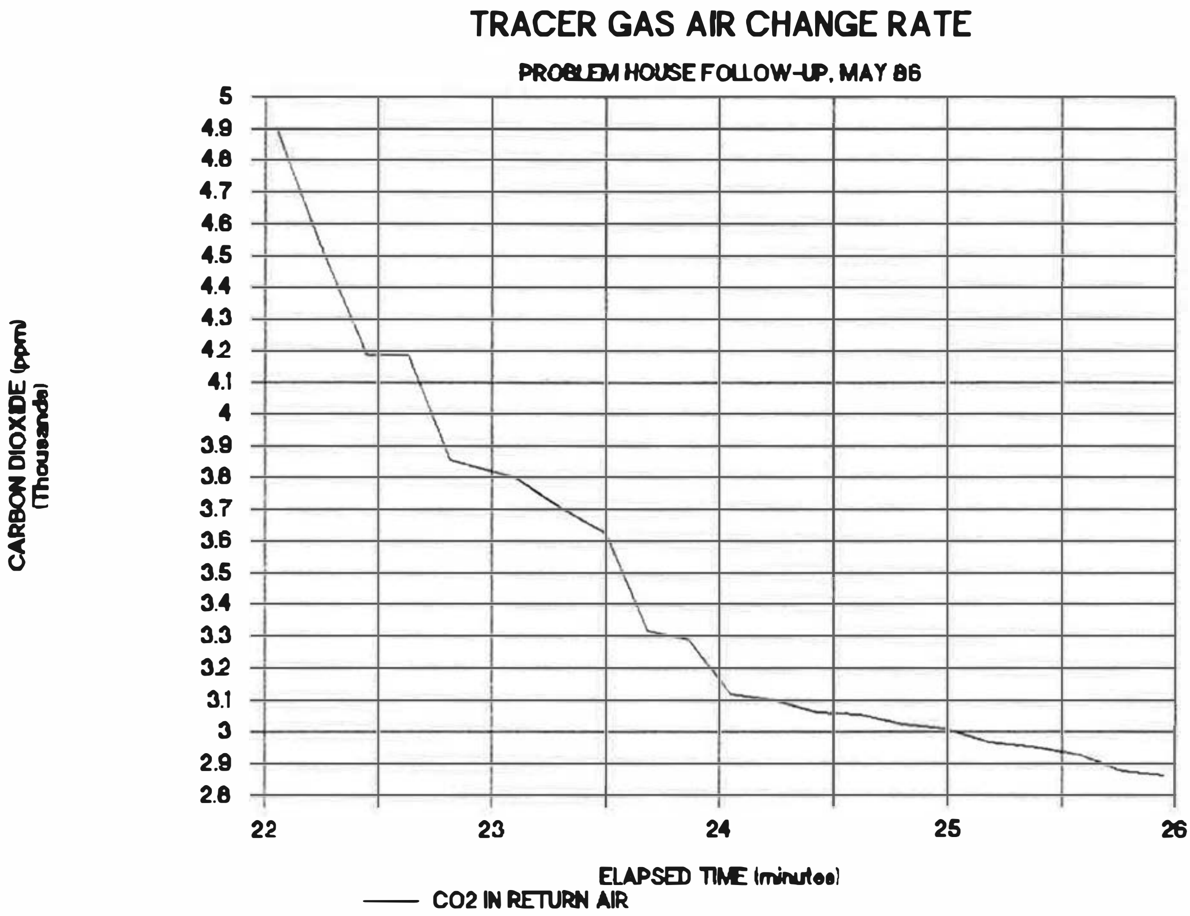
GRAPH 5 - 2022



GRAPH 6 - 2022



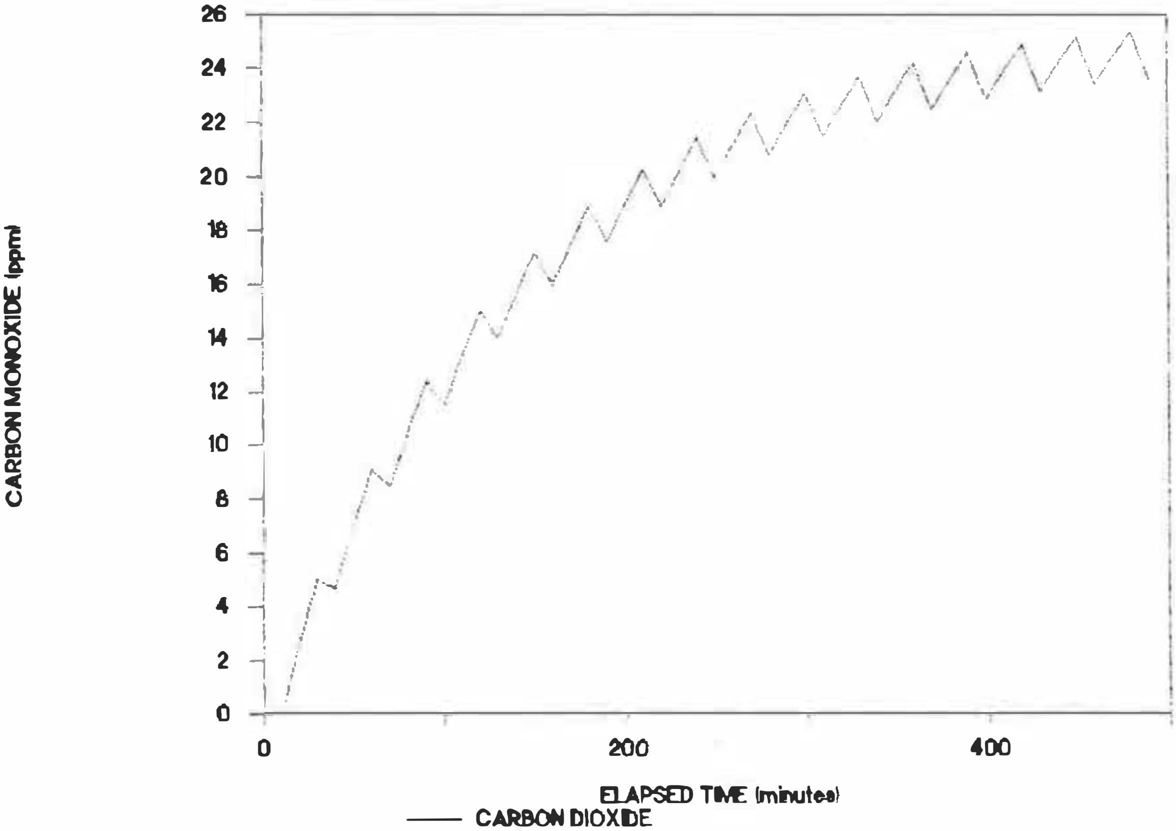
GRAPH 7 - 2022



TRACER GAS AIR CHANGE RATE
PROBLEM HOUSE FOLLOW-UP, MAY 86
CARBON DIOXIDE (ppm)
(Thousands)
5
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
4.1
4
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
22
23
24
25
26
ELAPSED TIME (minutes)
CO2 IN RETURN AIR

GRAPH 8 - 2022 **IAQ MODELING OF CO BUILD-UP DURING**

6 HOUR FAILURE EVENT SIMULATION



Model Input Sheet HOUSE # 2022

House Data		CO
	Heat Load of house at To - Ti (Kj/hr)	
V	House Volume (m^3)	578
A	Envelope Area (m^2)	231.2
	Surface Area (m^2)	
ELA	House ELA @ 10 Pa (cm^2)	472
n	Flow Exponent (n)	0.757
k	Mixing Factor (%)	0.85
H	Height of House (m)	6

Infiltration model

Z'	Height of Wind Measurement (m)	10
fw	Wind Parameter	0.136
C	Shielding Class	0.24
a	Terrain class for house	1
y	Terrain class for house	0.15
a'	Terrain Class for wind measurement	1
y'	Terrain Class for wind measurement	0.15
g	The acceleration of Gravity (m/s^2)	9.8
fs	Stack Parameter	0.170
	Fraction of Leakage in Floor And Cieling (R)	0.77
	Fraction of Leakage Imbalance (X)	0.43
Ti	Indoor Temperature (K)	293
L	Effective Leakage Area (m^2)	0.023
q0	Infiltration Rate (M^3/s)	0.080
ACPH	Air Change Per Hour Rate (House Volumes\Hour)	0.501

Appliance Data

		2
Ft	Appliance Type (Oil, Gas, Propane)	gas
Fr	Appliance Firing Rate (btu\hr)	150000
	Appliance Firing Rate (KJ\hr)	158250
M	Pollutant as a % of Combustion Gas	
	Fraction of Gas Spilling	1
	Fraction of Cycle that Spills	1
	Fraction of On Time	1
Tc	Time Between Cycles (hr)	0.05

Weather Data

dT	To - Ti at Start	5
To	Temperature Outdoors (K)	288
V	Wind Speed (m/s)	0

Flow Rates, House Depressurization, and Filtration

FO	Make-up Filter Efficiency (%)	0
Fi	Recirc Filter Efficiency (%)	0
qO	Make-up Flow Rate (m^3/s)	0
qi	Recirculation Flow Rate (m^3/s)	0
q0	Infiltration Flow Rate (m^3/s)	0.080

q*	Characteristic Flow Rate (Flow/time)		0.069
	Calculated Exhaust Flow (L/s)		
Ex	Default Exhaust Flow (L/s)		80
HDP	House Depressurization (Pa)		5.8

Pollutant Data

		CO	
P	Pollutant		
	Generation Rate Per (mg/kJ)		0.068
R	Pollutant Decay Rate		
Ki	Inverse Deposition Rate		
Vdst	Deposition Velocity (length/time)		0.007
S	Indoor Source Strength (mg\sec)		2.969

Steady State Pollutant Data		CO	
t*	Caharacteristic Time (hrs)		2.347
Css	Steady State Concentration (Css)		43.705
Cs	Start Concentration (mg\m^3)		0.003
CO	Outdoor Pollutant Concentration (mg/m^3)		0.003
Ci	Concentration of Pollutants (mg/m^3)		5.244
	Steady State Concentration (ppm)_		38.023541

AIRTIGHTNESS TEST RESULTS

HOUSE IDENTIFICATION - SWARTZ

DATE - MAY 28/86

OUTDOOR TEMPERATURE - 22 (C)

WIND SPEED -CALM KPH

VOLUME - 578 M^3

HOUSE PRESSURE (Pa)	FLOW PRESSURE (Pa)	FLOW MEASURED (L/s)	FLOW CORRECTED (L/s)	FLOW FITTED (L/s)	RELATIVE STANDARD ERROR (%)
40	545	337.78	338.44	335.87	-0.76%
35	445	305.38	305.97	303.58	-0.78%
30	333	264.35	264.87	270.15	1.99%
25	258	232.83	233.29	235.33	0.87%
20	182	195.72	196.11	198.75	1.35%
15	125	162.36	162.67	159.86	-1.73%
10	68	119.93	120.16	117.61	-2.12%
0	0	0.00	0.00	0.00	0.00%
0	0	0.00	0.00	0.00	0.00%
0	0	0.00	0.00	0.00	0.00%
0	0	0.00	0.00	0.00	0.00%
0	0	0.00	0.00	0.00	0.00%
0	0	0.00	0.00	0.00	0.00%

C = 20.58

n = 0.757

ELA = 472 CM^2

Q @ 50 Pa = 398

Q @ 10 Pa = 118

AIR CHANGE PER HOUR @ 50 Pa = 2.476872317

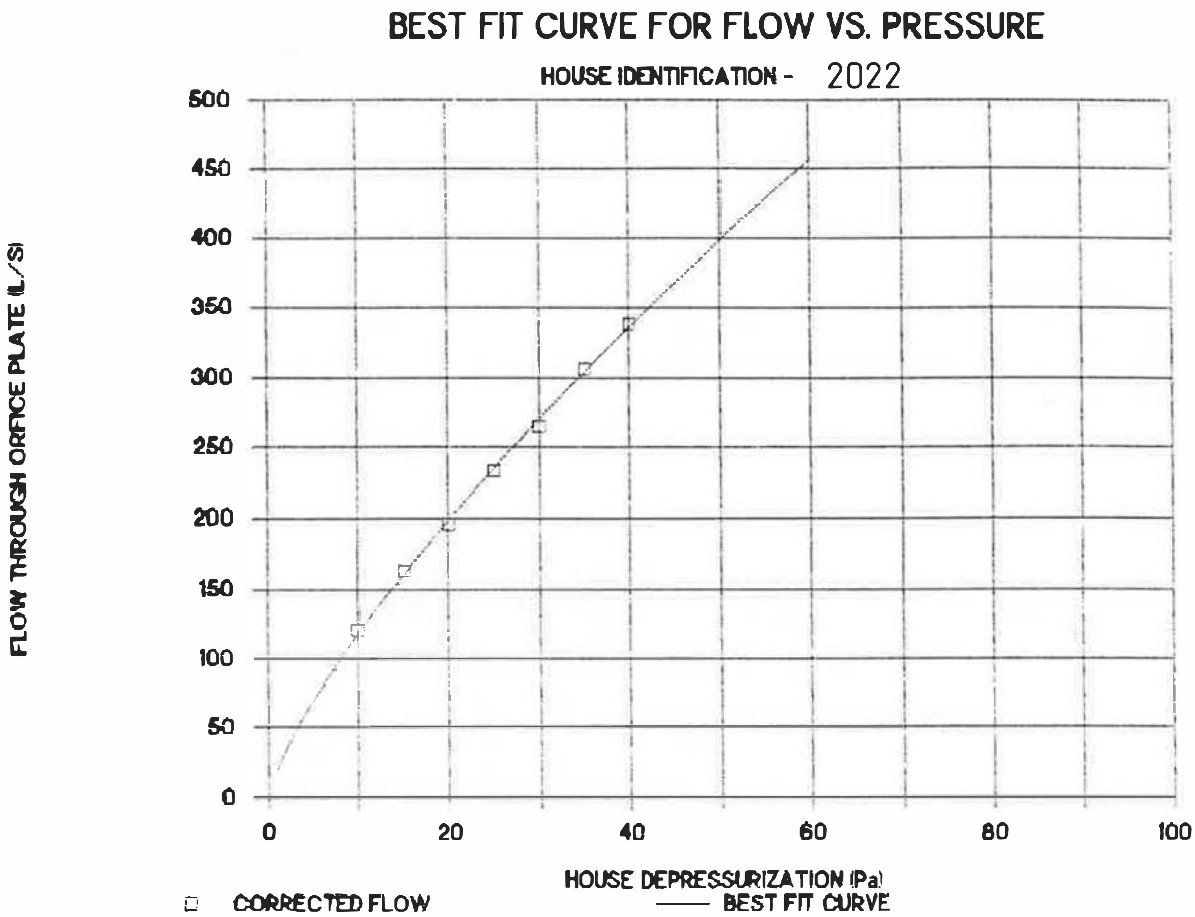
SXX = 20442425826

SYY = 1.174E+10

SXY = 15473527369

SYX = 7.2541572

CORRELATION COEFFICIENT = 0.998851213



BEST FIT CURVE FOR FLOW VS. PRESSURE
HOUSE IDENTIFICATION - 2022
FLOW THROUGH ORFICE PLATE (L/S)
500
450
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
HOUSE DEPRESSURIZATION (Pa)
CORRECTED FLOW
BEST FIT CURVE

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

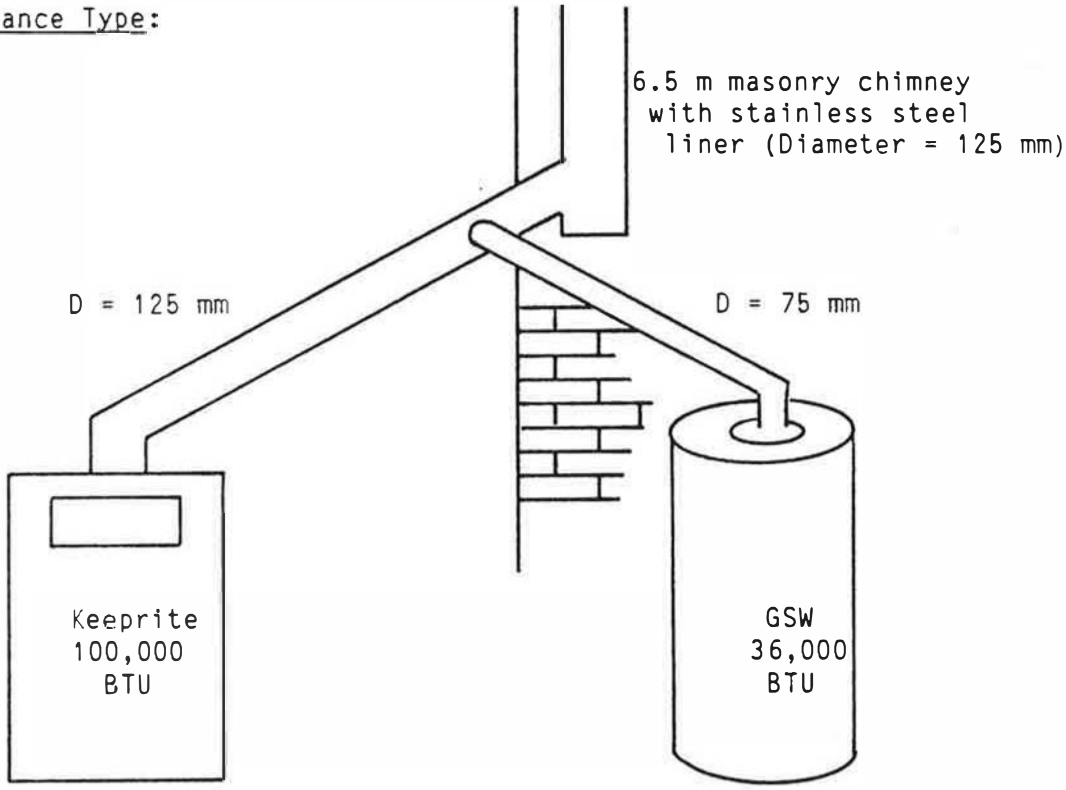
HOUSE NO: 2138 (WINNIPEG)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 71°C
DHW - 54°C

House Type: One storey with full basement
1956-1960
Natural ELA @ 10 Pascals = 226 cm^2
Natural ACPH @ 50 Pascals = 2.05

Appliance Type:



Less than 5 years old

Less than 5 years old

Competing Exhaust Systems:

1 - Clothes dryer
Measured fan flow - 15 L/s

Fireplace:

1 - Metal fireplace with doors
Measured fireplace flow - 15 L/s

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted H.D. - 8.5 Pa
H.D. Limit for furnace - 5.0 Pa
House is prone to venting failure.
H.D.Limit exceeded by 7.6 Pa.

2) Inspection:

Restrictive chimney top.
Water staining at base of chimney.
Masonry dust at bottom of flue pipe,
indicating a deteriorated tile liner.

3) Venting Systems Test:

H.D. from fans - 2.0 Pa
H.D. from fans plus fireplace - 4.2 Pa
H.D. from fans plus furnace - 4.0 Pa
Only the H.D. limit for fireplace was exceeded.

4) Total Flue Draft:

Full operation = 9.0 Pa.
Standby = [illegible].5 Pa.

5) Spillage Observations:

Furnace spilled for more than 30 seconds in a tight house.
Spillage observed in an open house.

6) Heat Exchanger Test:

No perceptible leakage.

7) Questioning of Occupant:

Occupant was not aware he had a problem but was very interested in the cause, and effecting a solution.

Failure Event and Description Simulation: House 2138

A restrictive chimney top, a restrictive flexible metal liner, and a leaky flue pipe all appeared to contribute to an inadequately sized chimney in this house. As a result, prolonged start-up spillage was observed, even under "open" house conditions. When the house was depressurized to 2 Pa by the weak exhaust fans, the quantity and duration of spillage increased significantly.

An attempt was made to simulate a failure event by cycling the furnace on and off at frequent intervals over a two hour period, while operating the exhaust fans. Unfortunately, electrical grounding problems and computer software bugs prevented operation of the data logger and gas analysis. Carbon dioxide levels were observed to increase slowly over the two hour period. No significant level of carbon monoxide were measured.

Conclusions and Comments: House 2138

o The chimney liner that had been retrofitted into the masonry chimney restricted flow in two ways. The liner was constructed of expandable, corregated stainless steel that is known to have poor flow characteristics. And the chimney top cap, although not measured at this time, was identical to another top that had been measured and was known to have less free area than the liner. The draft was strong but these excessive restrictions prevented the chimney from handling the entire flow until it was well heated.

o The exhaust fans and fireplace did not exceed the H.D. Limit for either appliance. However, the combined effect of depressurization and restrictions increased both the duration and quantity of spillage from the chimney.

o Masonry dust was found at the foot of the chimney on the inside of the liner. If the liner had been damaged or cracked on installation, this is what you would expect to find. However, it is impossible to determine if the liner was cracked by means of a visual inspection only.

o The construction date for this house was 1945 to 1960; and yet the ELA was only 226 cm^2. This house is an example of the extreme levels of airtightness to be found in some conventional, older, prairie houses. Installation of a powerful exhaust fan in such a house would create major problems.

o The basement fireplace had a combustion air supply which was totally ineffective in delivering air. This would be due to the small diameter of the supply duct and the restrictions caused by bends in the duct work.

AIRTIGHTNESS TEST RESULTS

HOUSE IDENTIFICATION - HAWKINS

DATE - MAY 10/8

OUTDOOR TEMPERATURE - 28 (C)

WIND SPEED -CALM KPH

VOLUME - 382 M^3

HOUSE PRESSURE (Pa)	FLOW PRESSURE (Pa)	FLOW MEASURED (L/s)	FLOW CORRECTED (L/s)	FLOW FITTED (L/s)	RELATIVE STANDARD ERROR (%)
60	305	253.05	257.80	254.71	-1.20%
55	258	232.83	237.20	236.70	-0.21%
50	212	211.16	215.12	218.43	1.54%
45	180	194.65	198.30	199.88	0.79%
40	145	174.80	178.08	180.99	1.64%
35	120	159.09	162.08	161.73	-0.22%
30	97	143.11	145.79	142.02	-2.59%
25	0	0.00	0.00	0.00	0.00%
20	0	0.00	0.00	0.00	0.00%
15	0	0.00	0.00	0.00	0.00%
10	0	0.00	0.00	0.00	0.00%
5	0	0.00	0.00	0.00	0.00%
0	0	0.00	0.00	0.00	0.00%

C = 8.08

n = 0.843

ELA = 226 CM^2

Q @ 50 Pa = 218

Q @ 10 Pa = 56

AIR CHANGE PER HOUR @ 50 Pa = 2.058548682

SXX = 3722738598.

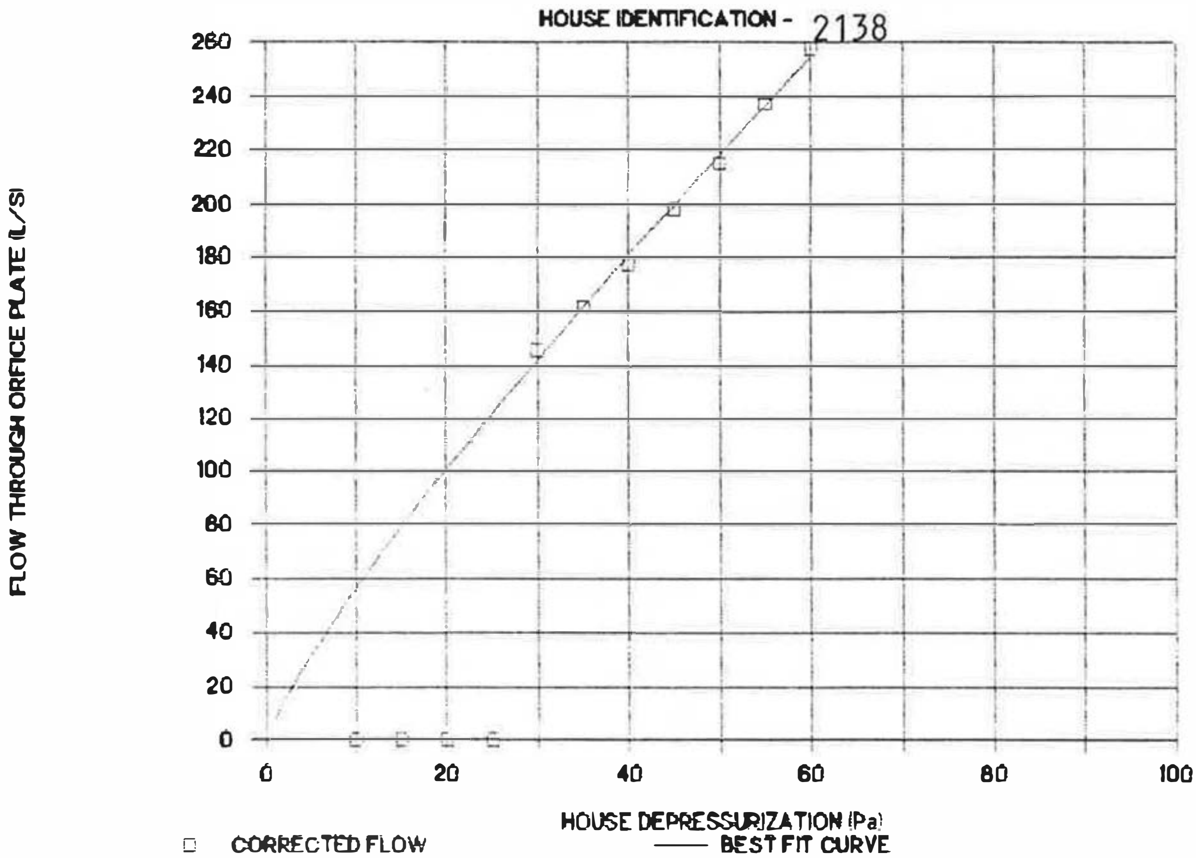
SYY = 2657191507

SXY = 3137288244.

SYX = 6.31797243

CORRELATION CODFFICIENT = 0.997497287

BEST FIT CURVE FOR FLOW VS. PRESSURE



RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

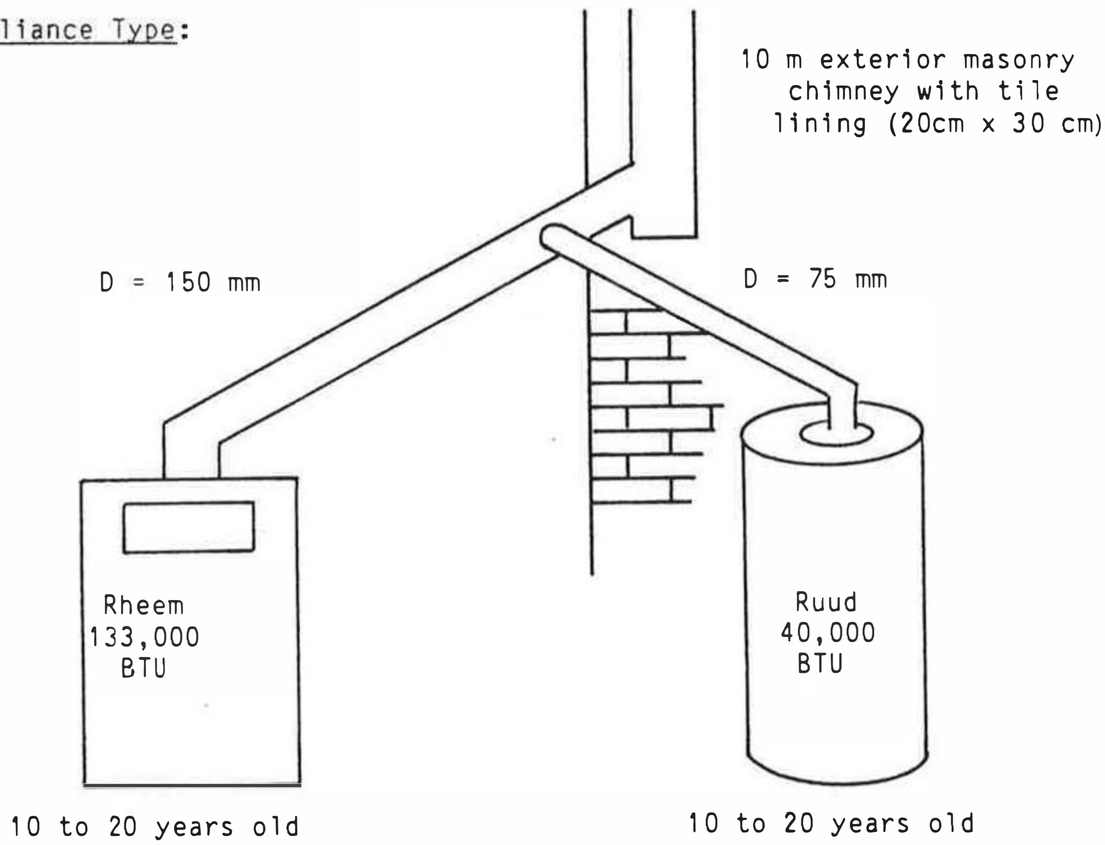
HOUSE NO: 3056 (TORONTO)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 54°C
DHW - 2nd: 38°C

House Type: One storey with full basement
1945-1960
Natural ELA @ 10 Pascals = 2243
Natural ACPH @ 50 Pascals = 11.5

Appliance Type:



Competing Exhaust Systems:

1 - Bathroom fans
1 - Clothes dryer
Total flow was insufficient for an accurate measurement.

Fireplace:

1 - Open brick fireplace
Total exhaust flow of 147 L/s

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted H.D. - 1.2 Pa
H.D. Limit for furnace - 5.0 Pa
Not prone to venting problems.

2) Inspection:

Major spillage of combustion gases from sides of boiler.
Boiler was improperly rebuilt.
Cap needs repair; metal lining required; loose fittings; leaky fittings; water stains.

3) Venting Systems Test:

Measured H.D. - 1 Pa
House passed Venting Systems Test.

4) Total Flue Draft:

Full operation = 6.5 Pa.
Standby = 1.0 Pa.

5) Spillage Observations:

Major spillage unrelated to house depressurization.

6) Heat Exchanger Test:

Not applicable.

7) Questioning of Occupant:

Occupant had noticed smells and stuffiness in basement.

Failure Event Description and Simulation: House 3056

The dot detector had identified gas spillage which was found to be occurring on a continuous basis wherever the appliance was operating. An improperly rebuilt boiler was spilling gases through holes in the side of the boiler where cover plates had been omitted.

The failure event was simulated by simply allowing the boiler to cycle on and off over a 90 minute period in a tight house. The CO2 and CO levels were measured continuously in the basement at head level. Grab bag samples were taken on the main floor and second floor of the house to show the distribution of pollutants in the house during the simulation.

Graph 1 - 3056 and 2 - 3056, show temperature monitoring of the dilution air inlet and furnace flue during the failure event simulation. Graph 1 shows the first 60 minutes and Graph 2 show the second 60 minutes. The rise and fall of temperatures correspond to the cycling of the boiler. The inlet temperatures do not exceed the dot detector temperature of greater than 54°C. However, Graph 3 - 3056 and Graph 4 - 3056, show carbon dioxide monitoring in the basement for the two 60 minute periods. Concentrations rose quickly and then began to stabilize just over 3000 ppm.

Graph 5 - 3056, shows the concentration of CO in the basement area during the simulation. The levels averaged 3 ppm, with no noticeable rise in the CO levels. The one peak reading of 20 ppm was a direct sampling of combustion gases from the DHW tank. The boiler was producing insignificant levels of CO.

Table 1 - 3056, shows the concentrations of CO2 and CO on the main floor and second floor of the house. Samples were taken every 15 minutes. The table shows delay of 20 or 30 minutes between peaks in the level of combustion gases reaching the higher floors in the house, in comparison with the basement levels. It would also appear that mixing of ventilation in the bedroom and dining room help to keep the absolute concentrations of CO_2 as much as 60% below the basement levels.

Graph 6 - 3056, shows the natural decay rate of CO2 following the event simulation. This indicated that the natural air change rate was 1.0 ACPH in the basement. Such a high air change rate may be related to the spillage of hot combustion gases.

Conclusions and Comments: House 3056

o The accidental positioning of the detector on the side of the draft hood, allowed the detector to extend over the side of the boiler casing. Consequently, the dot detector was exposed to the spillage gasses rising from leaks in the side of this improperly rebuilt boiler. This was a fortunate occurrence, since the boiler was spilling large quantities of gas. Under normal circumstances, a detector mounted on the dilution air inlet would be unable to detect this type of failure.

o When the flue pipe was temporarily plugged, flames were observed coming out the holes in the sides of the boiler.

o It required a persistent and thorough inspection to uncover the reason why the detector had indicated spillage. The natural air currents around a boiler cause major disruptions to smoke pencil investigations.

o The inspection uncovered a number of other problems with the system. In particular the measurement of only 6.5 Pa operating draft indicated a poorly performing chimney. This was probably the reason the DHW tank detector indictated spillage at start-up (2nd 38°C dot). It was suspected that the chimney had a blockage. A tall ladder was used to access the roof, and a trouble light was dropped down the chimney. This proved to be a tricky and dangerous exercise, especially because the top of the chimney was unstable. No blockage was observed. The low draft is possibly a result of cooling due to poor design (i.e., 10 m tall exterior masonry chimney), and excess leakage in the flue pipe and masonry liner. A more detailed diagnostic procedure for chimneys with low draft is required.

o The homeowner had already considered having a liner installed and had gone so far as to obtain prices. She indicated to us that there was a large range in prices for installing a liner and repairing the brick work, from $150.00 to $500.00.

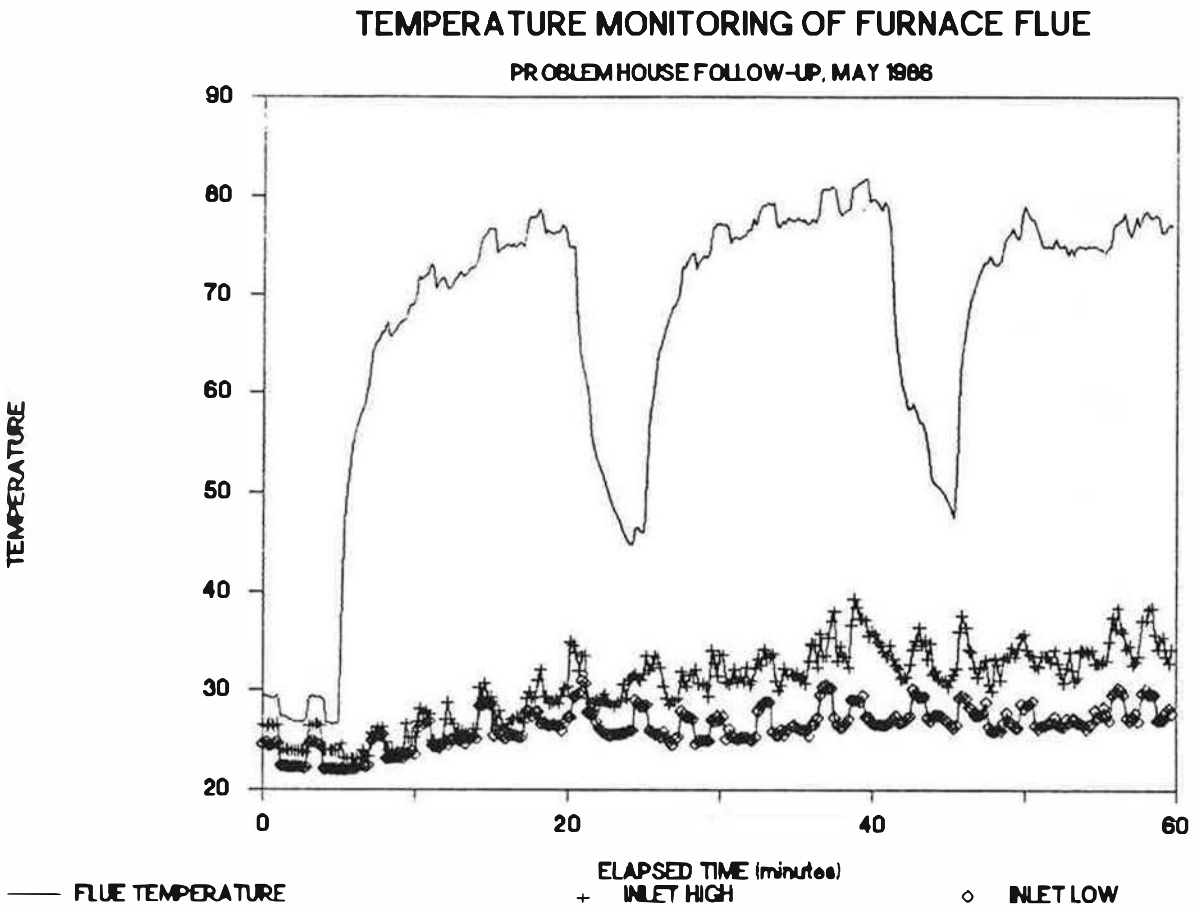
o This house would have been a good candidate for the total chimney draft measurement diagnostic that is to be included in the final version of the checklist.

TABLE 1 - 3056

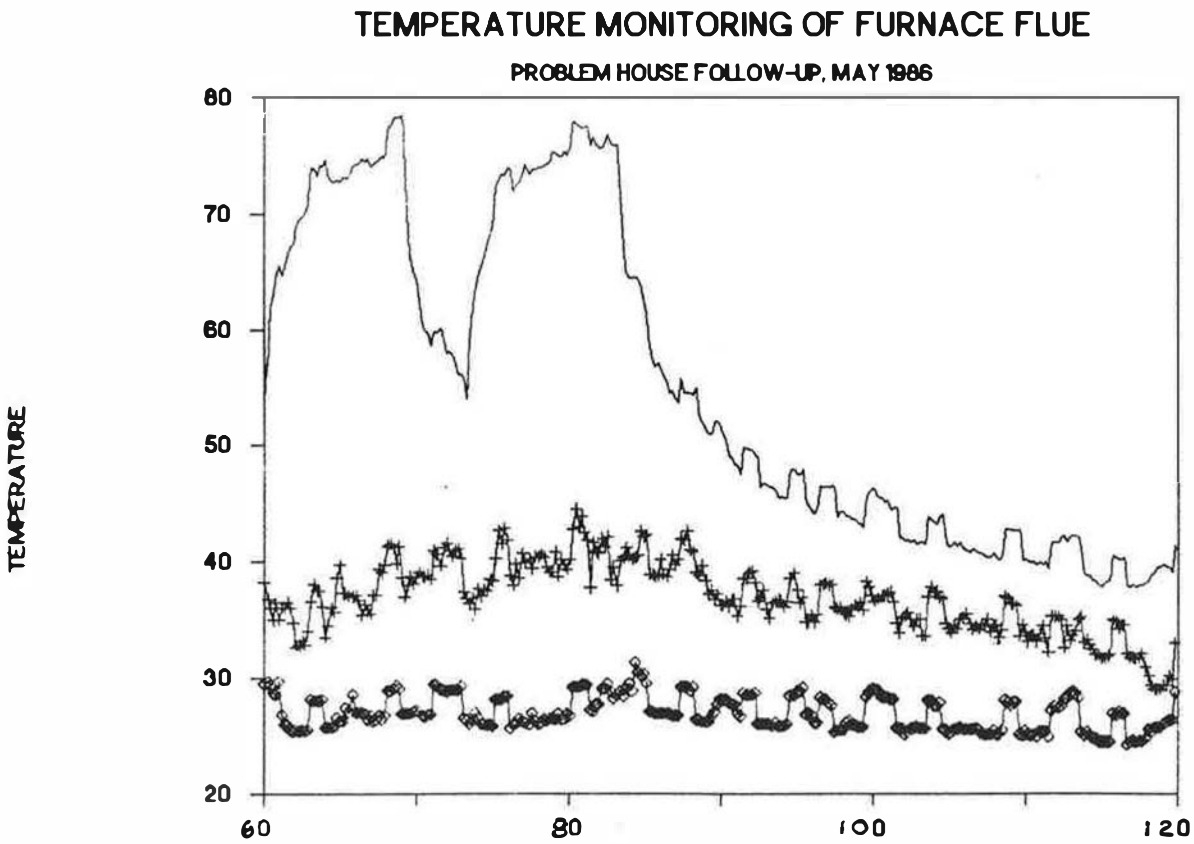
DISTRIBUTION OF POLLUTANTS DURING FAILURE EVENT SIMULATION

Time (minutes)	CO/Bedroom	CO_2/Bedroom	CO/Dining Room	CO_2/Dining Room
0	002	870	002	723
15	001	740	002	740
30	002	690	002	803
45	002	808	003	864
60	001	856	002	1082
75	002	910	002	1090
90	001	967	002	1200

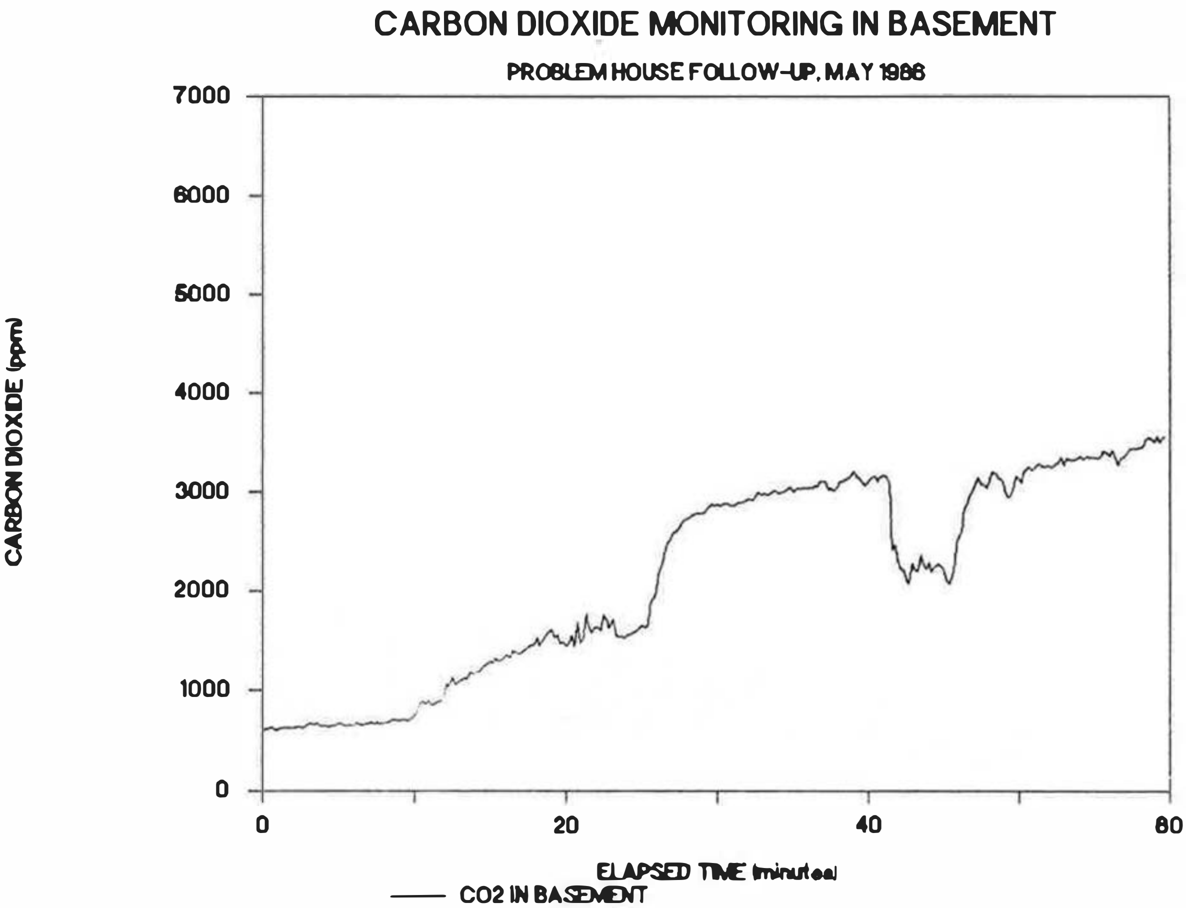
GRAPH 1 - 3056



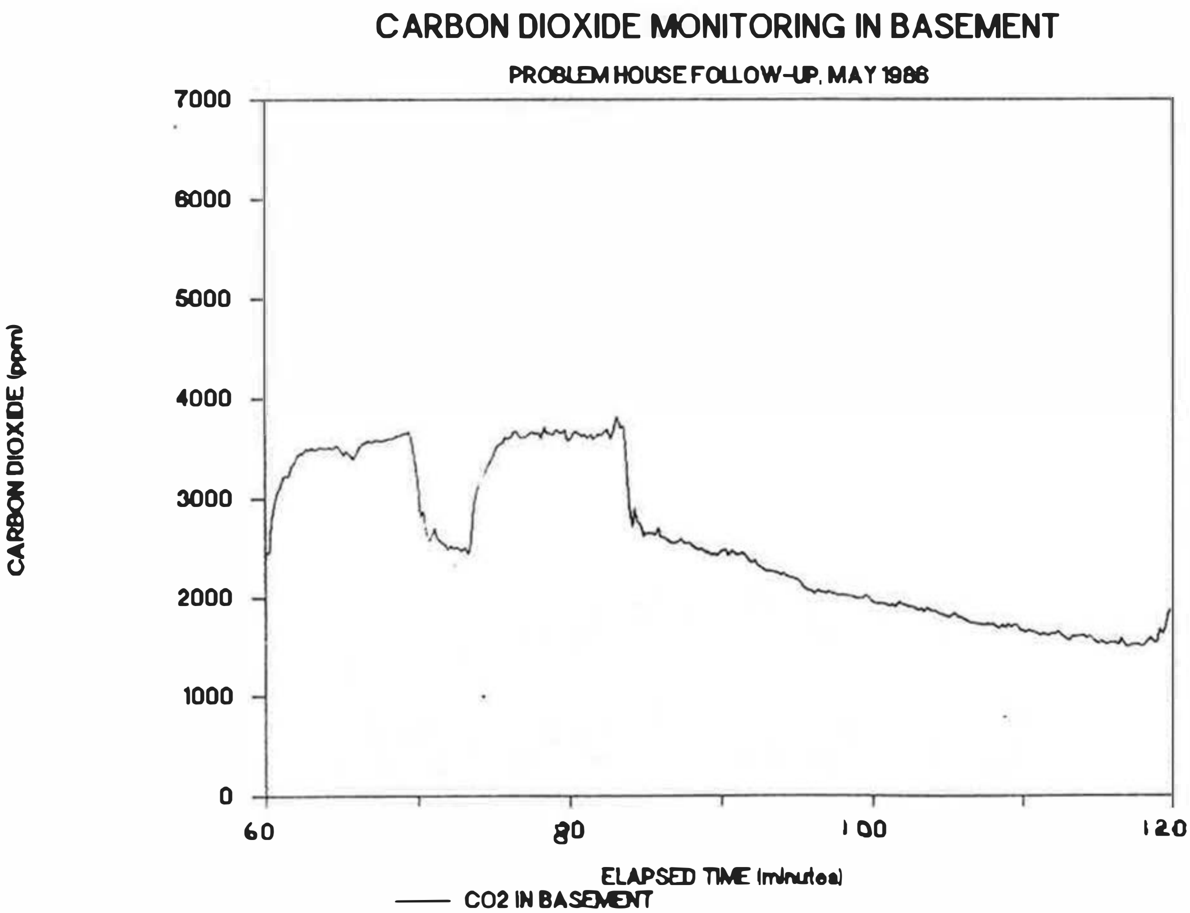
GRAPH 2 - 3056



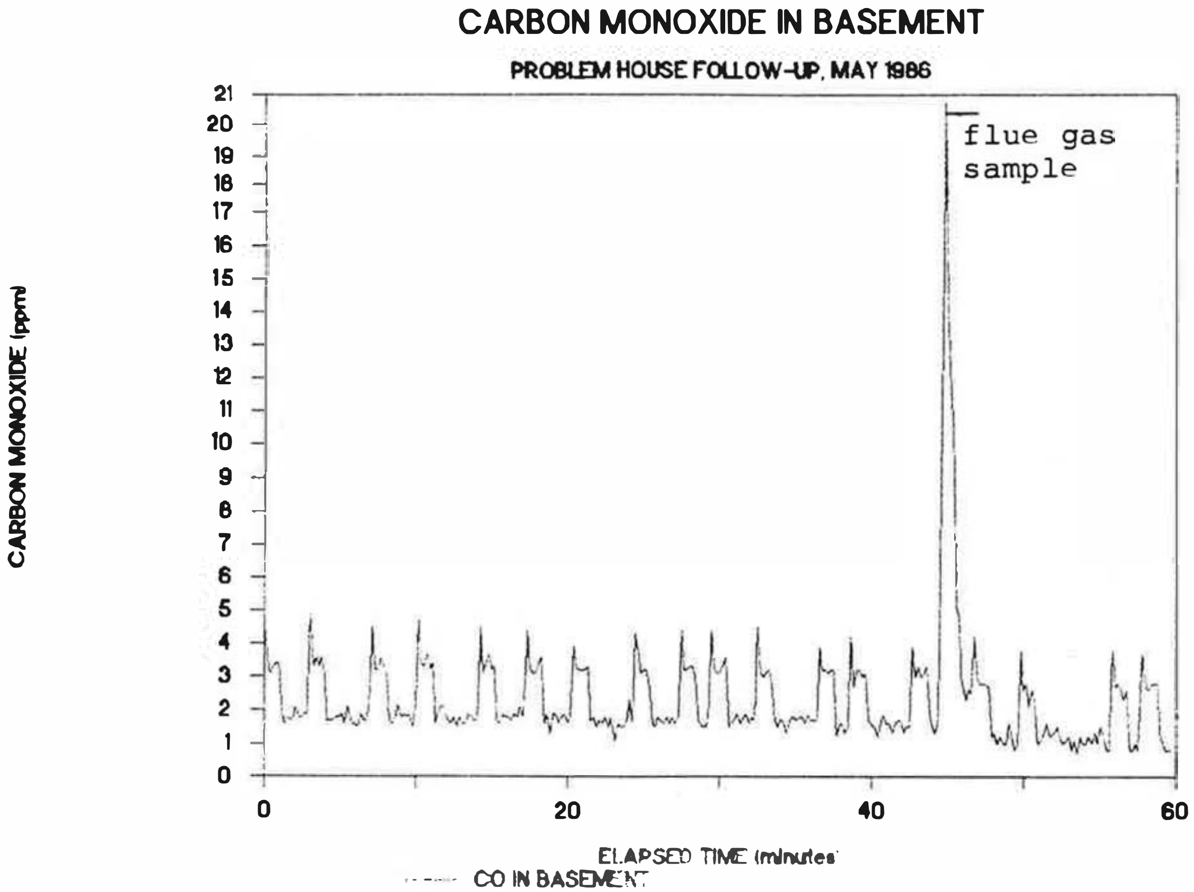
GRAPH 3 - 3056



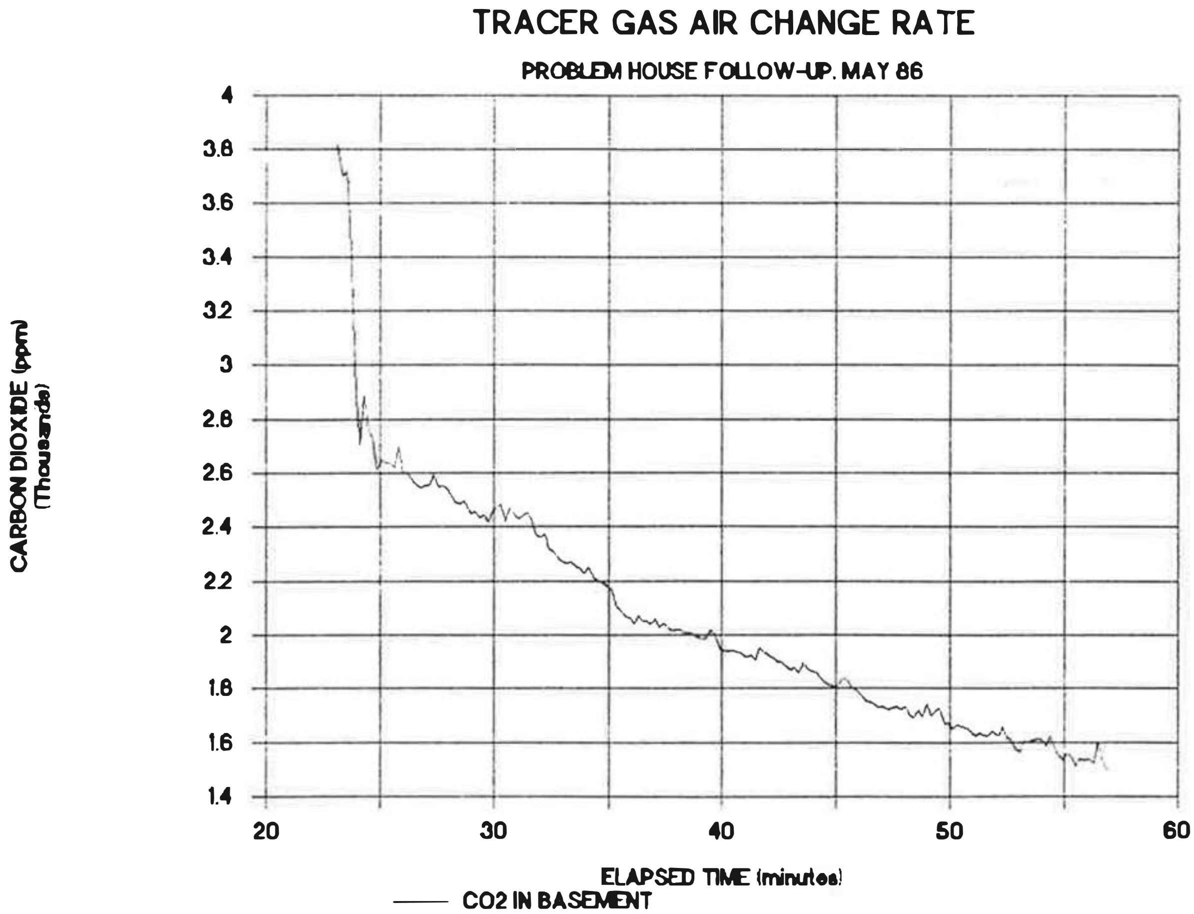
GRAPH 4 - 3056



GRAPH 5 - 3056



GRAPH 6 - 3056



AIR LEAKAGE TEST RESULTS
(Fan Depressurization)
HOUSE # 3056

DATE: 22 MAY/86
TSTR: AMC
HOUSE IDENTIFIER:
T1

OUTDOOR CONDITIONS

OUTDOOR TEMP (DEG C) +16.50
AMBIENT PRESSURE (KPA) +101.45
WIND SPEED (KM/H) = 0

INPUT DATA

#	UNADJ. FLOW (L/S)	PRESSURE (SHELL) (PA)	TEMPERATURE OF AIR FLOW (DEG C)
1	543.90	10.0	18.9
2	625.62	15.0	18.9
3	881.38	20.0	18.8
4	1032.92	30.0	18.8
5	1263.20	40.0	18.9
6	1435.50	50.0	18.8

#	ADJUSTED FLOW (L/S)	FITTED FLOW (L/S)	RELATIVE ERROR (%)
1	539.16	554.90	2.94
2	690.72	704.79	2.00
3	853.79	835.10	-2.24
4	1081.39	1060.08	-1.95
5	1252.18	1256.70	0.37
6	1422.98	1433.55	0.74

C = 142.7230
N = 0.589722
E.L.A. = 0.2243 M^2
VOL (M^3) = 447
Q @10PA = 554.901
Q @50PA = 1433.55

AIR CHANGE/HOUR @ 50PA
AC/HR = 11.545
SXX = 8.20868
SYY = 2.86329
SXY = 4.84084
SYX = .0184671

RELATIVE STANDARD ERROR OF Q
@ 10 PA (PERTURAP# 6) (%)

1.864 %

AIR CHANGE TEST RESULTS
(CO_2 Decay Rate)

TEST: 3056 - TORONTO

TIME = 0 CO2 = 2.64
TIME = 5 CO2 = 2.45
TIME = 10 CO2 = 2.375
TIME = 15 CO2 = 1.95
TIME = 20 CO2 = 1.8
TIME = 25 CO2 = 1.66
TIME = 30 CO2 = 1.55
CORRELATION= .9871164
CONSTANT= 2.68837
ACPH= 1.13764
VOL= 447
FLOW (L/S) = 141.2061
FLOW PER PERSON = 2.719885E-02
FLOW/PERSON ACTUAL = 47.06871

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

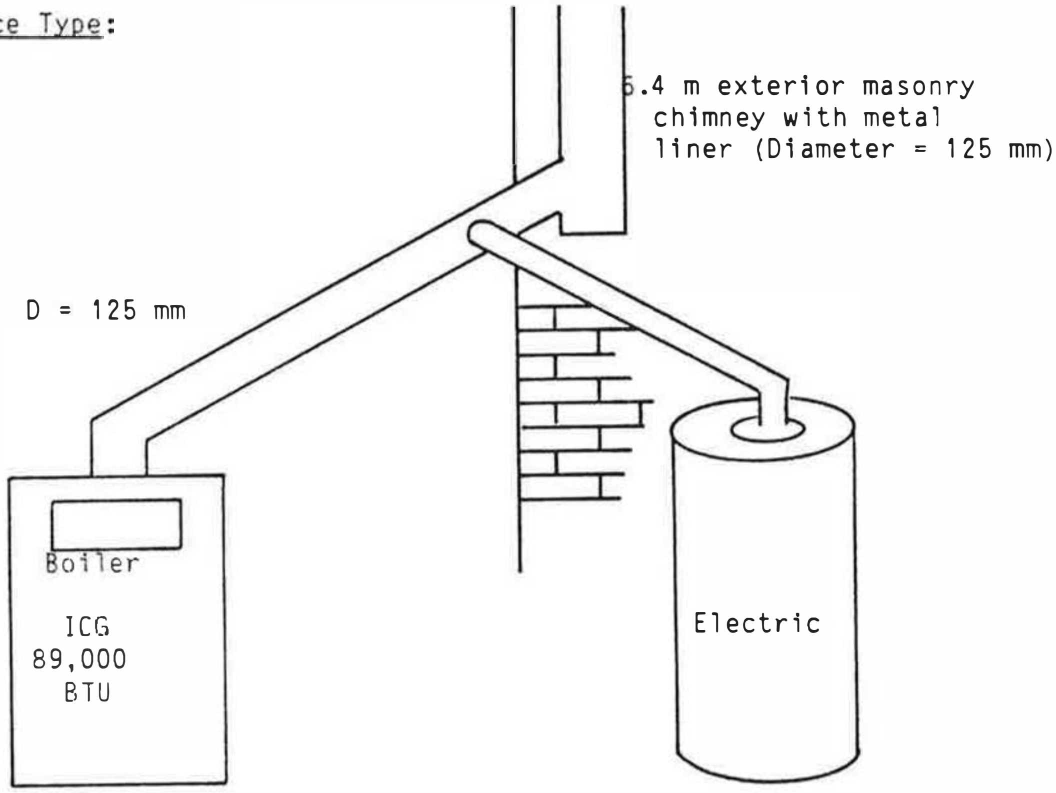
HOUSE NO: 3113 (TORONTO)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 121°C
DHW - N/A

House Type: One storey with full basement
1945-1960
Natural ELA @ 10 Pascals = 704 cm
Natural ACPH @ 50 Pascals = 2.6

Appliance Type:



Less than 5 years old   Less than 5 years old

Competing Exhaust Systems:

1 - Kitchen range hood fan
1 - Clothes dryer

Fireplace:

None

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted H.D. - 2.1 Pa
H.D. Limit - 5.0 Pa
Not prone to venting problems.

2) Inspection:

Cap needs repair; brickwork needs repair;
flue too wet.

3) Venting Systems Test:

H.D. fans - 8 Pa
Exhaust fans exceeded H.D. Limit for furnace.

4) Total Flue Draft:

Full operation = 16 Pa.
Standby = 3 Pa

5) Spillage Observations:

Furnace spilled for more than 30 seconds in a tight house.
No spillage in open house.

6) Heat Exchanger Test:

Not applicable.

7) Questioning of Occupant:

Occupants aware of smells and dampness originating from furnace.

Failure Event Description and Simulation: House 3113

o Exhaust fans were operated and the chimney was blocked to prevent gusty winds from re-establishing draft during the simulation.

o The fans in this house were able to exhaust 150 litres per second and, consequently, the air exchange rate in the house was high during the simulation averaging.

o The boiler was arbitrarily cycled on and off every 20 minutes to replicate a typical winter heating scenario.

o It is interesting to note that the house was not noticeably over-heated during the simulation, despite summertime temperatures outdoors. Longer operating runs may have been warranted.

Graph 1 - 3113, shows temperature monitoring of the furnace flue and dilution air inlet during the simulation. The high inlet temperatures ranged from 180 to 200°C, and correspond well with the 121°C dot detector.

Graph 2 - 3113, shows the monitoring of carbon dioxide in the basement at head level. The concentration builds up rapidly at a rate of approximately 150 ppm per minute. Table 1 - 3113, shows the grab bag concentrations of CO_2 in the living room and the bedroom during the same failure event simulation. Concentrations in these rooms reach similar levels to the basement, lagging by 2 or 3 minutes.

Graph 3 - 3113, shows the decay rate of CO2 following the simulation and is used to calculate the natural air change rate.

Conclusions and Comments: House 3113

o Chimney spillage was almost certainly a result of backdrafting due to house depressurization. The major contributing factors were a tight envelope and a powerful kitchen exhaust fan.

o The kichen fan creates enough depressurization to cause the boiler to backdraft. Frequency of backdrafting may be directly related to use of this fan.

o The homeowners were aware that there was a problem with their appliance. They spend a good portion of their time in the basement where a family room is adjacent to the boiler.

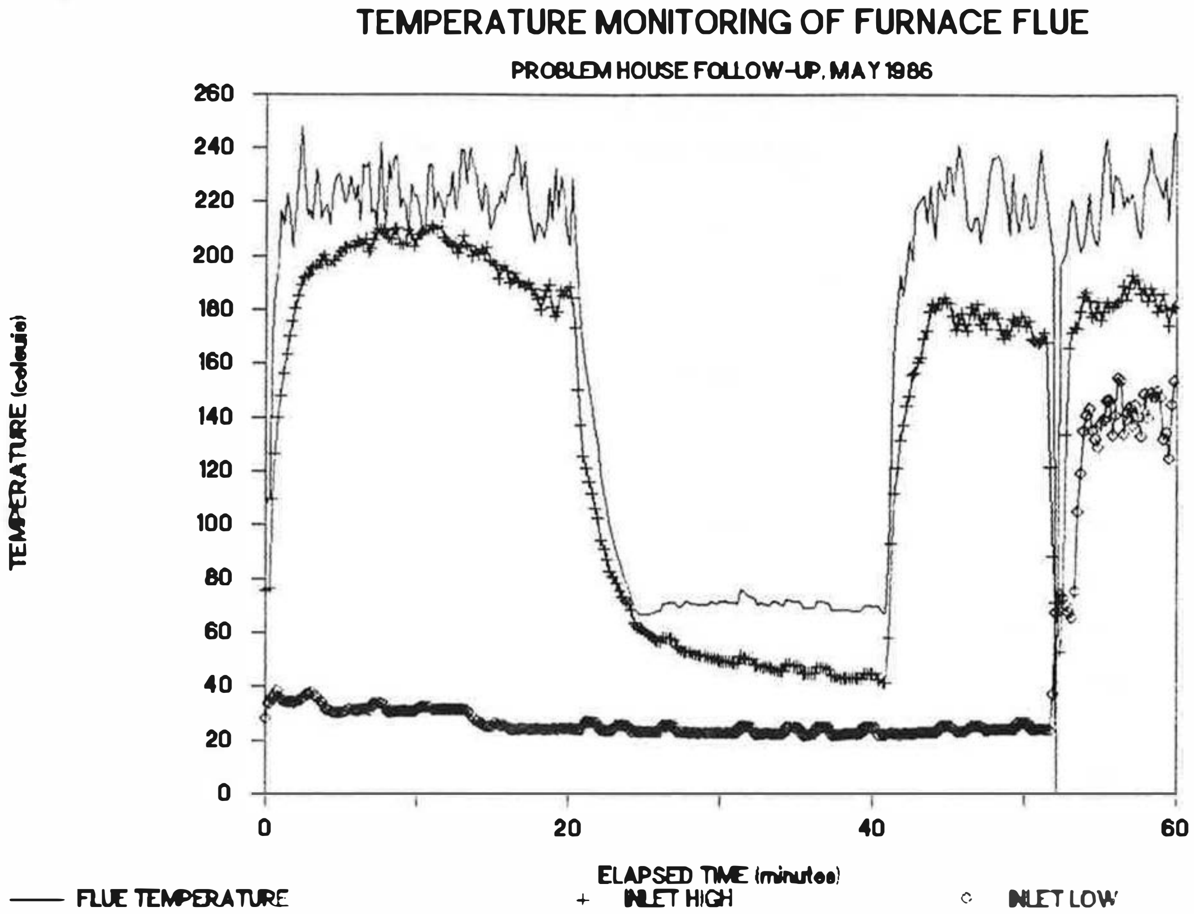
o Interlocking the boiler with the kitchen fan would be the least expensive remedial measure to prevent backdrafting in this house.

o Another option would be an alarm that would remind homeowners to open a window when operating their kitchen fan.

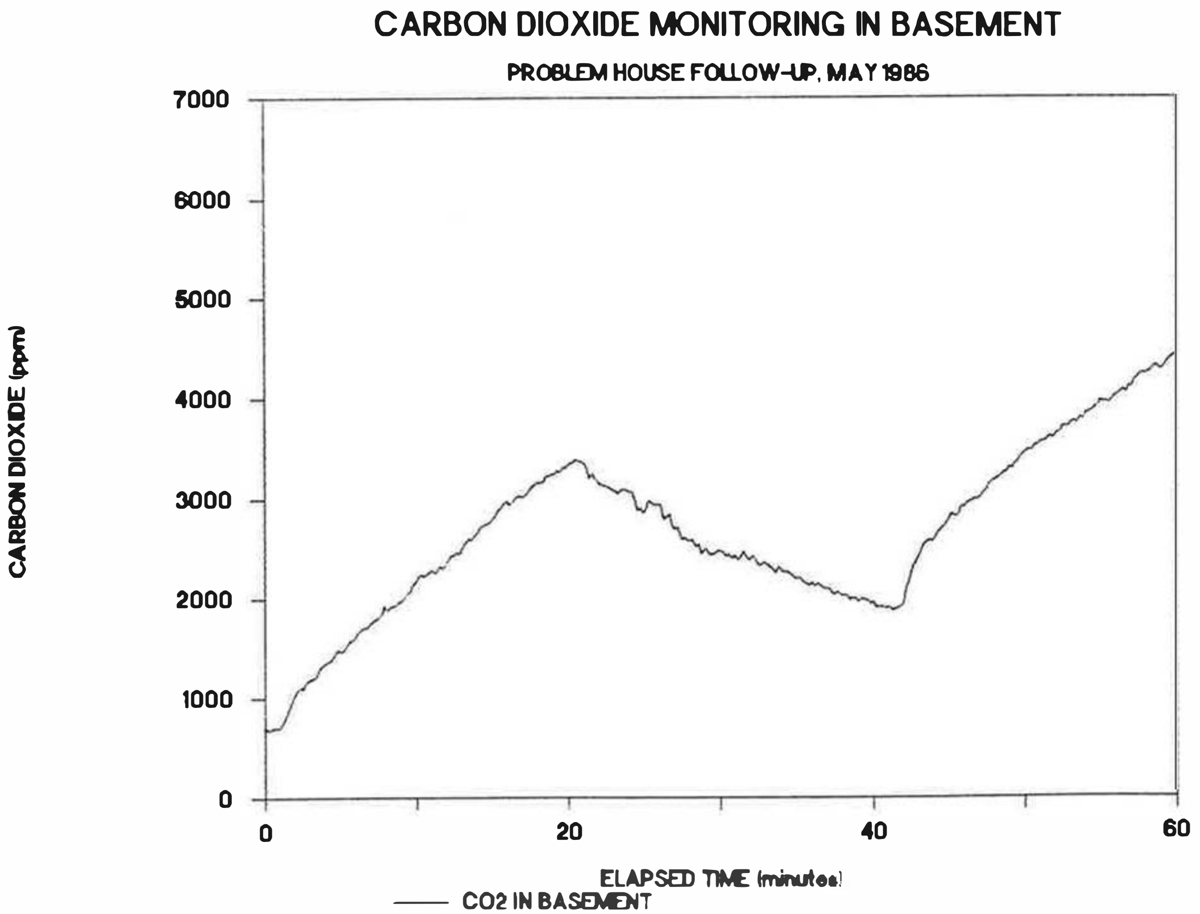
o This house is similar to House 2022 which had a kitchen top barbecue fan that caused a boiler to backdraft. It would be a common occurrence for the boiler to fire after the kitchen fan was turned on, because the heat loss caused by the fan-induced air change.

o The homeowner is retrofitting this house with new windows. Any remedial measure must take into account that the house is being made tighter and will become even more susceptible to backdrafting.

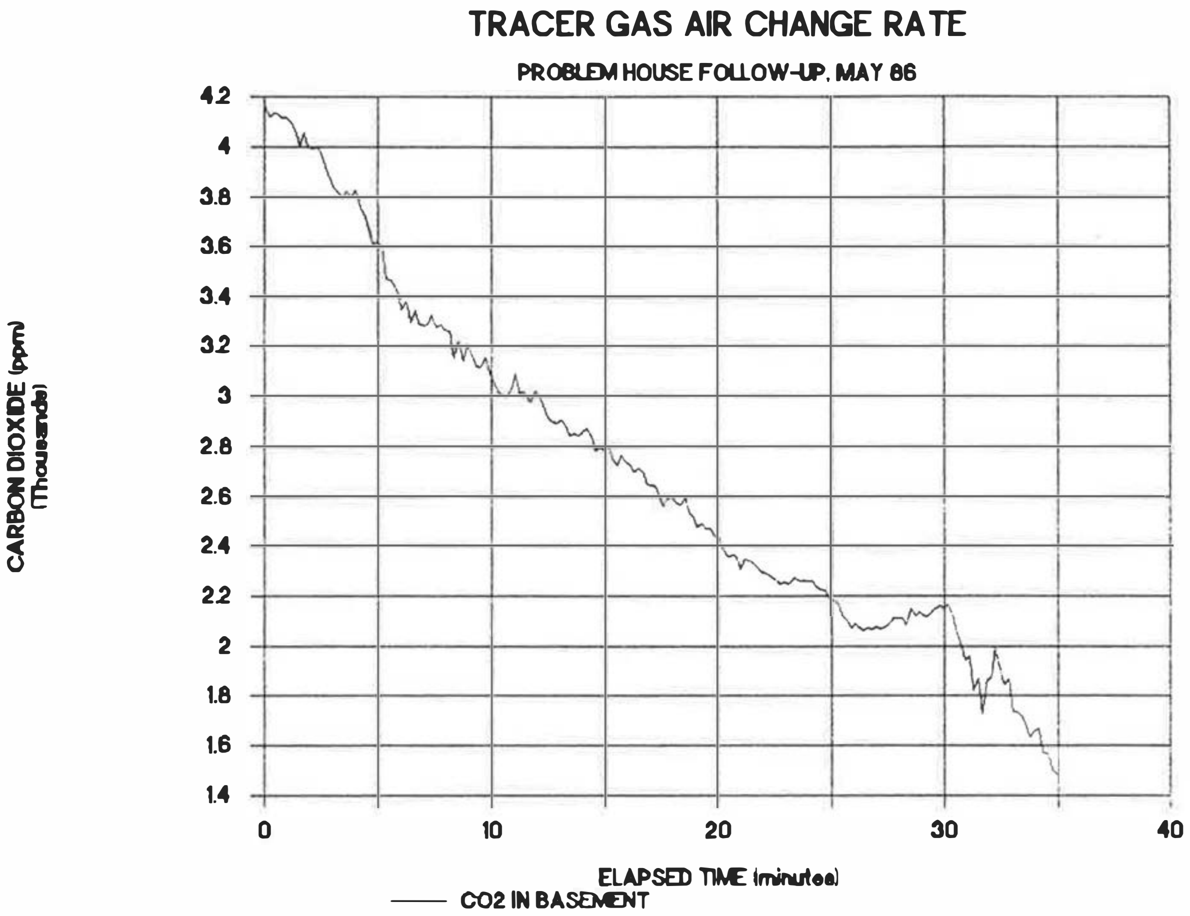
GRAPH 1 - 3113



GRAPH 2 - 3113



GRAPH 3 - 3113



TRACER GAS AIR CHANGE RATE
PROBLEM HOUSE FOLLOW-UP, MAY 86
CARBON DIOXIDE (ppm)
(Thousands)
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
0
10
20
30
40
ELAPSED TIME (minutes)
CO2 IN BASEMENT

TABLE 1 - 3113

DISTRIBUTION OF POLLUTANTS DURING FAILURE EVENT SIMULATION

Time (Minutes)	CO/Kitchen	CO/Basement	CO_2/Kitchen	CO_2/Living Room
0	000	000	1007	895
15	000	001	2215	3700
30	000	001	2482	3041
45	000	000	2450	2804
60	000	000	3356	4675
75	000	000	3046	3170
90	000	000	2777	2330

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

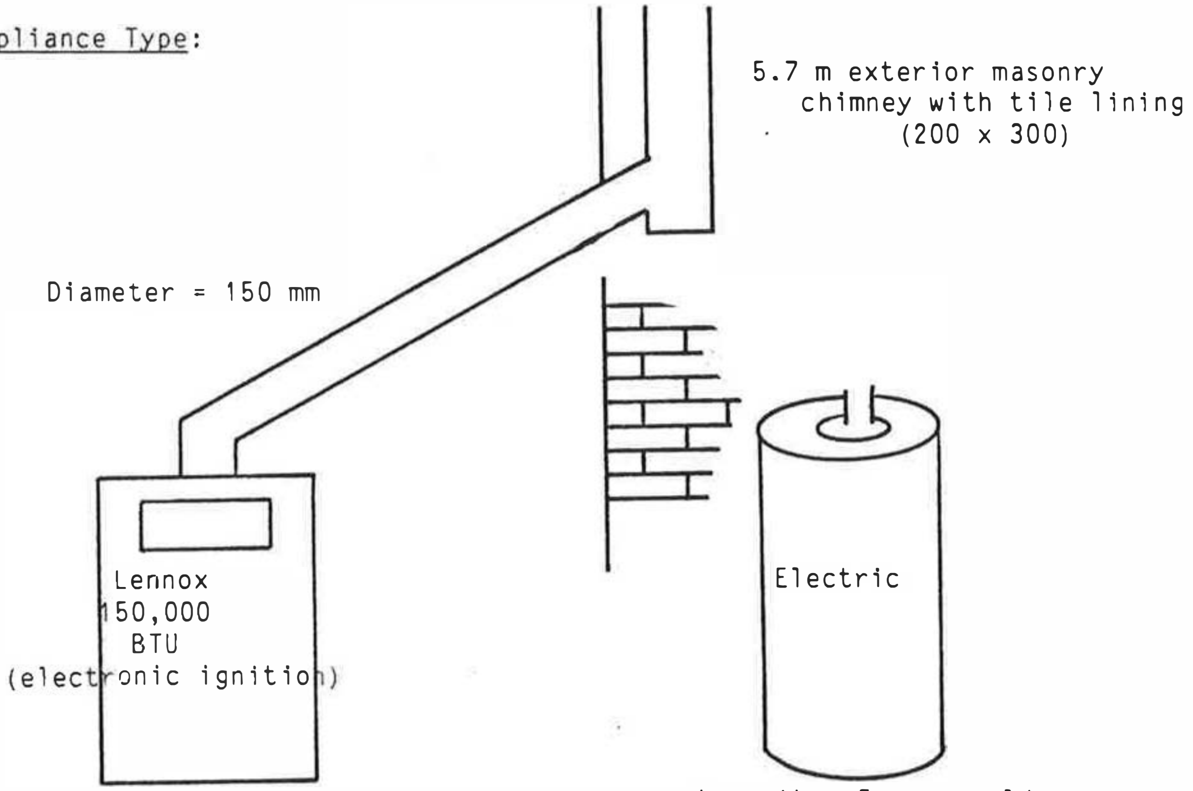
HOUSE NO: 3102 (TORONTO)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 121°C

House Type: Two storey with full basement
1960-1975
Natural ELA @ 10 Pascals = 1441
Natural ACPH @ 50 Pascals = 5.25

Appliance Type:



Competing Exhaust Systems:

1 - Kitchen range hood fan
1 - Clothes dryer
Total exhaust flow measured 91 L/s

Fireplace:

1 - Fireplace
Total fireplace flow measured 68 L/s at 6 Pa H.D.

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted H.D. - 2.2 Pa
H.D. Limit for furnace - 5.0 Pa
House is not prone to venting problems.

2) Inspection:

Cap needs repair; brick work needs repair; metal lining required; loose fittings; pipe slope inadequate (negative slope); filter not installed; warm air register missing in furnace room.

3) Venting Systems Test:

H.D. measured with fans - 6.0 Pa
H.D. measured with fans plus fireplace - 7.5 Pa
H.D. Limit - 5.0 Pa
H.D. Limit exceeded for furnace with fans and furnace blower on and basement door shut

4) Total Flue Draft:

Full operation = 15 Pa.
Standby = 6 Pa.

5) Spillage Observations:

Start-up spillage for 3 minutes

6) Heat Exchanger Test:

No perceptible leaks.

7) Questioning of Occupant:

Lady of house has had headaches since they moved into the house six months ago. She thought it had something to do with the furnace.

Failure Event Description and Simulation: House 3102

The primary failure mechanism that caused spillage in House 3102 was excess house depressurization, resulting from an imbalanced forced air distribution system (i.e., a tight furnace room, leaking return air ducts, and no warm air registers in the furnace room). However, chimney draft was also weak, due to a negative slope on the flue pipe, and a large (125 cm) hole in the flue pipe where a DHW flue pipe connector had been removed.

It was difficult to decide how to simulate a failure in this house, since a number of unacceptable design flaws had been uncovered. As a compromise, the exhaust fans were operated with the furnace room door closed and the appliance was cycled 20 minutes on, 10 minutes off. Because of gusty winds, the flue pipe was disconnected and plugged so that, during furnace operation, 100% of combustion gases spilled into the house. These conditions were intended to simulate full backdrafting during calmer weather, due to furnace room depressurization. Indoor air was sampled in the cold air return of this forced air furnace.

Graph 1 - 3102, shows the temperature monitoring of the furnace flue and the dilution air inlet during the cycling of the appliance. The high inlet temperatures (240°C) correspond with the 121°C dot detection, although temperatures could be much lower if the flue was backdrafting, instead of plugged.

Graph 2 - 3102, shows the monitoring of carbon dioxide in the return air. After one 20 minute cycle, the concentrations exceeded the 5000 ppm limit of the analyzer. The concentrations peak briefly at start-up, due to hot combustion gases leaking into the return air ducts in the furnace room.

Graph 3 - 3102 , shows CO concentrations in the return air plenum during the failure event. Carbon monoxide levels are insignificant.

Table 1 - 3102, shows the build-up of CO_2 on the first and second floors of the house during the simulation. The forced air system distributes the pollutants about the house with little delay. In this house, sampling in the return air plenum has exaggerated the impact of spillage on household air, since the ducts are so leaky, that the air is a combination of return air, and furnace room air. A sampling location upstream in the furnace room would have been preferable. It is interesting to note that concentrations were higher on the second floor than on the first floor, suggesting an imbalance in the system or a high degree of stratification.

Conclusions and Comments: House 3102

o House 3102 was an oil to gas conversion. The oil appliance that had been replaced must have been taller than the gas appliance. The installer did not break a new hole in the masonry chimney. The result was that the flue connector had a down slope. This was not, in itself, enough to cause the appliance to spill for over 30 seconds.

o The oil DHW tank had been replaced with an electric tank. The installer had inserted a crimped piece of flue connector in the old hole. This was ineffective at sealing the chimney. As a result the chimney draft was poor, (the draft increased considerably when this hole was plugged).

o The closing of both the basement door and the furnace room door had a major effect on the depressurization of the furnace room. The problem was suspected because, when researchers arrived on site, a continuous backdraft was already established in the chimney. The furnace blower was operating in its low-speed, or "summer mode", and both basement and furnace room doors had been closed.

o Leaky duct work, a shortage of cold air returns in the basement, and possibly a particularly tight basement door all contributed to the depressurization of the furnace room. Unless the manometer is set up in the furnace room, during a Venting Systems Test, this problem would not be uncovered. It is interesting to note that the house had a large number of returns, but the duct runs appeared undersized and constricted.

o The chimney was in poor shape and a steel liner would be an improvement.

o The appliance had an electronic ignition which would encourage the establishment of a down draft during off periods.

o Although the fireplace was not observed to spill during the Venting Systems Test, there was clear evidence of mantle staining. A deep fireplace design made spillage unlikely unless there had been chimney draft problems.

o It is interesting to note that the occupants of the house were aware that this appliance had been "acting up". They had called a furnace maintenance company to check the system several times in the six months they had lived in the house. Imbalanced forced air distribution systems are a difficult problem to diagnose. The V.S.T. needs to include closing the basement and furnace rooms as part of the standard test procedures.

o The multiple problems which could cause spillage failures in this house exposed the limitations of the one test as a diagnostic tool.

TABLE 1 - 3102

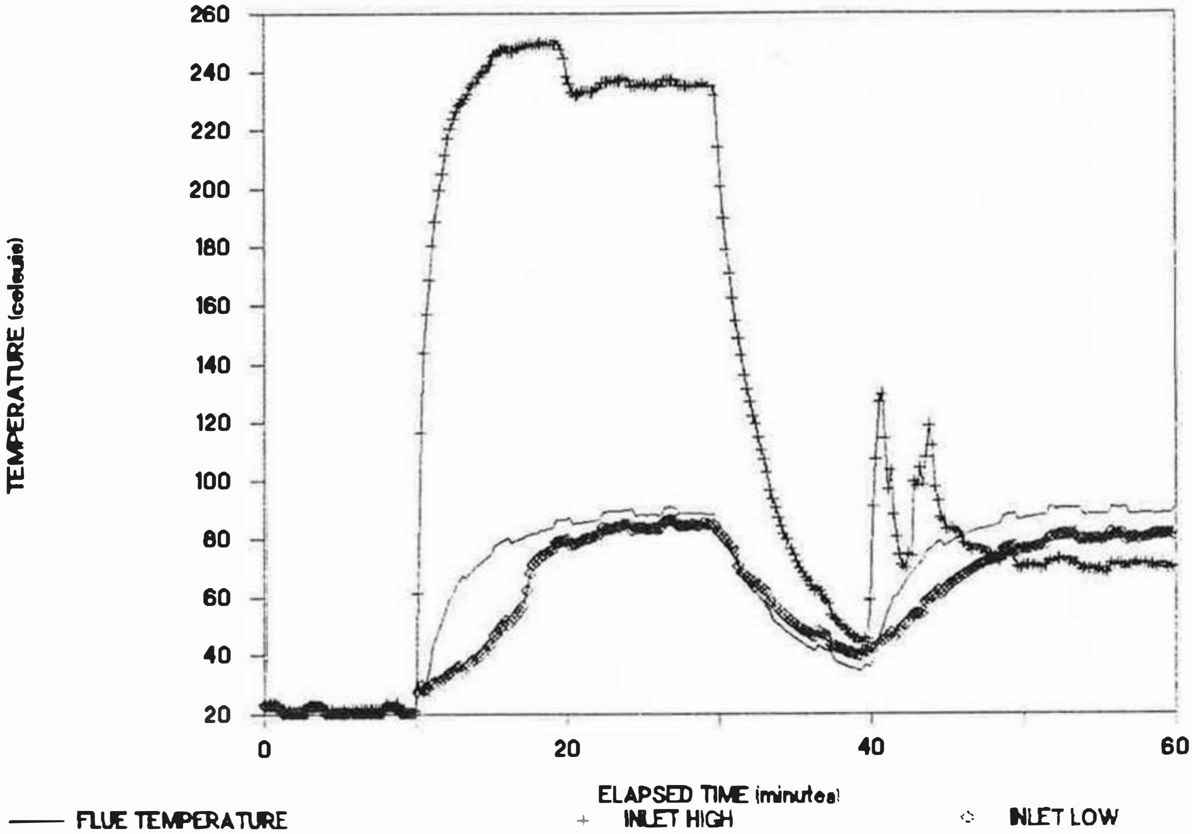
DISTRIBUTION OF POLLUTANTS DURING FAILURE EVENT SIMULATION

Time (Minutes)	Bsmt CO	Bsmt CO_2	1st Flr CO	1st Flr CO_2	2nd Flr CO	2nd Flr CO_2
-00	001	722	001	875	001	807
00	–	–	002	1076	001	905
15	–	–	002	1180	002	1305
30	–	–	002	2148	002	2620
45	–	–	002	2662	002	2901
60	–	–	002	3705	002	4380
75	–	–	002	3789	002	4461
90	–	–	002	4068	002	4022

GRAPH 1 - 3102

TEMPERATURE MONITORING OF FURNACE FLUE

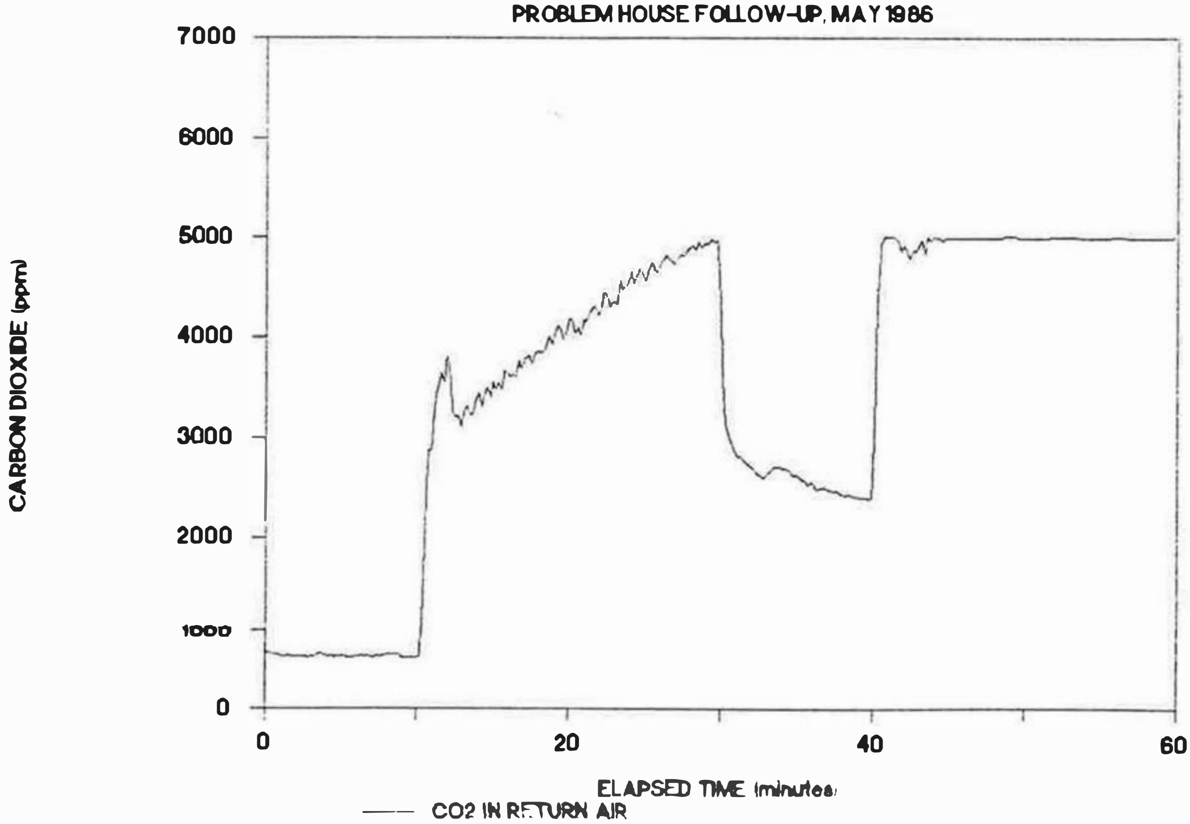
PROBLEM HOUSE FOLLOW-UP, MAY 1986



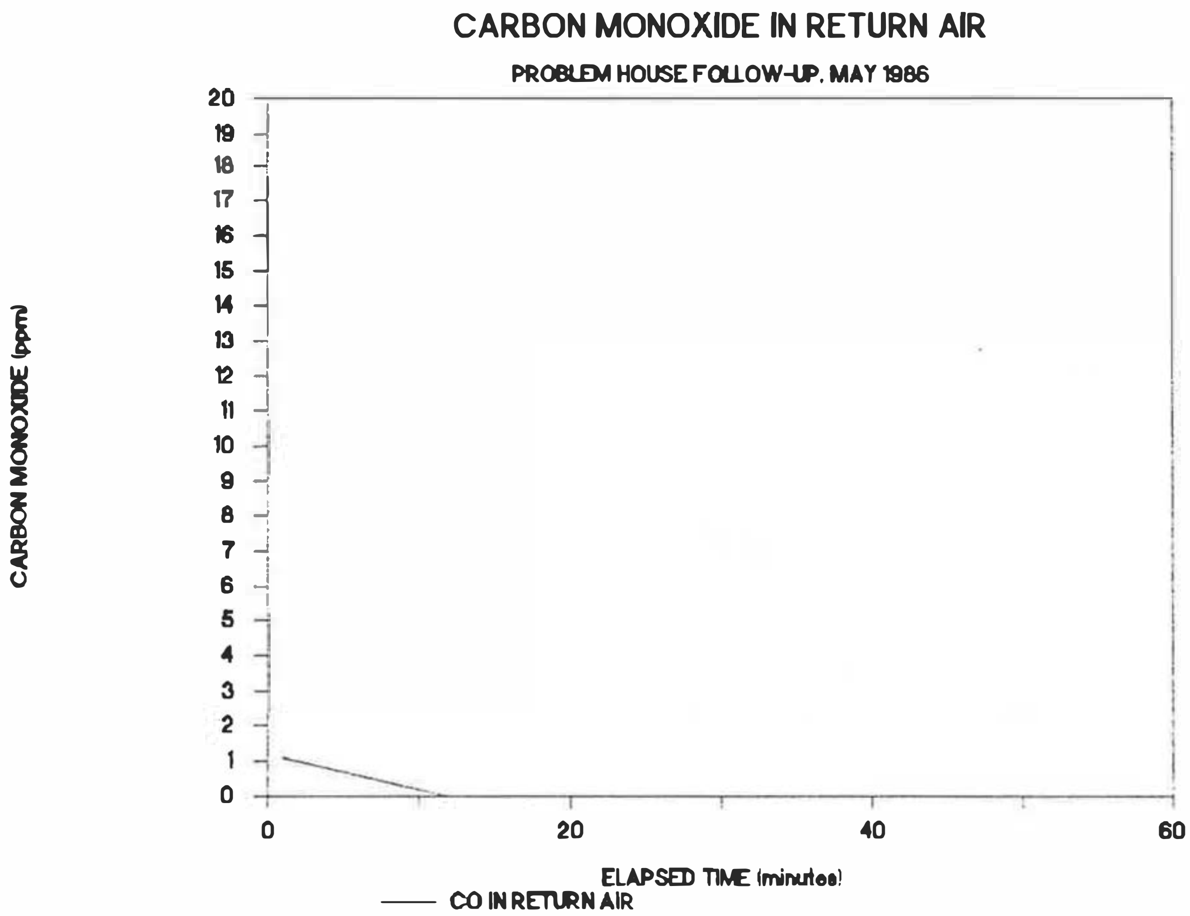
GRAPH 2 - 3102

CARBON DIOXIDE MONITORING IN RETURN AIR

PROBLEM HOUSE FOLLOW-UP, MAY 1986



GRAPH 3 - 3102


CARBON MONOXIDE IN RETURN AIR
PROBLEM HOUSE FOLLOW-UP, MAY 1986
CARBON MONOXIDE (ppm)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0
20
40
60
ELAPSED TIME (minutes)
CO IN RETURN AIR

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

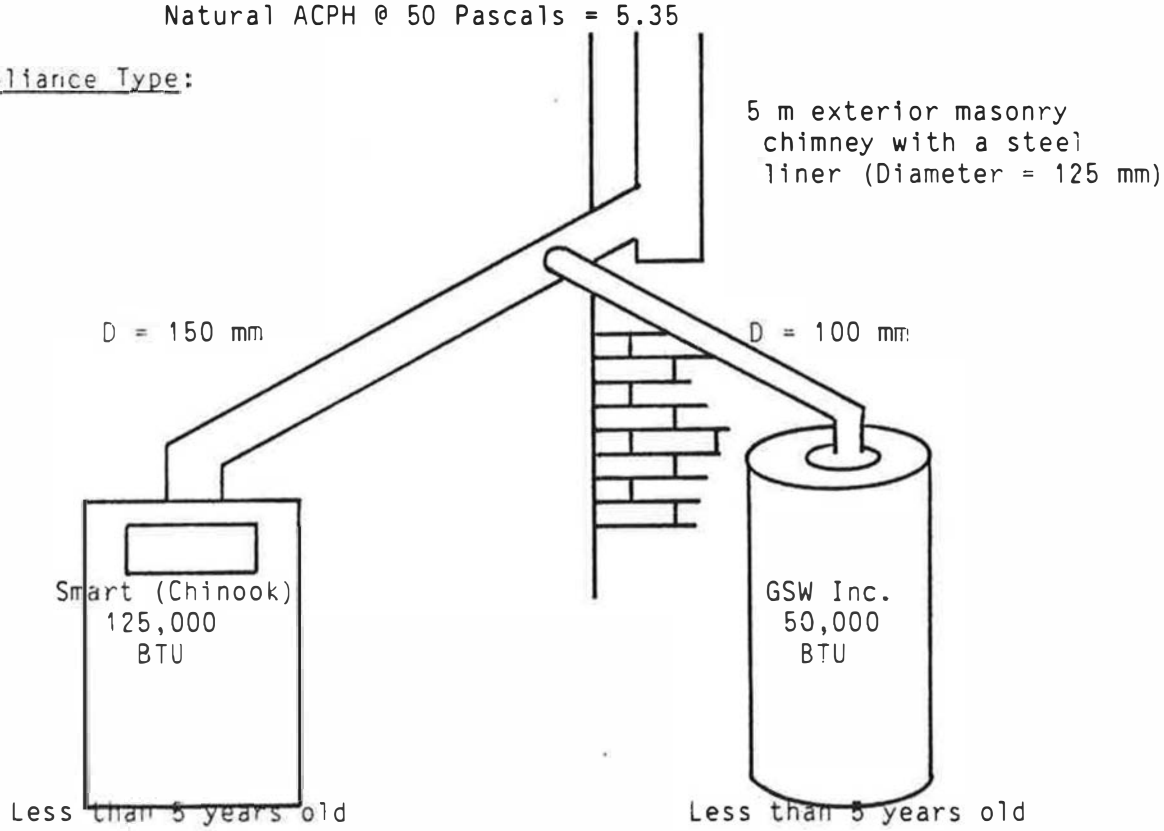
HOUSE NO: 4181 (OTTAWA)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 71°C
DHW - 38°C

House Type: One storey with full basement
1960-1975
Natural ELA @ 10 Pascals = 470 cm2
Natural ACPH @ 50 Pascals = 5.35

Appliance Type:



Competing Exhaust Systems:

1 - Kitchen range hood fan
1 - Clothes dryer
1 - Other fan
Total exhaust fan flow measured - 121 L/s

Fireplace:

1 - Open brick fireplace
1 - Wood stove
Fireplace flow could not be measured due to 7 Pa H.D. for fans.

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted H.D. - 19.1 Pa
H.D. Limit for furnace - 5.0 Pa
House prone to venting failure.

2) Inspection:

Grommets melted on DHW heater.
Restrictive chimney top.
Undersized chimney liner (not to code)

3) Venting Systems Test:

H.D. Limit with fans - 7 Pa
H.D. Limit for furnace - 5 Pa
H.D. Limit for DHW - 4 Pa
Fans exceeded H.D. Limit for both appliances.

4) Total Flue Draft:

Full operation = 10 Pa.
Standby = 3 Pa.

5) Spillage Observations:

Furnace spilled for more than 30 seconds with house tight and fans operating.

6) Heat Exchanger Test:

No perceptible leakage.

7) Questioning of Occupant:

Occupants unaware of problem.
Had liner installed because of chimney deterioration.

Failure Event Description and Simulation: House 4181

Spillage had occurred in House 4181 primarily as a result of a restricted chimney, causing prolonged, major start-up spillage. Backdraft is also a possibility in House 4181, and may have caused continuous, 100% spillage on occasion. The major contributing factors were an improperly sized flue liner, a restrictive chimney cap, tight building envelope, a powerful kitchen fan, and one open fireplace.

To simulate a failure event, exhaust fans were operated and the appliance was allowed to cycle on and off at regular intervals. The intention was to simulate both the effect of the restrictive chimney liner and the depressurization caused by house exhaust fans.

o The furnace kept reaching its high limit control in less than 5 minutes of operating time (outdoor temperatures were at 30°C). This resulted in multiple cycles during the simulated failure.

Graph 1 - 4181 and Graph 2 - 4181, show temperature monitoring of furnace flue and dilution air inlet during the two 60 minute simulation periods. Despite the chimney restrictions and house depressurization, a majority of combustion gases were exhausted via the chimney. Inlet temperatures peaked during the first 2 minutes of each cycle, and averaged 110°C (approximately). These temperatures correspond well with a 71°C dot temperature.

Graph 3 - 4181 and Graph 4 -4181, show monitoring of carbon dioxide in the return air of the forced air distribution system. The short cycling on periods clearly show the ratcheting effect of backdrafting on indoor air pollution. Concentrations never exceed 3000 ppm, and averaged about 1500 ppm during the second hour of failures.

Conclusions and Comments: House 4181

- o Codes would require that a minimum 150 mm liner be placed in chimneys to handle 170,000 BTUs of output. The 125 mm liner was causing major restrictions.

- o The chimney top that had been fitted to the metal liner further restricted the free area by 10%.

- o This house suffered from problems which may be common when converting from oil to gas. Whereas the oil furnace flue collar was located within 1 meter of the masonry chimney, the new gas furnace required a 2.5 meter flue connector with several elbows. In general, oil furnaces have flue pipe connectors at the rear, and gas furnaces at the front. The new flue pipe is therefore longer and more twisted. It may be the case that conversion houses are more susceptible to backdrafting because of the restrictions introduced in the flue connector.

- o The range hood fan was particularly powerful in this house and by itself would cause appliances to backdraft.

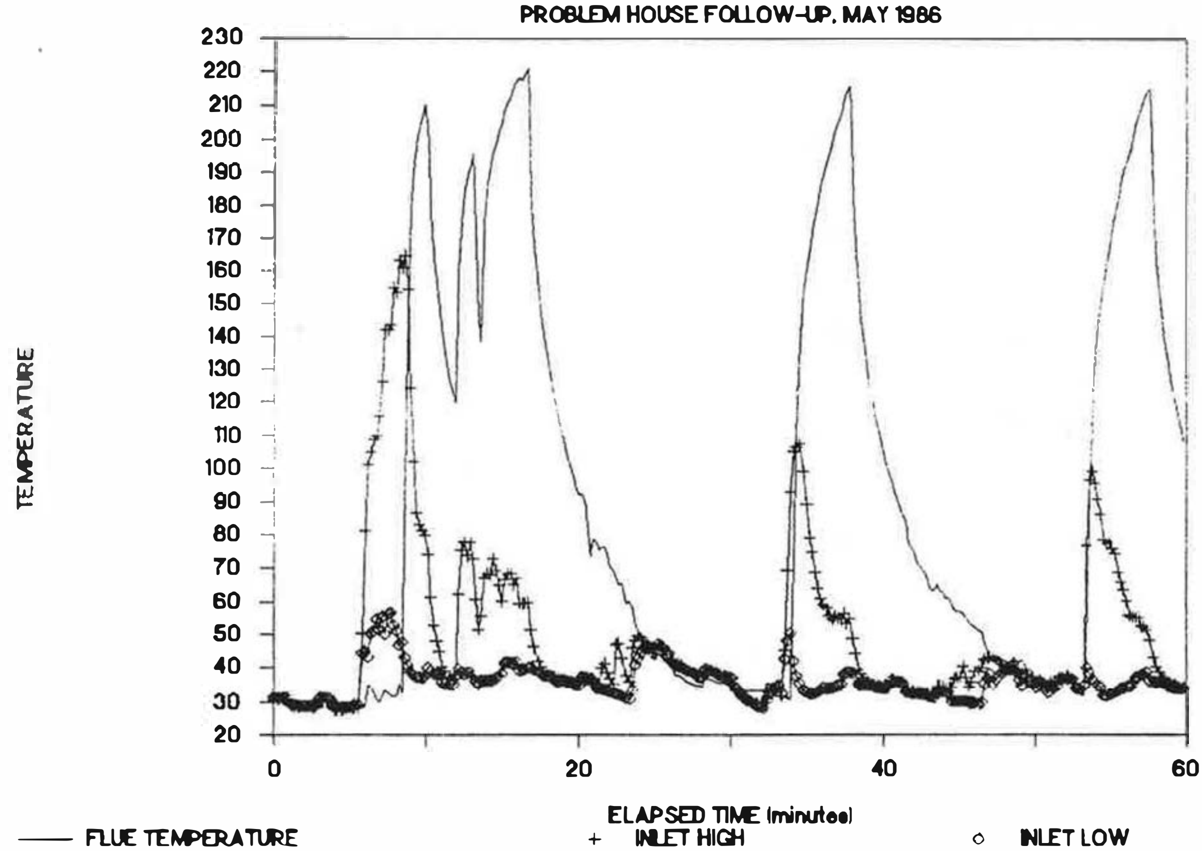
- o This house had a dummy chimney with a turbine vent installed on top. In theory, the dummy chimney would exhaust air from the attic in the summertime and from the house in wintertime. The measured draft in this dummy chimney, with the turbine being manually turned at high speed, was found to be 7 Pascals. With so little pressure it would be difficult for this system to move much air. However, the dummy chimney could become an air inlet, when all house exhaust fans are operating - a useful contingency plan!

- o The "airtight" wood stove in the living room was observed to spill severely from combustion air screws on the loading door.

- o An appropriate remedial measure for the furnace would be to reduce the heating input (if possible), or to replace the liner with a larger size (if the existing masonry chimney permits). Interlocking of the furnace and DHW heater with the kitchen exhaust fan would prevent backdrafting from depressurization.

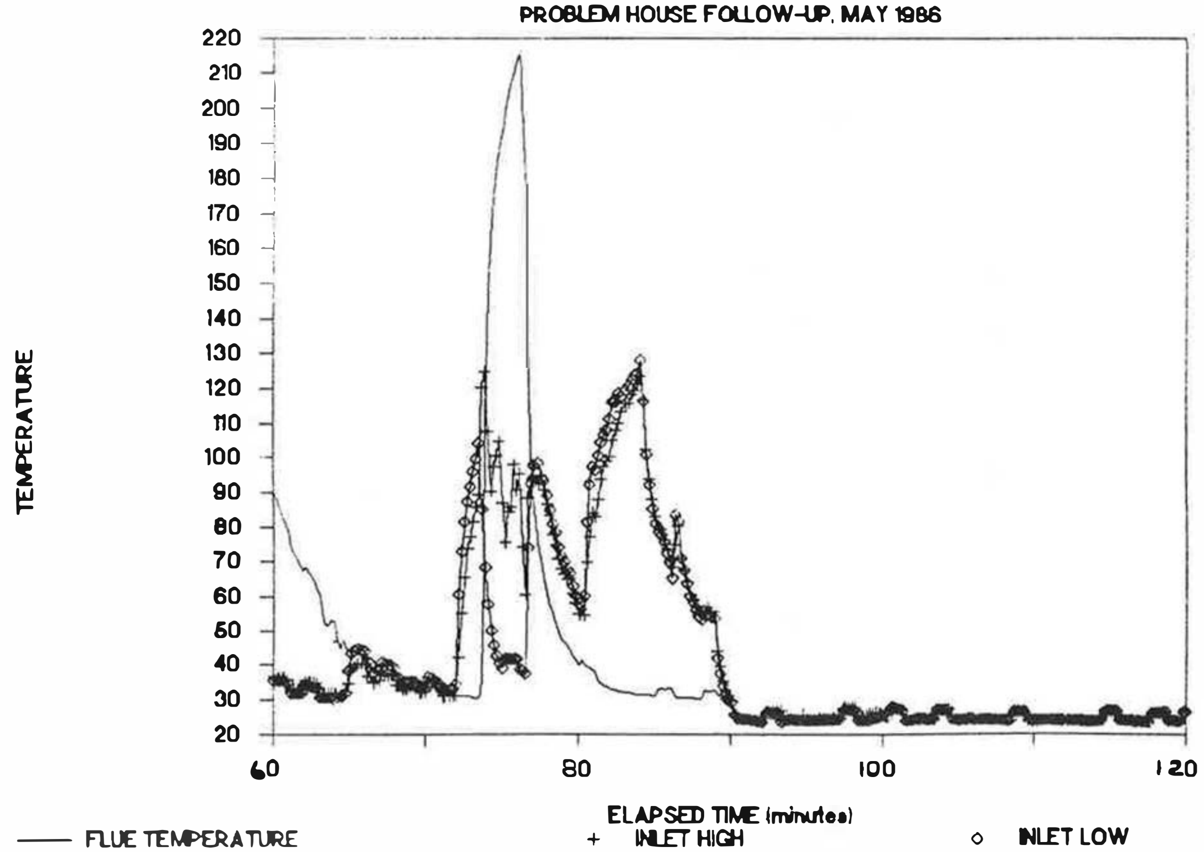
GRAPH 1 - 4181 **TEMPERATURE MONITORING OF FURNACE FLUE**

PROBLEM HOUSE FOLLOW-UP, MAY 1986

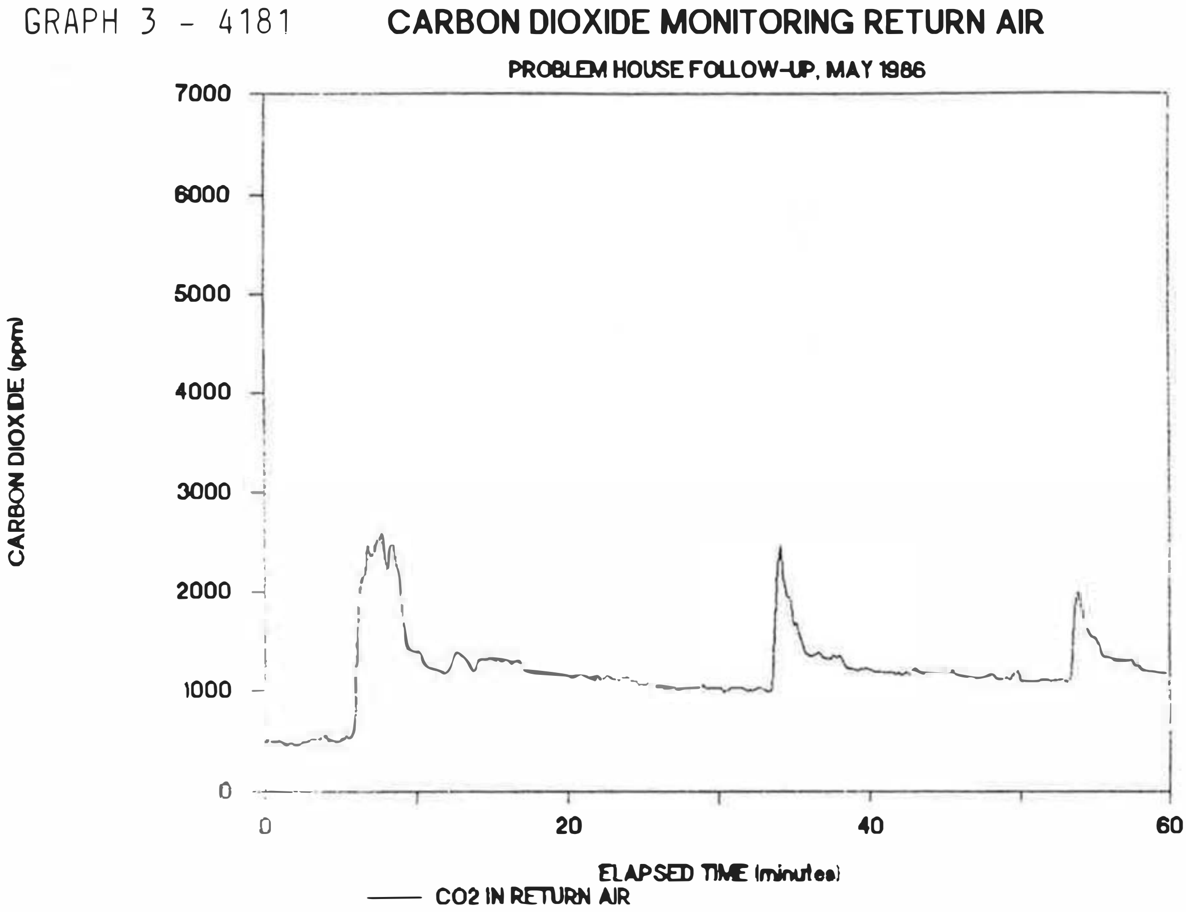


GRAPH 2 - 4181 **TEMPERATURE MONITORING OF FURNACE FLUE**

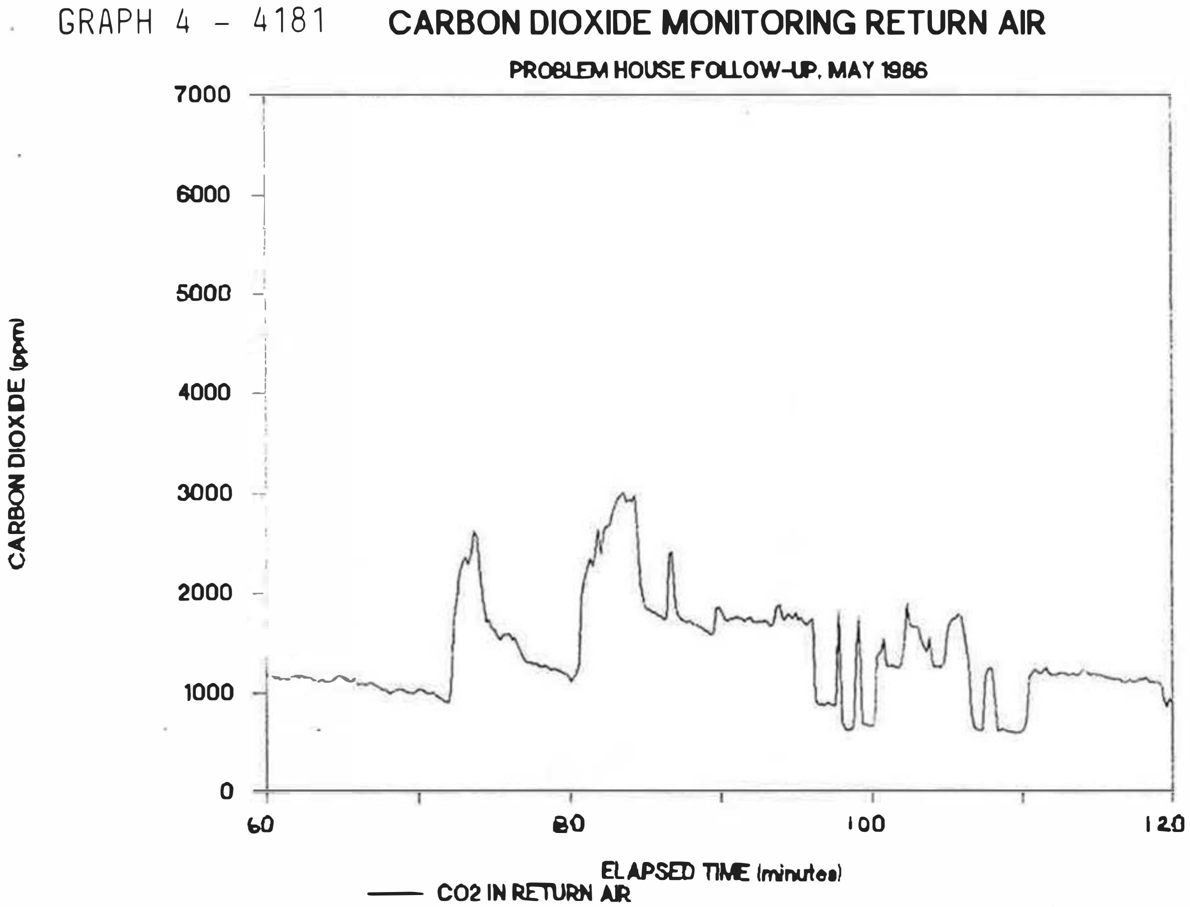
PROBLEM HOUSE FOLLOW-UP, MAY 1986



GRAPH 3 - 4181



GRAPH 4 - 4181



RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

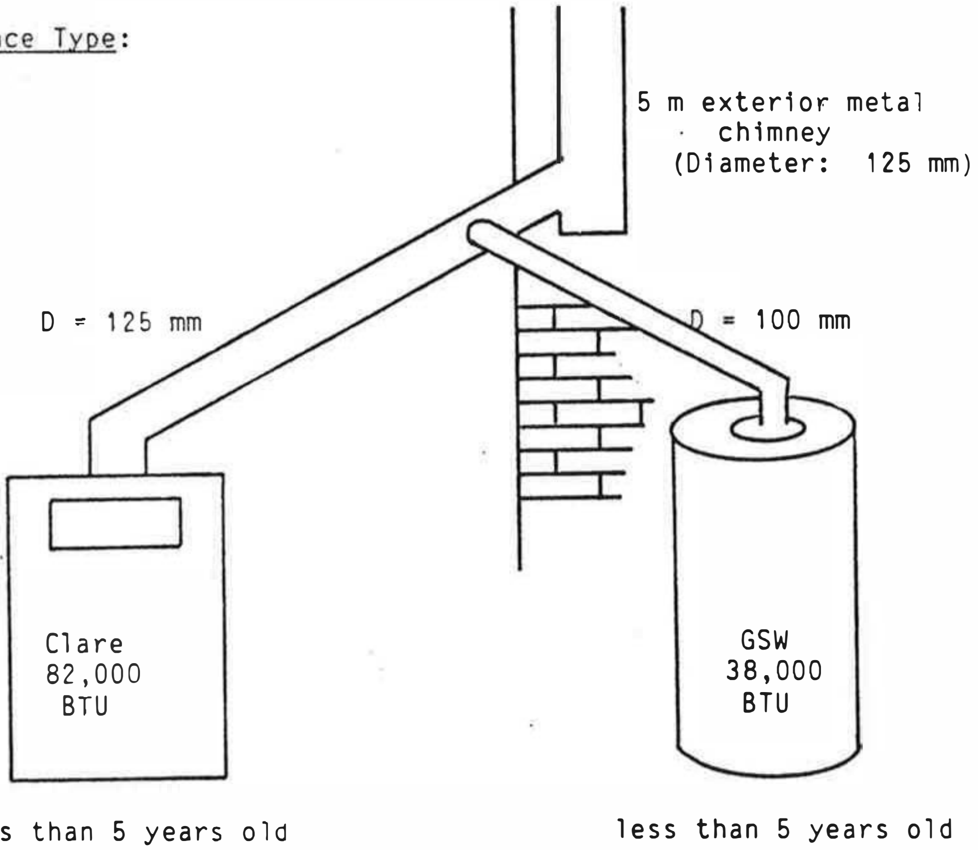
HOUSE NO: 4184 OTTAWA)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 54°C
DHW - 71°C

House Type: One storey with full basement
Post-1975
Natural ELA @ 10 Pascals = 857 cm^2
Natural ACPH @ 50 Pascals = 3.64

Appliance Type:



Competing Exhaust Systems:

1 - Clothes dryer
1 - Other fan
Total exhaust fan flow measured 132 L/s

Fireplace:

1 - Metal fireplace with doors

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted H.D. - 8.7 Pa
H.D. Limit for furnace - 6.0 Pa
H.D. Limit for DHW - 5.0 Pa
House prone to venting problems.

2) Inspection:

Faulty electronic damper on combustion air duct; faulty defrost damper on air exchanger; improperly installed air exchanger; tight furnace room door.

3) Venting Systems Test:

H.D. from fans - 5 Pa
H.D. from fans plus fireplace - 7 Pa
H.D. Limit for furnace - 6 Pa
H.D. Limit for DHW - 5 Pa
Fireplace spilled when operated with fans.
Marginal pass for furnace.

4) Total Flue Draft:

Full Operation = 9 Pa.
Standby = 2 Pa.

5) Spillage Observations:

Furnace spilled for more than 30 seconds with fans, fireplace and air exchanger operating, furrnace room door shut, and house tight.

6) Heat Exchanger Test:

No perceptible leakage.

7) Questioning of Occupant:

Occupant was unaware of problem, but was not surprised to learn that dampers were faulty on the combustion air duct.

Failure Event Description and Simulation: House 4184

o This house was a case of multiple failures. The simulation had the HRV partially in the defrost mode and on high speed, the Acapac combustion air damper jammed, and the furnace room door shut. This was the normal operating mode for this house. The appliances were cycled on and off in 20 minute intervals.

o Graph 1 - 4184 and Graph 2 - 4184, show temperature monitoring of furnace flue and dilution air inlet during the simulated failure.

o Graph 3 - 4184 and Graph 4 - 4184, show the monitoring of carbon dioxide in the return air of the forced air system. The maximum levels reached were just over 4000 ppm, although with higher cycling or monitoring times, steady state concentrations would be read at much higher levels.

o Graph 5 - 4184, shows the decay of CO_2 directly following the simulation and was used to calculate the natural air change rate during and after the simulation.

Conclusions and Comments: House 4'84

o The heat recovery ventilator, located in the furnace room, had a faulty defrost damper that was jammed open. The furnace room had originally been constructed so as to be outside the envelope. A wall had been moved, and the large air inlets for the furnace room had been used by the HRV as an inlet and outlet. However, the tight fitting weatherstripped door on the furnace room had not been removed, nor had a warm air outlet been located in the furnace room. Whenever the HRV entered defrost mode, it would cause a rapid depressurization of the furnace room, and presumably backdraft the chimney. Since the defrost damper had jammed, the HRV depressurized the furnace room on a continuous basis.

o An Acapac combustion air damper was found to have been improperly wired so that it failed to open as intended when the furnace fired. It was not wired to the DHW heater. Had the damper been operational, it would still have failed to prevent the DHW from backdrafting continuously.

o A simple remedial measure would be to remove the furnace room door, or duct the HRV defrost inlet to outside the furnace room. However, the exhaust fans and fireplace are able to fail both appliances, and would require further remedial measures.

o This furnace room had been 'state of the art' in 1980, and was updated to 1986 standards after the addition of an HRV and an electronic combustion air damper.

o Even though the appliances were spilling into a tightly confined furnace room that had a 100 litre per second HRV fan exhausting air continuously, the return air distribution system still managed to suck a considerable amount of the spilled combustion gases and distribute them to the rest of the house.

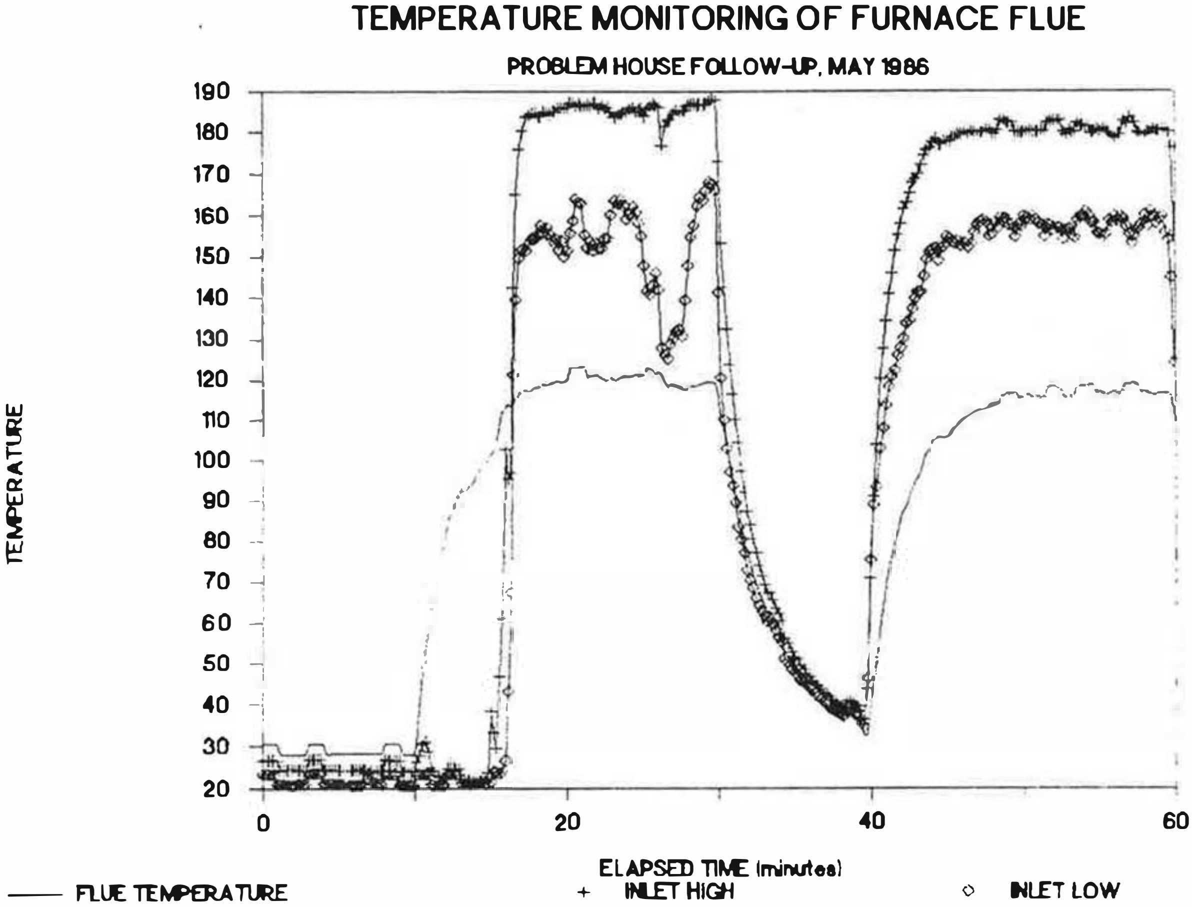
o It is interesting to note that an HRV had been added several years after construction at the cost of the builder. Apparently, the home plans showed an HRV was to be installed originally, and thus a recirculating hood fan had been installed in the kitchen. However, the house has an ELA of 857 cm^2 (3.6 ACPH) and does not require an HRV for controlling moisture. (There were no signs of moisture problems in this house.) Had the house been tight enough to warrant an HRV, the backdrafting problem would have been much worse.

o It is interesting to note that HRV could cause the furnace to backdraft during full operation.

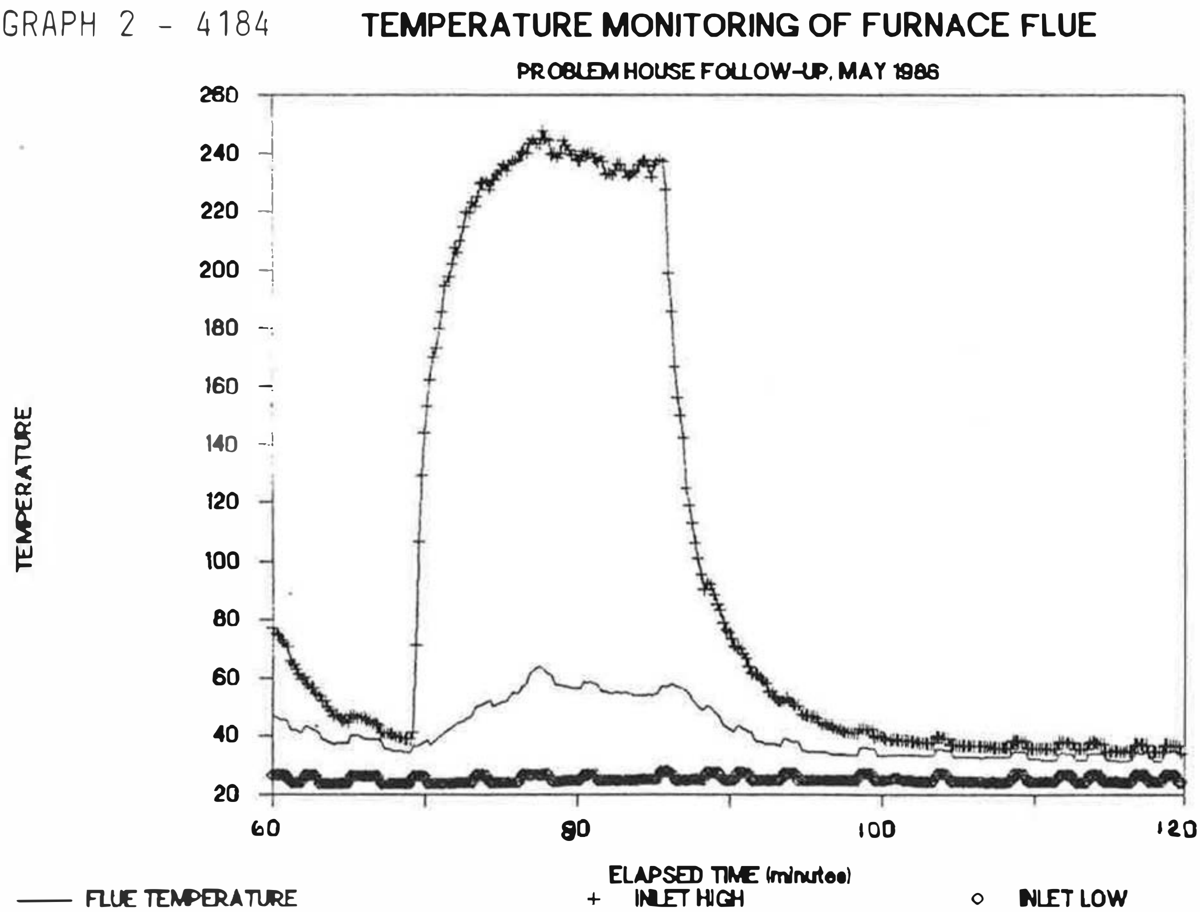
o The checklists were very complicated to carry out in this house with so many separate systems and modes of operation. However, it did succeed in diagnosing the problem.

o The fireplace spilled with the combustion appliances operating and the fans operating. However, when the doors were shut it stopped spilling. The fireplace had never been used and the doors were relatively tight.

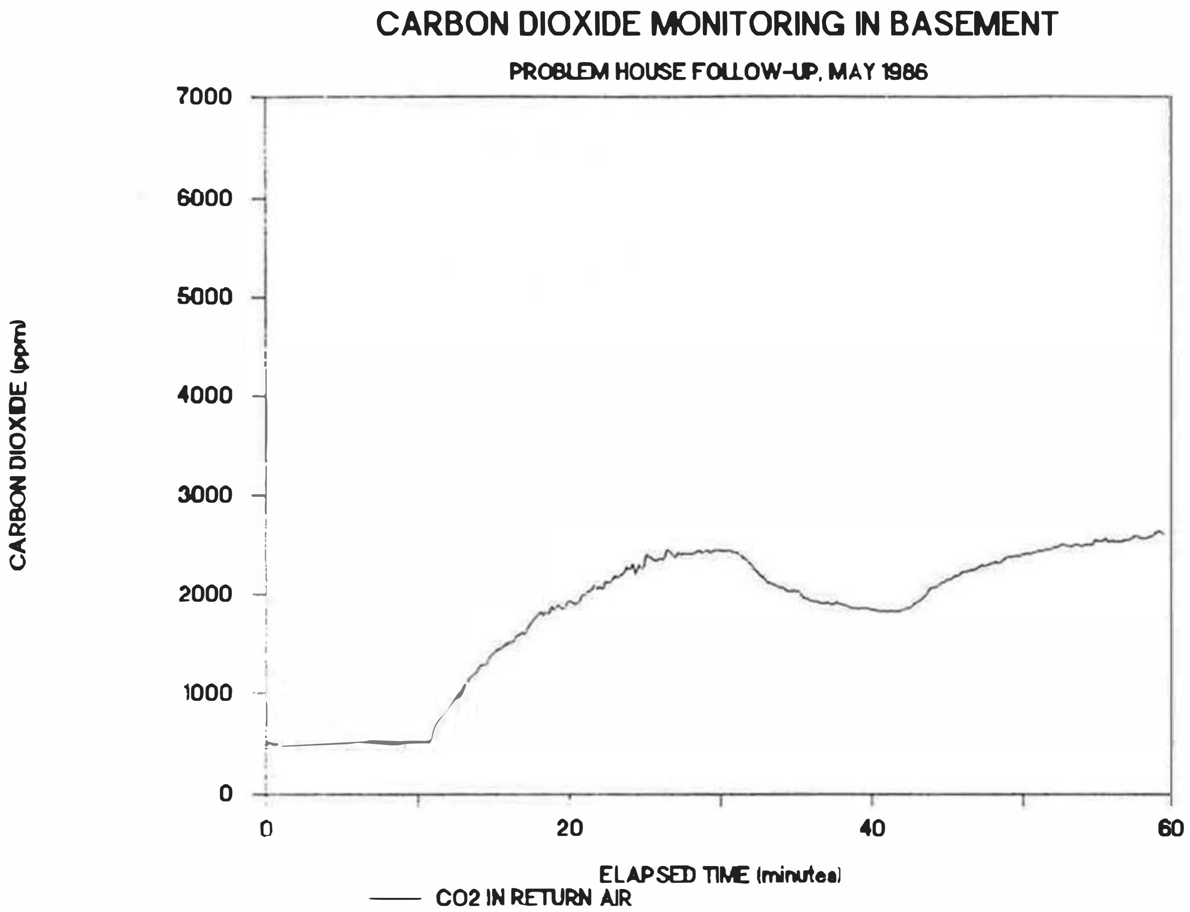
GRAPH 1 - 4184



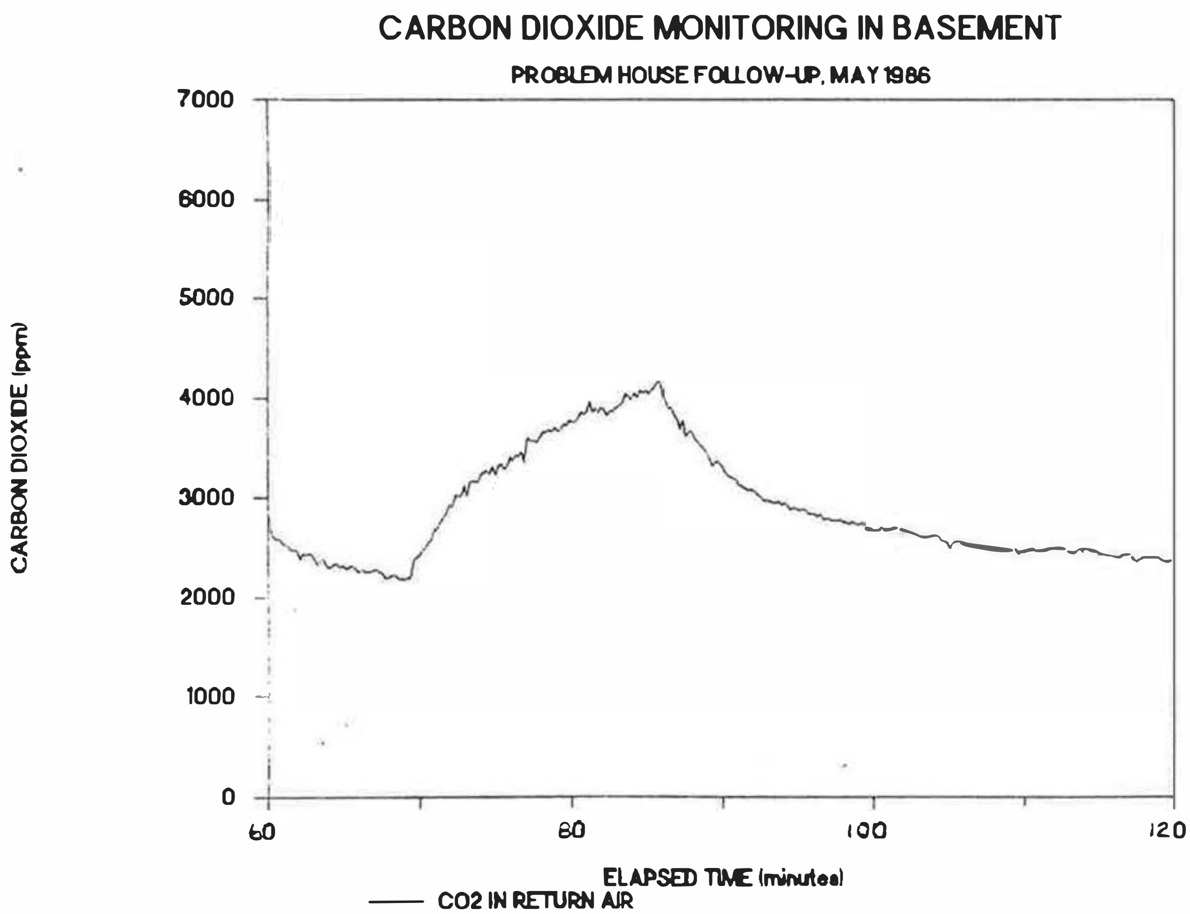
GRAPH 2 - 4184



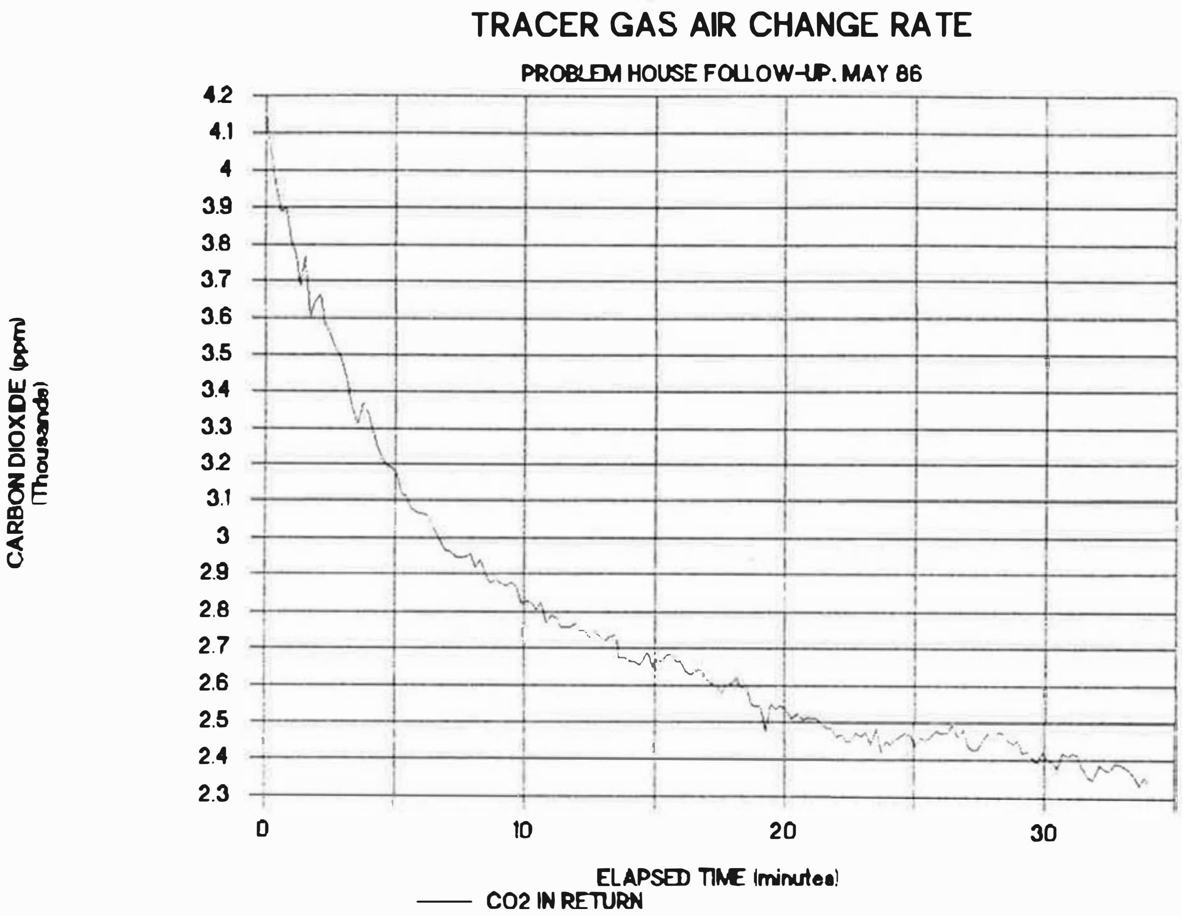
GRAPH 3 - 4184



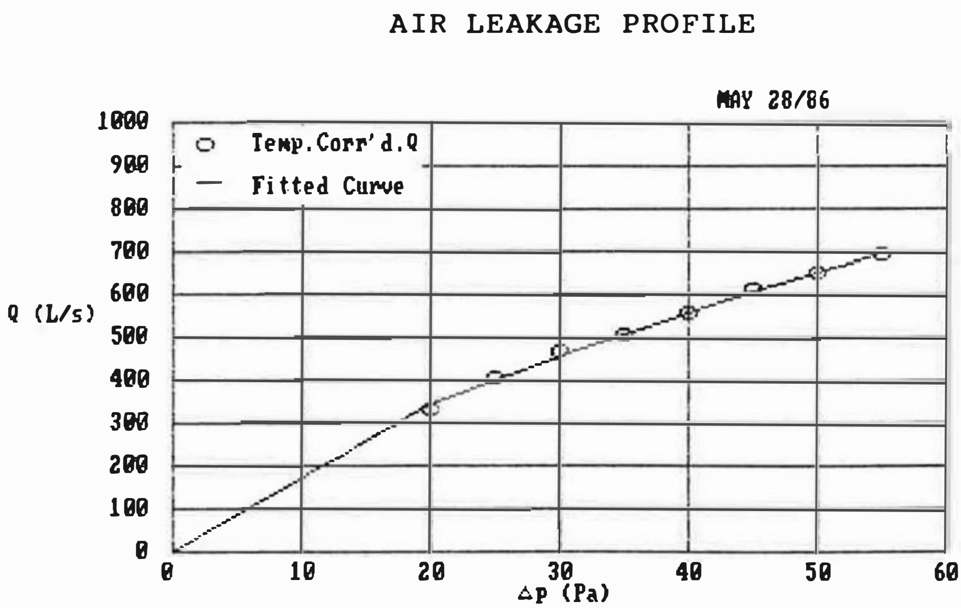
GRAPH 4 - 4184



GRAPH 5 - 4184



TRACER GAS AIR CHANGE RATE
PROBLEM HOUSE FOLLOW-UP. MAY 86
CARBON DIOXIDE (ppm)
(Thousands)
4.2
4.1
4
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
0
10
20
30
ELAPSED TIME (minutes)
CO2 IN RETURN



AIR LEAKAGE PROFILE
MAY 28/86
Temp.Corr'd.Q
Fitted Curve
Q (L/s)
1000
900
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
Δp (Pa)

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

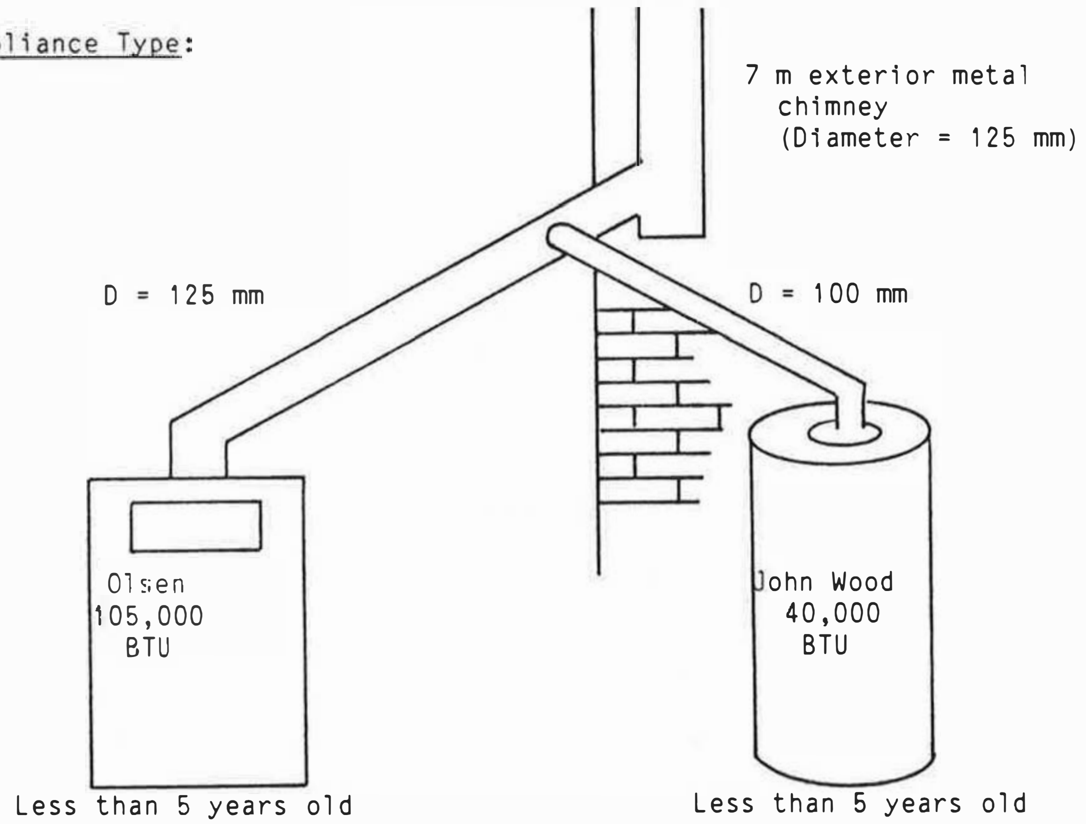
HOUSE NO: 4002 (OTTAWA)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 38°C
DHW - 71°C

House Type: One storey with full basement
Post - 1975
Natural ELA @ 10 Pascals = 587 cm²
Natural ACPH @ 50 Pascals = 1.913

Appliance Type:



Competing Exhaust Systems:

1 - Kitchen range hood fan
1 - Bathroom fan
1 - Clothes dryer
Exhaust from fan measured - 91 L/s

Fireplace:

1 - Brick fireplace with doors
Exhaust from fireplace at 4.5 Pa H.D. - 78 L/s

RESULTS OF SAFETY CHECK

1) <u>Preliminary Assessment</u>:

Predicted H.D. - 4.3 Pa
H.D. Limit for furnace - 5.0 Pa
H.D. Limit for DHW - 4.0 Pa
House prone to venting problems.

2) <u>Inspection</u>:

Installation as per code.
No abnormalities.

3) <u>Venting Systems Test</u>:

H.D. with fans - 4.5 Pa
H.D. with fans plus fireplace - 8.5 Pa
H.D. with fans plus furnace - 5.5 Pa
H.D. Limit for DHW appliance exceeded by 4 Pascals.

4) <u>Total Flue Draft</u>:

Full operation = 6 Pa.
Standby = [illegible] Pa.

5) <u>Spillage Observation</u>:

Appliance had major spillage for longer than 30 seconds in a tight house.

6) <u>Heat Exchanger Test</u>:

No perceptible leakage.

7) <u>Questioning of Occupant</u>:

Occupant noticed smoke in basement when operating fireplace on main floor. Smoke alarm in basement was being set off.

Occupant aware there was a problem, but did not understand dynamics.

Failure Event Description and Simulation: House 4002

House 4002 experienced combustion gas spillage as a result of house depressurization by fans and fireplace. During the failure event simulation, fans were operated and the furnace flue was blocked. The furnace was cycled on and off every 20 minutes to simulate shoulder season operation and backdrafting of combustions gases. Gusty winds prevented backdrafting during the simulation.

Graph 1 - 4002 and Graph 2 - 4002, show temperature monitoring of the furnace flue and dilution air inlet during the two 60-minute simulations. (Note how quickly temperatures rise and drop.) The high inlet temperatures would be more than sufficient to change a 71°C dot. Since the furnace detector showed only a 38°C dot, it is unlikely that backdrafting occurred on the furnace during the monitoring period. The 71°C dot on the DHW heater, however, shows that the chimney was backdrafting at times the furnace wasn't operating.

Graph 3 - 4002 and Graph 4 - 4002, show the monitoring of carbon dioxide in the cold air return. There is a steady, but slow build up of carbon dioxide in the house. Concentrations of CO_2 in the house slightly exceeds 2000 ppm after a hour and a half, and are unlikely to exceed 3000 ppm in the longer term.

o The slow rise of carbon dioxide level is partly due to the large volume of this new house (830 m^3) and the relatively small size of furnace (105,000 BTU).

Graph 5 - 4002, shows the decay of carbon dioxide following the event simulation.

Conclusions and Comments: House 4002

o The homeowner had noticed that smoke would appear in his basement when he operated the fireplace on the main floor. The furnace and fireplace chimneys shared a common cavity on the exterior wall of the house and were both the same height. The fire place would depressurize the house, causing air to be drawn down the furnace chimney. This air would be partially contaminated with smoke and would sometimes set off the basement fire alarm. (The questioning of the householder was essential to evaluating the problems in this house.)

o A simple solution to prevent cross-contamination between the two adjacent chimneys would be to extend one of the chimneys.

o It was windy during this house investigation and the fluctuations in pressure readings exceed what is allowable for the venting systems test. Although the readings were not accurate, it was obvious that the house had a problem due to the magnitude of depressurization. In other words, the less accurate test data seemed acceptable, because the house was not close to the margin of safety.

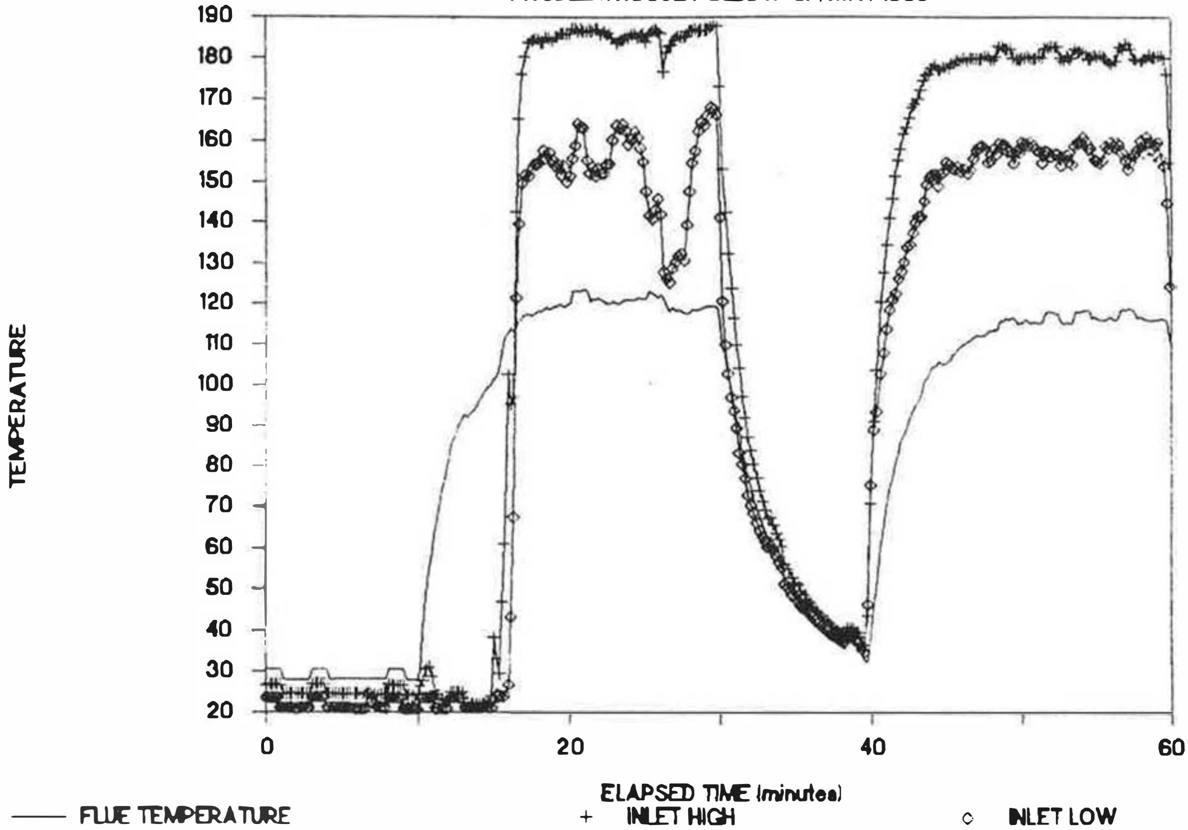
o It was pointed out to the occupant that the DHW heater had 71°C black dot and the furnace only had a 38°C black dot suggesting that backdrafting only occurred on the hot water heater. The occupant commented that he always turns down the furnace thermostat when operating the fireplace. The fans alone do not exceed the H.I. limit for the furnace, (although they do exceed the limit for the DHW heater).

o This house would be a good candidate for an induced draft fan. This fan would be activated by both appliances to ensure an updraft during start-up.

GRAPH 1 - 4002

TEMPERATURE MONITORING OF FURNACE FLUE

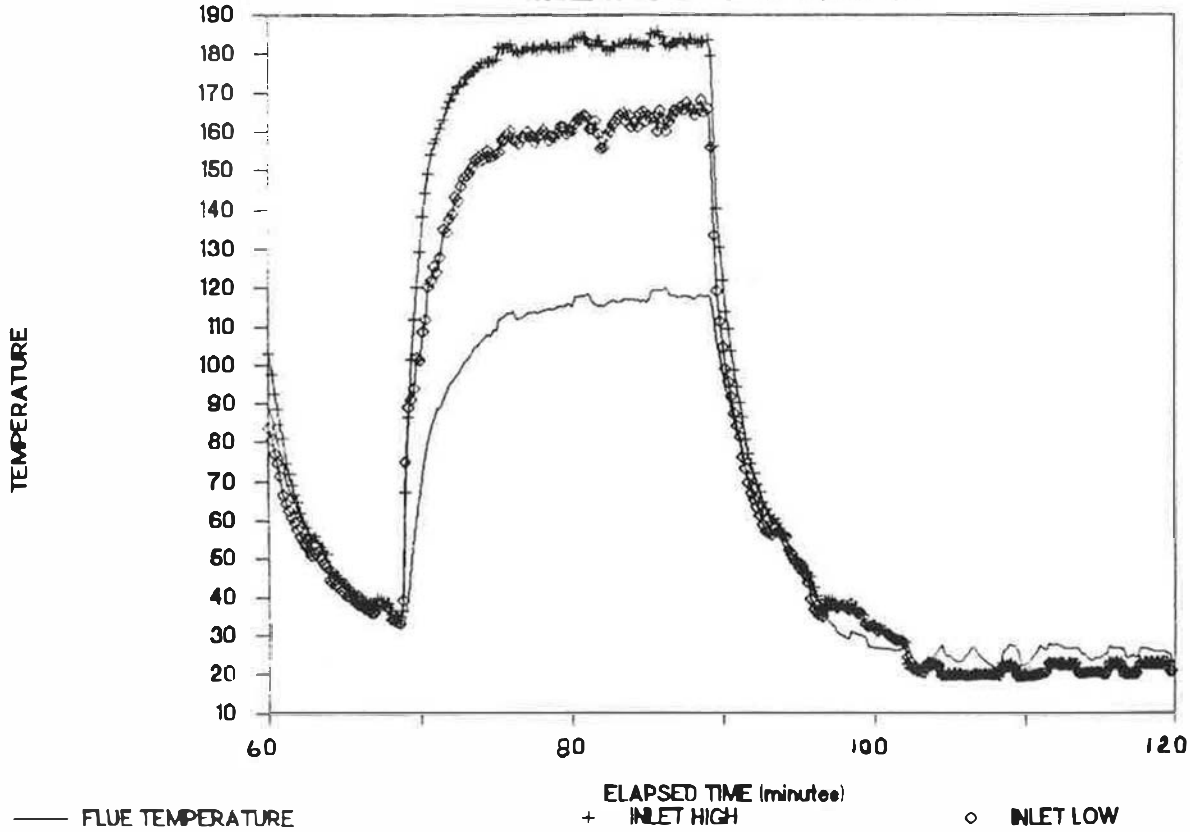
PROBLEM HOUSE FOLLOW-UP, MAY 1986



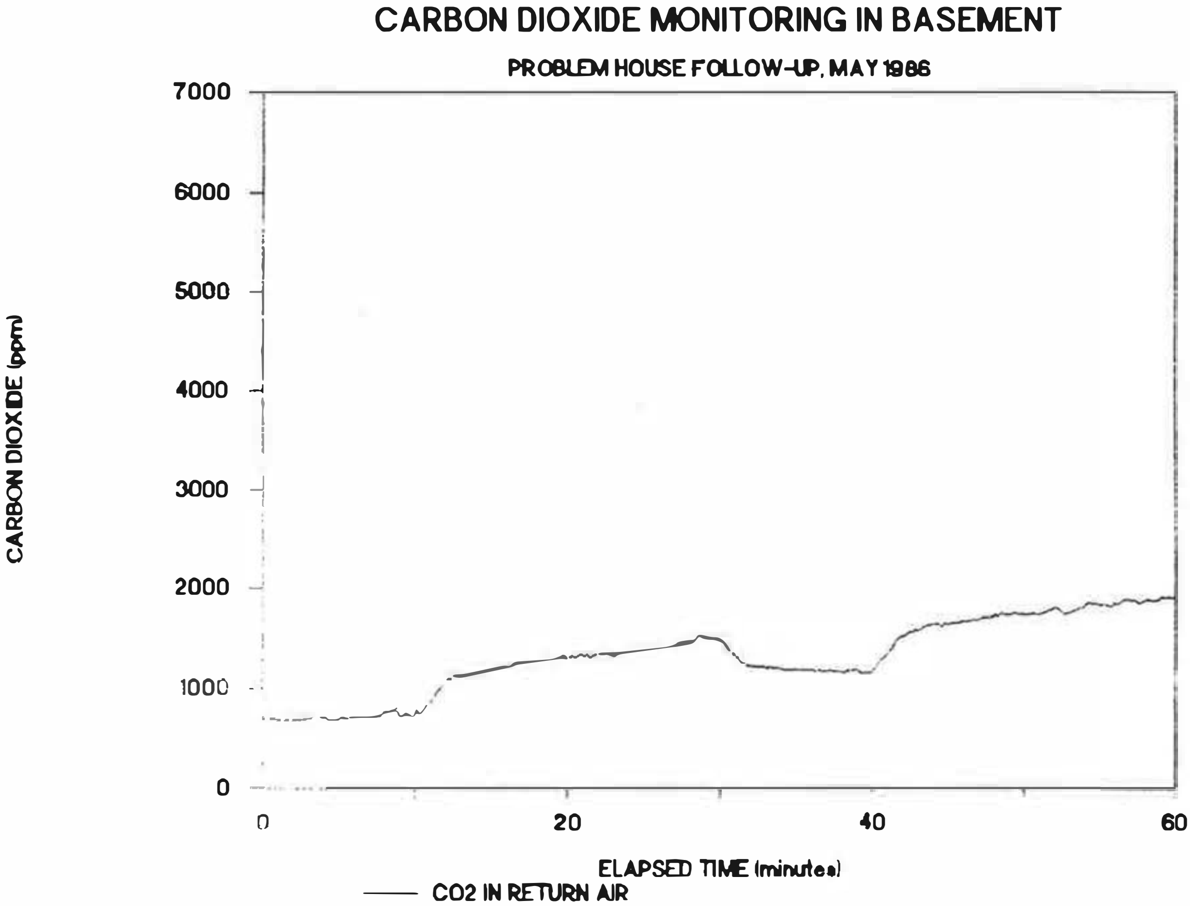
GRAPH 2 - 4002

TEMPERATURE MONITORING OF FURNACE FLUE

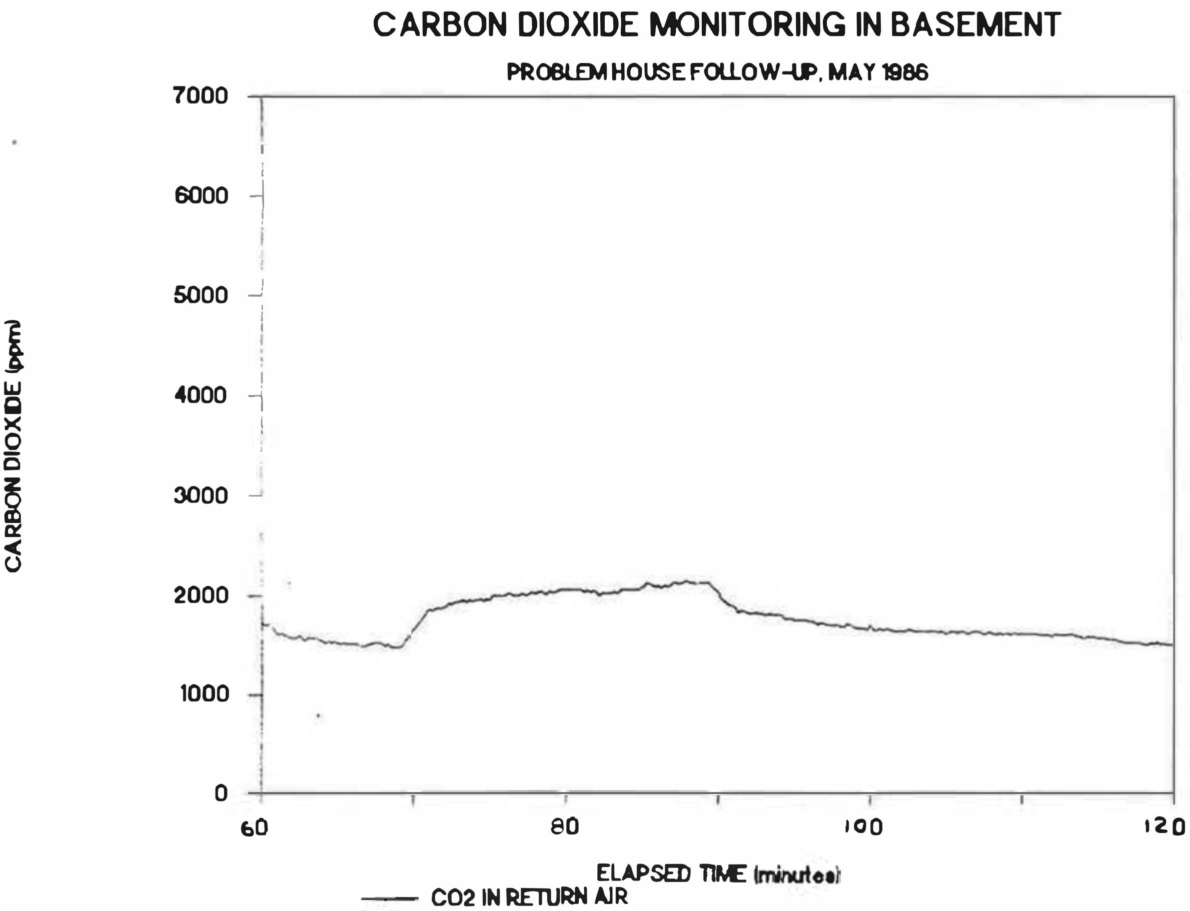
PROBLEM HOUSE FOLLOW-UP, MAY 1986



GRAPH 3 - 4002



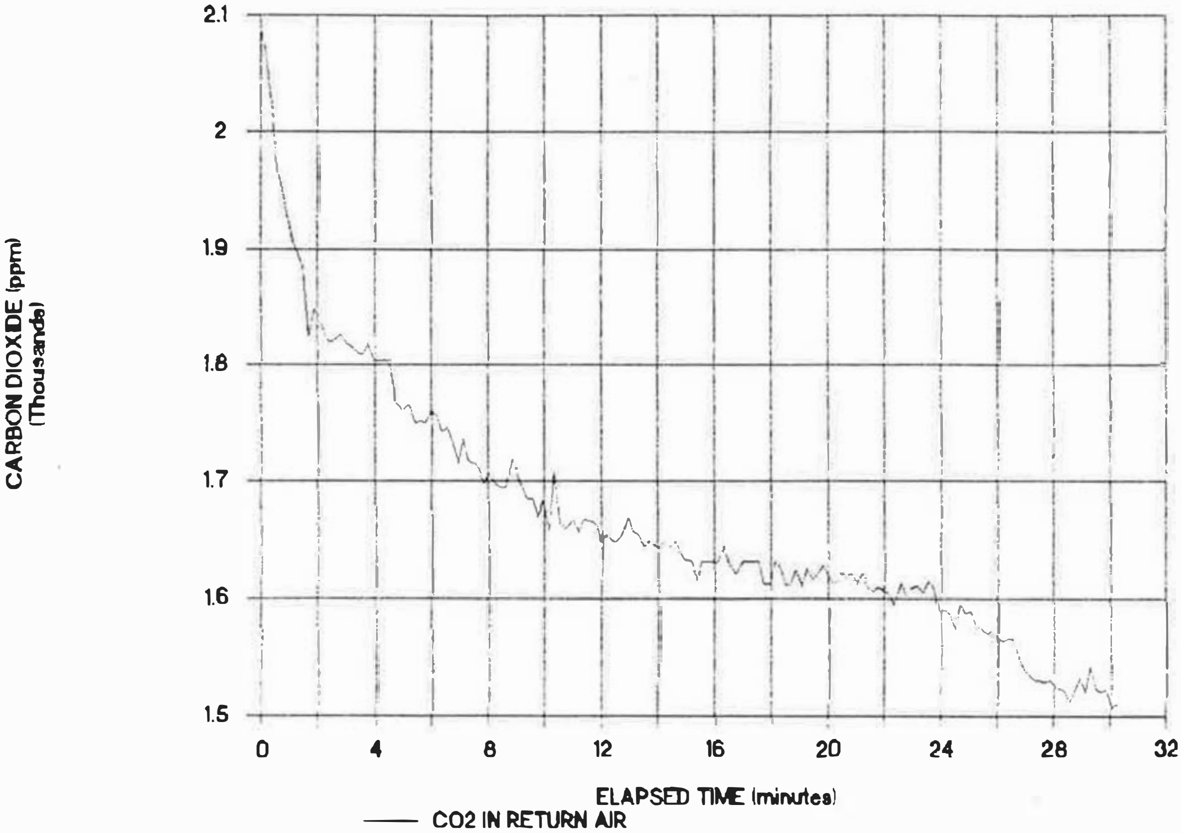
GRAPH 4 - 4002

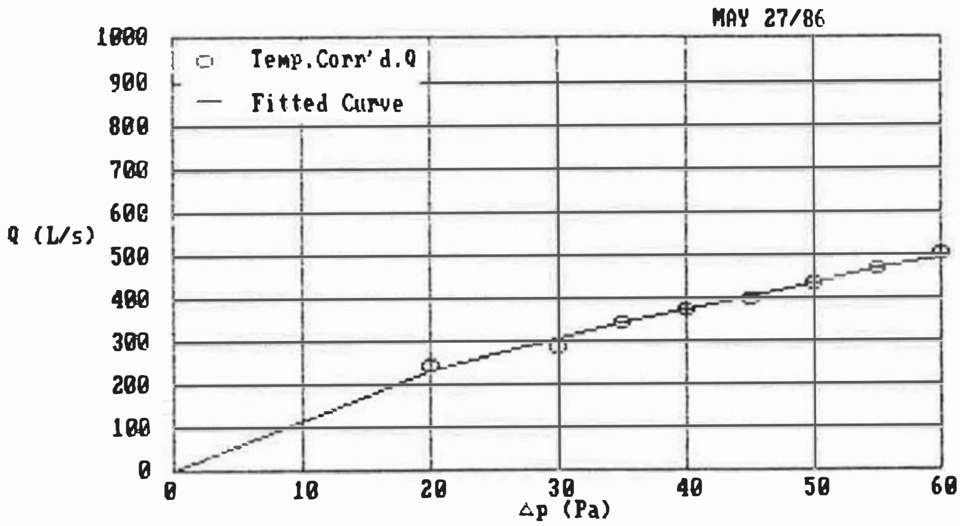


GRAPH 5 - 4002

TRACER GAS AIR CHANGE RATE

PROBLEM HOUSE FOLLOW-UP. MAY 86





AIRTIGHTNESS TEST RESULTS (AS PER CGSB DRAFT 12)

HOUSE NO. 4002

Ext.Temp. = 26 C

MAY 27/86
Wind Speed = 12 km/h
Volume = 829.5 m^3

PRESS. (PA)	TI (C)	FLOW(L/S) MEAS'D.	ADJ'D.	FITTED	RELATIVE ERROR(%)
20.0	24.0	238.20	247.64	235.12	5.06
30.0	24.0	281.90	293.08	310.52	5.95
35.0	24.0	334.10	347.35	345.16	0.63
40.0	24.0	361.90	376.25	378.27	0.54
45.0	24.0	388.00	403.38	410.10	1.67
50.0	24.0	426.30	443.20	440.84	0.53
55.0	24.0	455.90	473.97	470.63	0.71
60.0	24.0	487.20	506.52	499.58	1.37
65.0	24.0	508.10	528.24	527.77	0.09
70.0	24.0	530.70	551.74	555.30	0.65

C = 30.11455

n = .6860077

E.L.A. = 0.0587 m^2

N.L.A. =NOT AVAILABLE

Q @ 10Pa = 146.15 L/S

Q @ 50Pa = 440.84 L/S

Air Change per Hour @ 50Pa = 1.913

SXX= 2.949309E+11

SXY= 2.023248E+11

SYY= 1.398884E+11

SYX= 8.629149

Correlation Coefficient= .9960891

Relative Standard Error = 3.58%

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

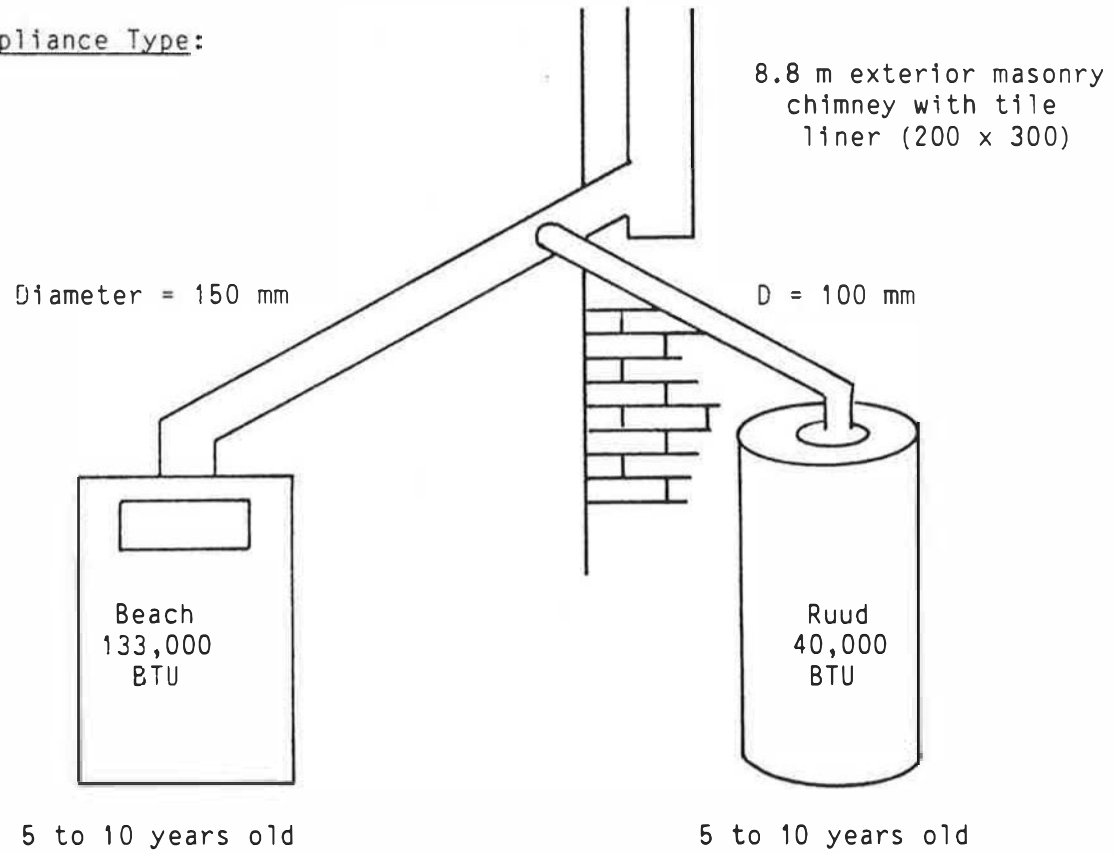
HOUSE NO: 4135 (OTTAWA)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 71°C
DHW - 38°C

House Type: Two storey with full basement
Post - 1975
Natural ELA @ 10 Pascals = 512 cm^2
Natural ACPH @ 50 Pascals = 3.14

Appliance Type:



Competing Exhaust Systems:

1 - Kitchen range hood fan
2 - Bathroom fans
1 - Clothes dryer
Total exhaust measured at 51 L/s

Fireplace:

1 - Open brick fireplace

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted H.D. - 13 Pa
H.D. Limit for furnace - 5 Pa
H.D. Limit for DHW - 4 Pa
House prone to venting problems.

2) Inspection:

Water stains.
Otherwise installation to code.

3) Venting Systems Test:

H.D. with fans - 3 Pa
H.D. with fans plus fireplace - 6 Pa
H.D. with fans plus furnace - 6 Pa
Fans plus fireplace exceeded H.D. Limit for furnace and DHW appliance.

4) Total Flue Draft:

Full operation = [illegible] Pa.
Standby = 3 Pa.

5) Spillage Observations:

Furnace spilled for less than 30 seconds with a tight house.
Winds assisted the appliance in re-establishing draft.

6) Heat Exchanger Test:

No perceptible leakage.

7) Questioning of Occupant:

Occupant noticed smoke from main floor fireplace in basement.
Was not aware furnace or DHW tank spilled.

Failure Event Description and Simulation: House 4135

The operation of both the fans and a fireplace created a house depressurization that exceeded the H.D. Limit for both the furnace and the fireplace. The chimney was plugged to simulate a continuous full backdraft during appliance operation. The furnace was cycled on for 20 minutes and off for 10 minutes.

Graph 1 - 4135, shows temperature monitoring of the furnace flue and dilution air inlet during the simulation. The plugged flue produces hotter inlet temperatures than would occur during backdrafting. The average temperatures of 170°C, are consistent with the 71°C dot change on the furnace detector. The exhaust temperatures from this low boy furnace are exceptionally high (300 + Celsius), at the upper limit for gas furnaces.

Graph 2 - 4135, shows the monitoring of carbon dioxide levels in the return air system. Carbon dioxide levels can be seen to rise rapidly in the house, reaching almost 5000 ppm during one 20 minute cycle.

Graph 3 - 4135, shows the decay rate of carbon dioxide following the failure event simulation. This decay rate was used to calculate a natural air change rate of 0.51 ACPH, caused by the combined effects of exhaust fans, wind and stack pressures.

Conclusions and Comments: House 4135

o This failure mechanism in this house resembles House 4002, also located in the Ottawa region. The homeowner had noticed that smoke would appear in his basement when he operated the fireplace on the main floor. The furnace and fireplace chimneys shared a common cavity on the exterior wall of the house, and were both the same height. The fireplace would depressurize the house, causing air to be drawn down the furnace chimney. This downdrafting air would be partially contaminated with fireplace smoke.

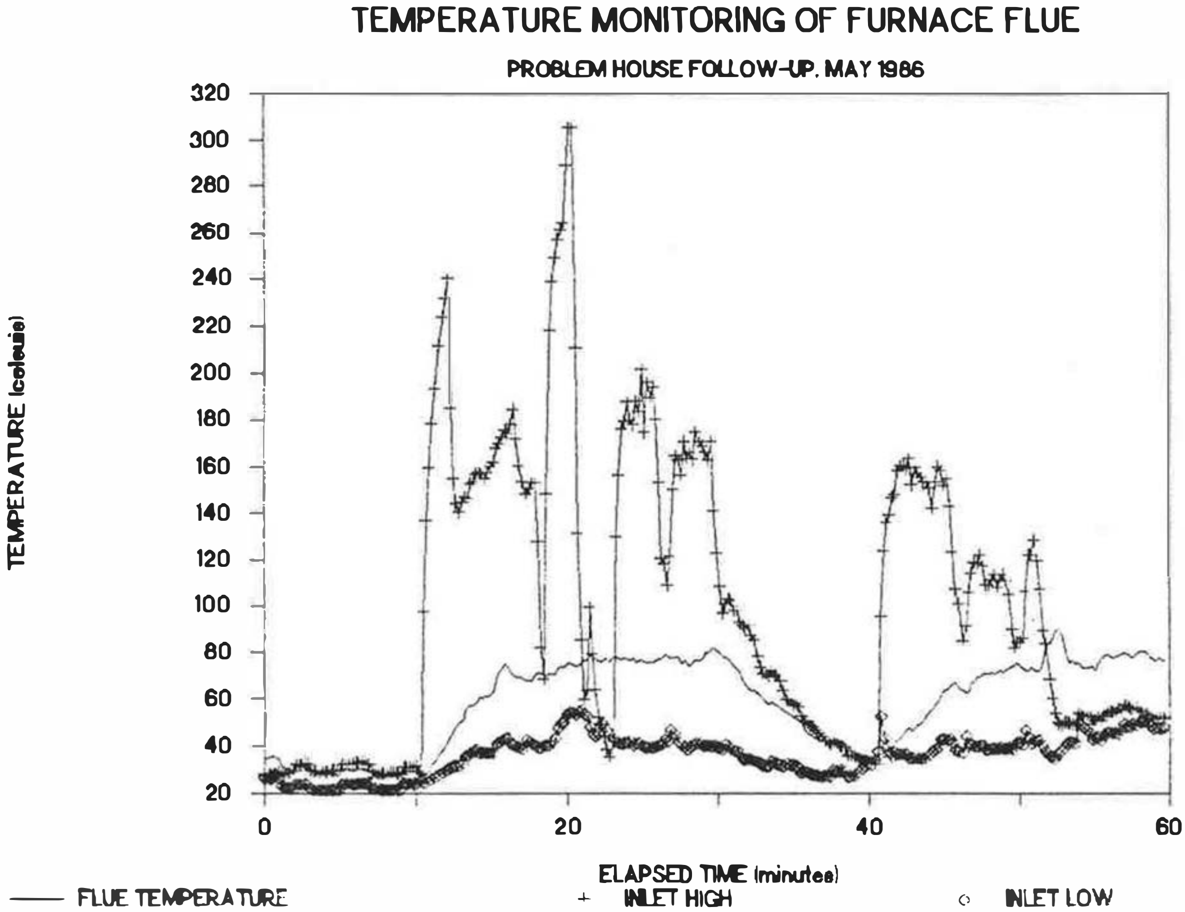
o A simple solution to the cross-contamination problem, would be to extend one of the chimneys.

o During the spillage observation test, the furnace spilled for less than 30 seconds. It was expected that the appliance would have spilled continuously, since the house was depressurized above its H.D. Limit. The lack of spillage was probably due to gusty winds. (The variance in manometer readings was 0.3 Pa during the house depressurization test, which suggest major wind effects.)

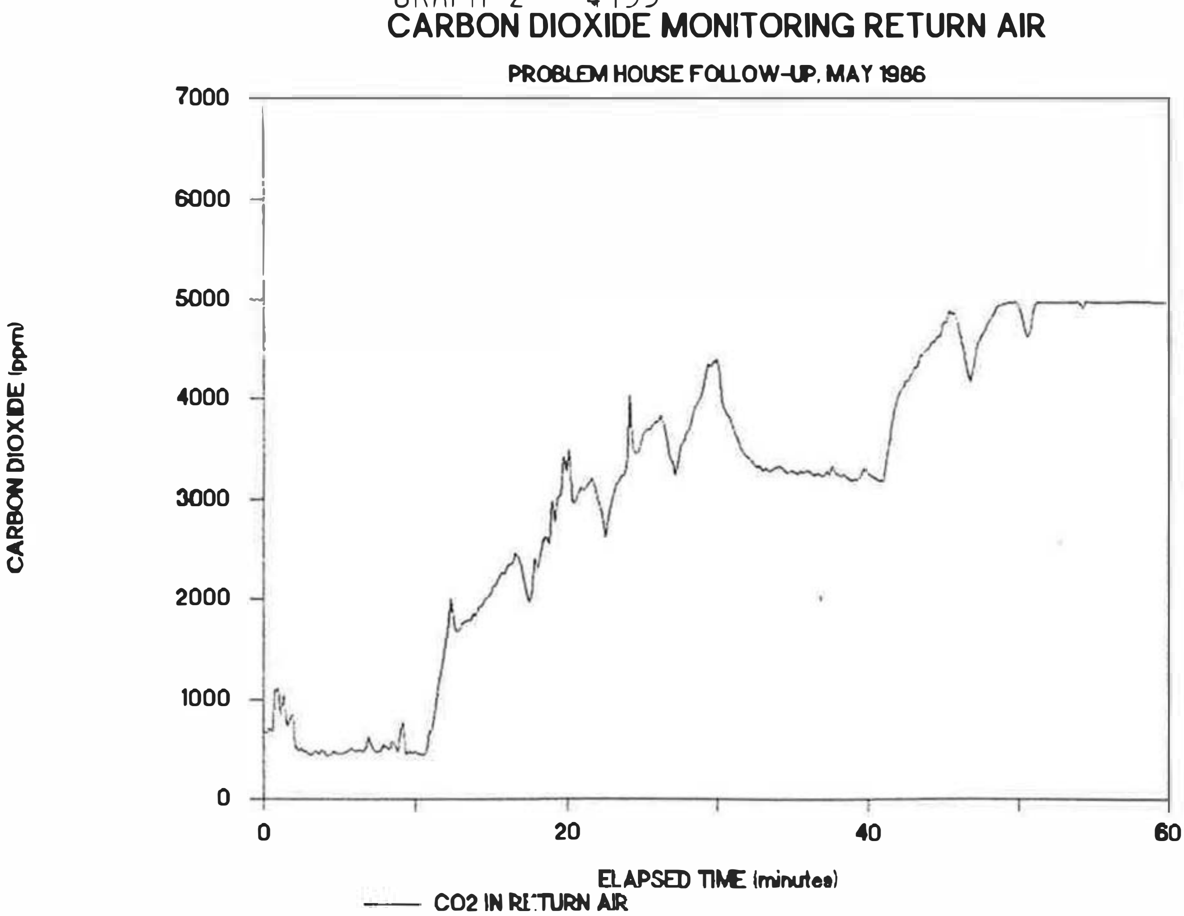
o With an ELA of 512 cm^2, this house was tighter than the average, conventional new house in Ottawa. However, the fans and the fireplace exhaust were was much less than predicted. Consequently, the predicted depressurization exceeds the measured depressurization by 15 Pascals (Table 11, Part 3). No obvious reason was found for the reduced fan flows.

o Many of the features of House 4135 are becoming typical for suburban Ottawa. Presumably, backdrafting will be a common event within this segment of the housing stock.

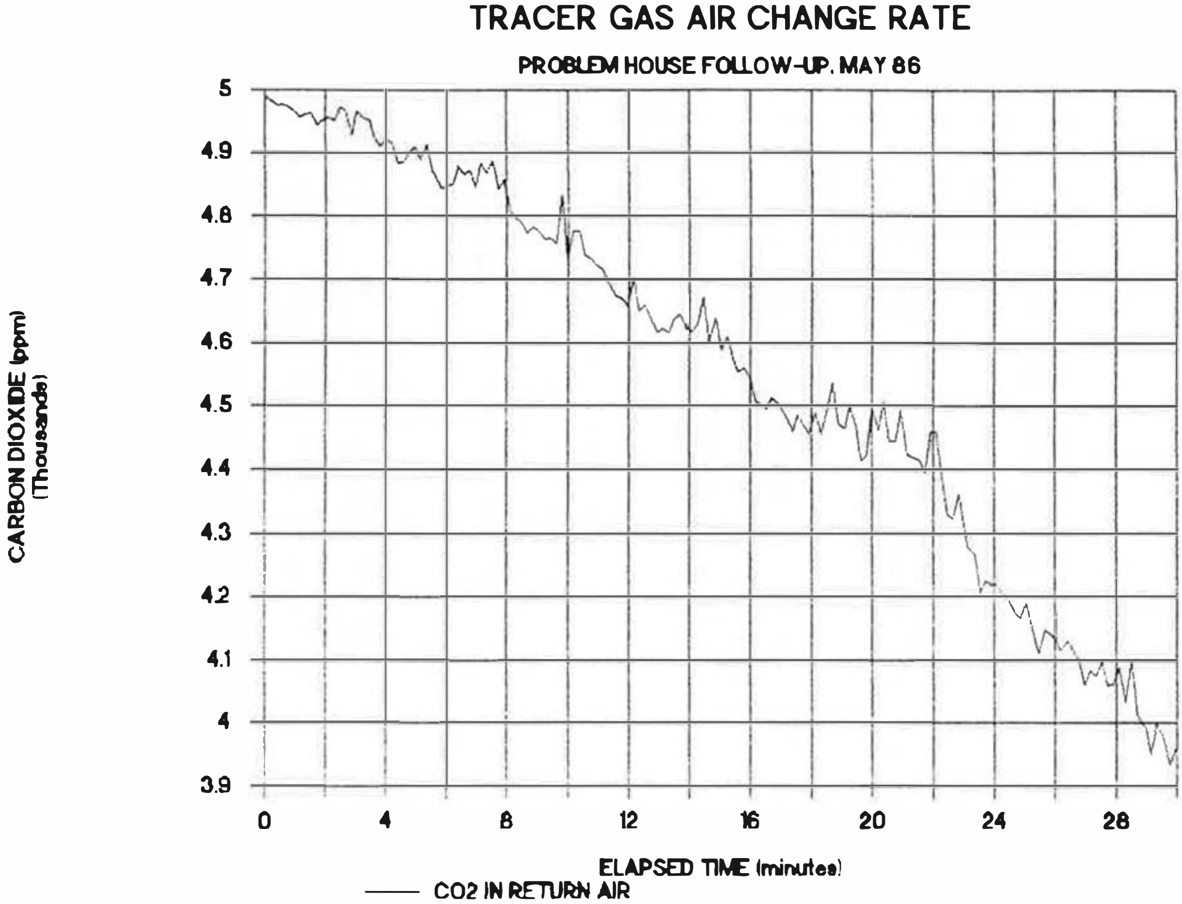
GRAPH 1 - 4135



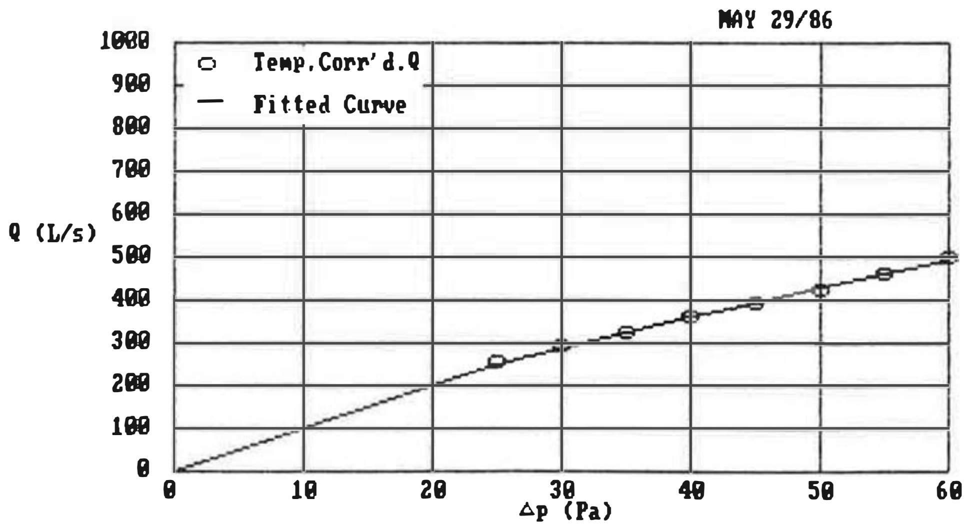
GRAPH 2 - 4135



GRAPH 3 - 4135



AIR LEAKAGE PROFILE



AIRTIGHTNESS TEST RESULTS
(AS PER CGSB DRAFT 12)

HOUSE NO. 4135

MAY 29/86

Ext.Temp. = 28 C

Wind Speed = 15 km/h

Volume = 495.3 m^3

PRESS. (PA)	TI (C)	FLOW(L/S) MEAS'D.	ADJ'D.	FITTED	RELATIVE ERROR(%)
25.0	25.0	247.10	257.75	255.59	0.84
30.0	25.0	281.90	294.05	293.50	0.19
35.0	25.0	313.20	326.70	329.91	0.98
40.0	24.0	348.00	363.00	365.07	0.57
45.0	24.0	382.80	399.30	399.19	0.03
50.0	24.0	412.40	430.18	432.40	0.52
55.0	25.0	443.70	462.83	464.82	0.43
60.0	25.0	483.70	504.56	496.53	1.59
65.0	24.0	513.30	535.43	527.61	1.46
70.0	23.0	525.50	548.16	558.12	1.82

C = 22.24284 n = .7585154

E.L.A. = 0.0512 m^2 N.L.A. =NOT AVAILABLE

Q @ 10Pa = 127.56 L/S Q @ 50Pa = 432.40 L/S

Air Change per Hour @ 50Pa = 3.143

SXX= 2.47141E+11 SXY= 1.874602E+11

SYY= 1.426567E+11 SYX= 5.696735

Correlation Coefficient= .9983681

Relative Standard Error = 2.56%

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

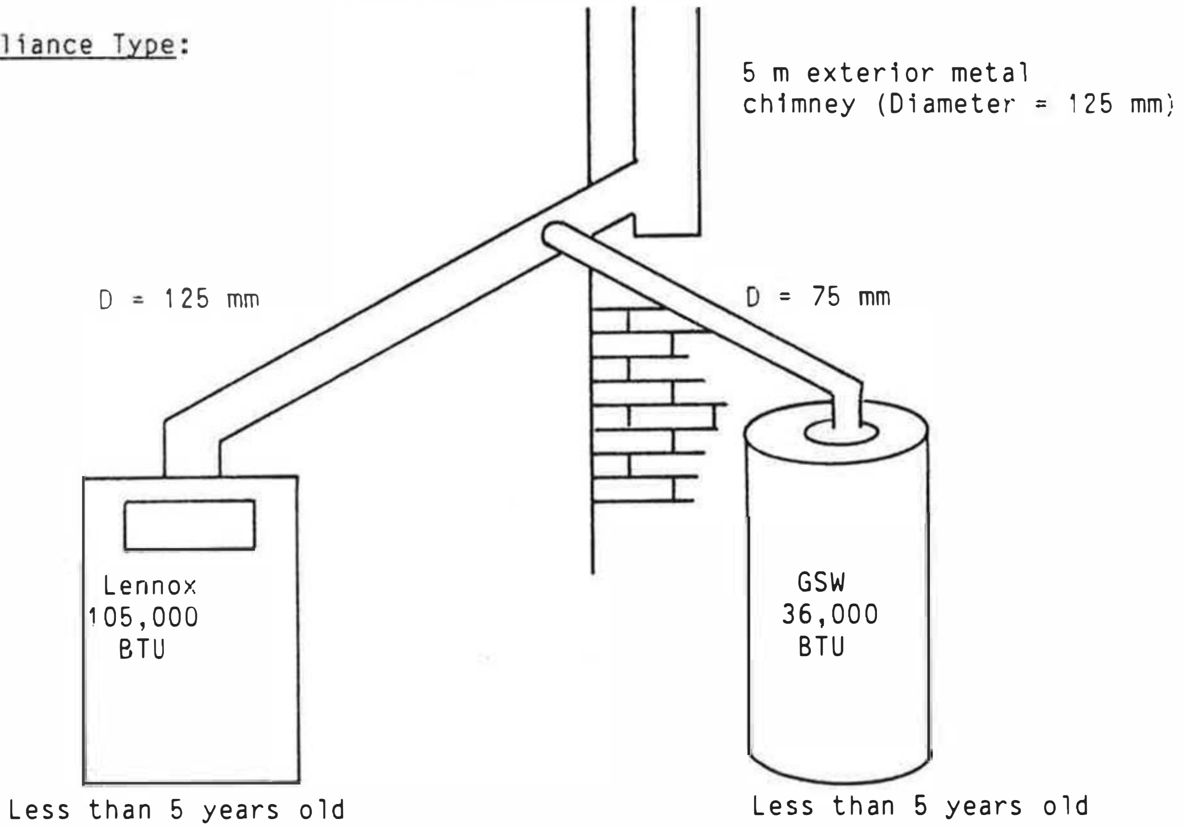
HOUSE NO: 1057 (VANCOUVER)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 54°C
DHW - 38°C

House Type: Two storey with full basement
Post-1975
Natural ELA @ 10 Pascals = 1668 cm^2
Natural ACPH @ 50 Pascals = 8.62

Appliance Type:



Competing Exhaust Systems:

1 - Kitchen range hood fan
2 - Bathroom fans
1 - Clothes dryer
Measured flow - 212 L/s

Fireplace:

1 fireplace.
Measured flow at 4 Pa H.D. - 126 L/s

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted H.D. = 7.6 Pa
H.D. Limit for furnace = 5.0 Pa
H.D. Limit for DHW = 4.0 Pa
House prone to venting failure.

2) Inspection:

Down slope on flue connector; restrictive chimney top; chimney dwarfed by trees and buildings; house located on slope of mountain; long uninsulated flue extension.

3) Venting System Test:

H.D. fans = 4 Pa
H.D. fans plus fireplace = 6 Pa
H.D. fans plus furnace = 4 Pa
Depressurization of house by fans and fireplace exceeded H.D. Limit for furnace and hot water heater.

4) Total Flue Draft:

Full Operation = 10 Pa.
Standby = 3 Pa.

5) Spillage Observations:

House spilled for over 30 seconds with house open and exhaust devices off.

6) Heat Exchanger Test:

No perceptible leakage.

7) Questioning of Occupant:

Occupant had only noticed spillage when detector was being installed.

Failure Event Description and Simulation: House 1057

The house had a strong draft in the chimney, but spilled continuously for several minutes at start-up, even with the house open. This indicated that the chimney was restricted and could not handle the gas flow from the furnace. Chimney restriction problems were aggravated by house depressurization caused by the exhaust fans and two open fireplaces.

To simulate a failure event, the furnace was cycled on for 10 minutes and off for 5 minutes over a 60 minute period with the house depressurized to 6 Pascals.

Graph 1 - 1057 and Graph 2 -1057, show temperature monitoring of the furnace flue and dilution air inlet during two failure event simulations, each of 30 minutes duration. Spillage is apparent throughout each operating cycle, although a majority of the combustion gases are being exhausted via the flue. The maximum inlet temperatures are 70°C, which is insufficient to explain a 54°C cut on the furnace detector. Backdrafting in colder weather may have caused periods of 100% spillage.

Graph 3 - 1057 and Graph 4 - 1057, show the monitoring of CO^2 in the return air distribution system during the two half-hour simulations. There was a slow and largely insignificant build-up of CO^2 in the house, reaching 200 ppm after one hour. The quantity of spillage into the house was relatively small and not enough to have an effect on the entire house volume. Moreover, this was a leaky house, and the natural air change rate during the simulation was so high that combustion pollutants were quickly diluted.

Conclusions and Comments: House 1057

o The flue pipe between the furnace and the metal exterior chimney had a large number of elbows, and a low slope. These were two factors responsible for the start-up spillage.

o The house was located on the slope of a mountain in a subdivision that had drastic height differentials between buildings. This meant that the chimney was dwarfed by both surrounding trees, and houses. The chimney top was level with a lower window in the adjacent house. This was a common occurence in this subdivision.

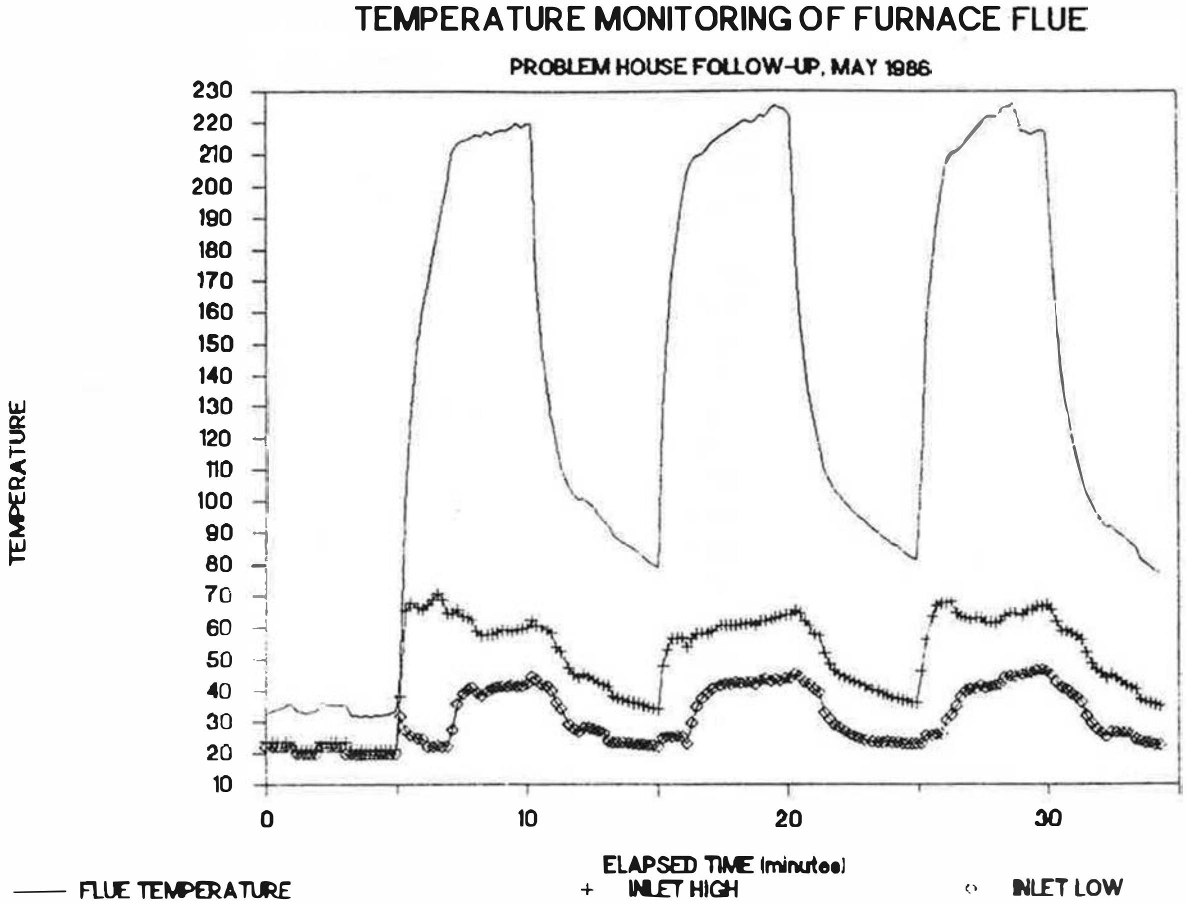
o Attempts had been made to extend the chimney, presumably to counteract wind downdrafts. A single-walled duct 1.5 meters in length had been affixed to the top of the chimney with a cap on top. The cap seemed to restrict the free area of the chimney. The extension was uninsulated and may have had little effect on the total effective length of the chimney.

o The exhaust fans and fireplaces did not cause the furnace to bacrdraft during the field testing. Rather the effect of the house depressurization was to increase the length of time that the appliance spilled at start-up. With the house depressurized by exhaust fans the spillage was almost continuous during a 10 minute cycle.

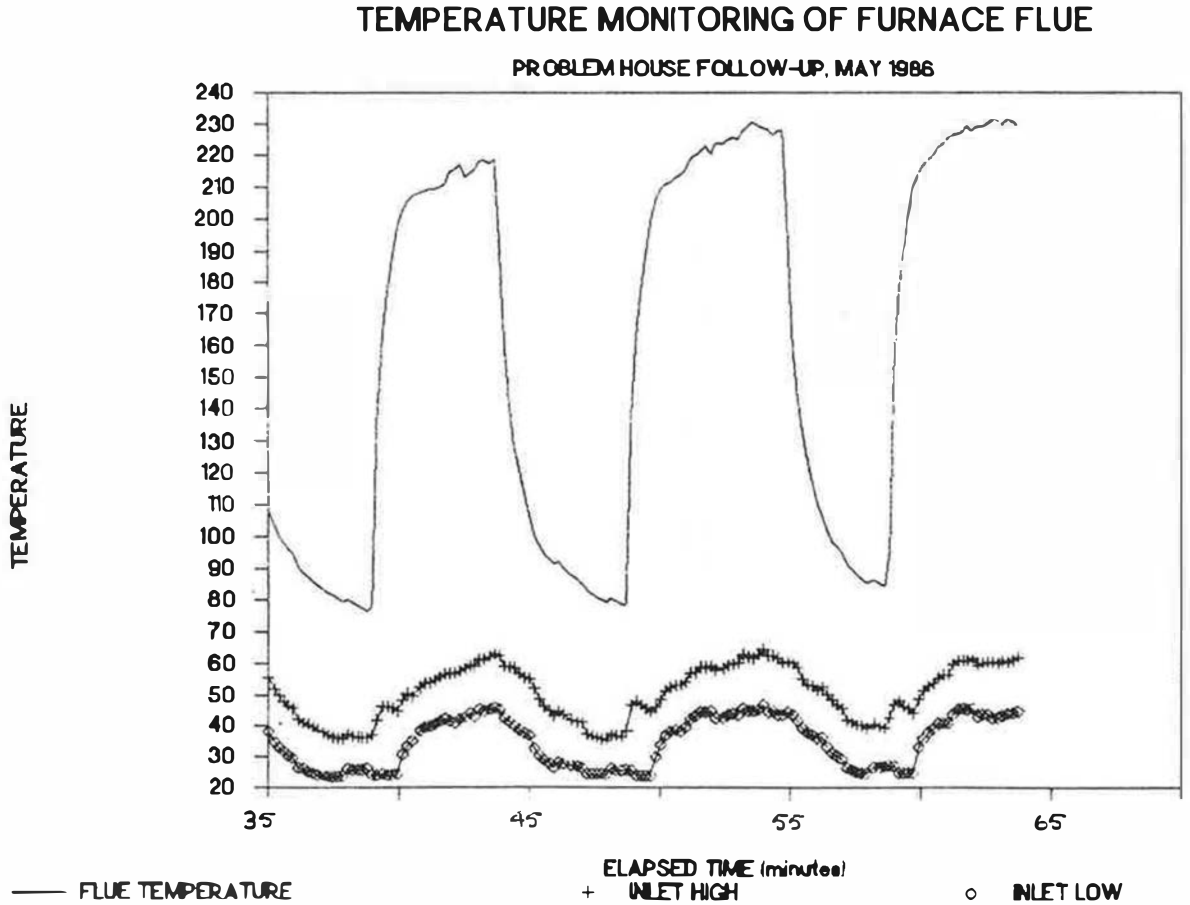
o The sizing of the flue connectors and chimney were in accordance with recent codes. However, because the sizing fell just within the limits of the code, the system may have inherent design problems.

o Other houses in this subdivision were almost identical to House 1057. The spillage problem that was uncovered in this survey house is presumably common to all the other houses.

GRAPH 1 - 1057



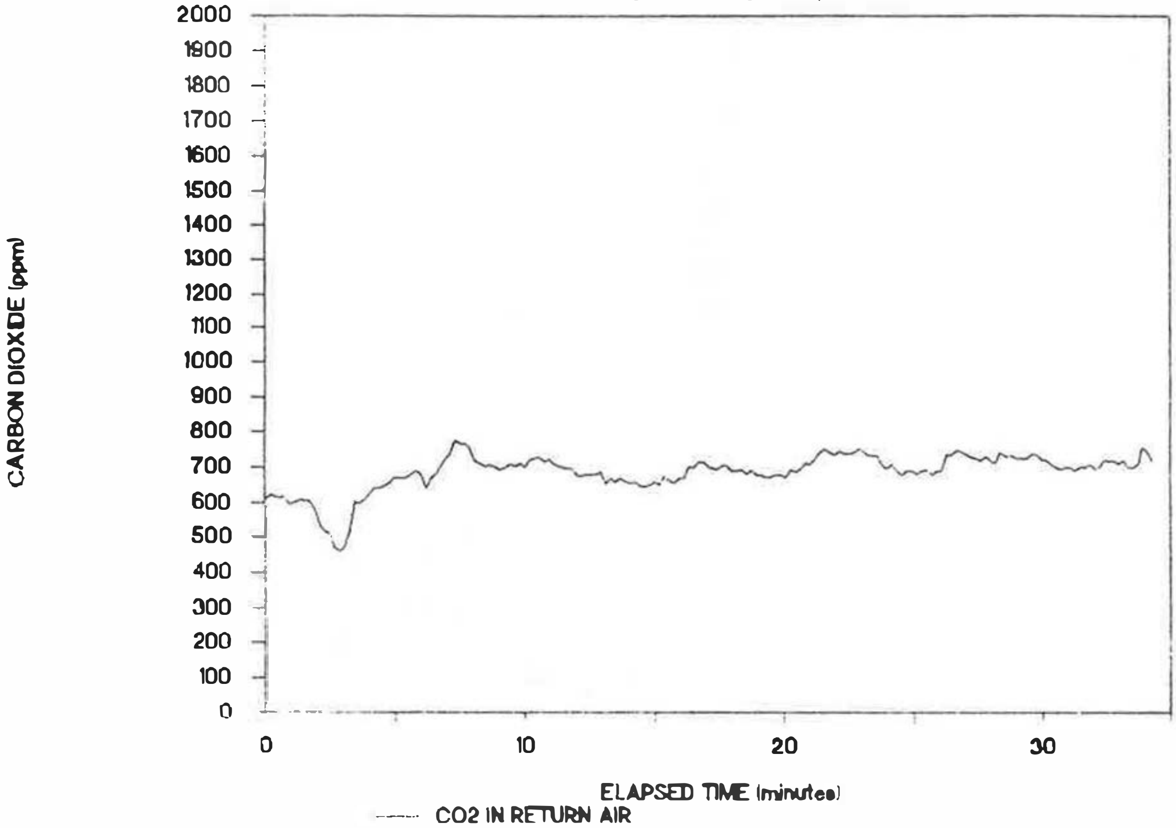
GRAPH 2 - 1057



GRAPH 3 - 1057

CARBON DIOXIDE MONITORING RETURN AIR

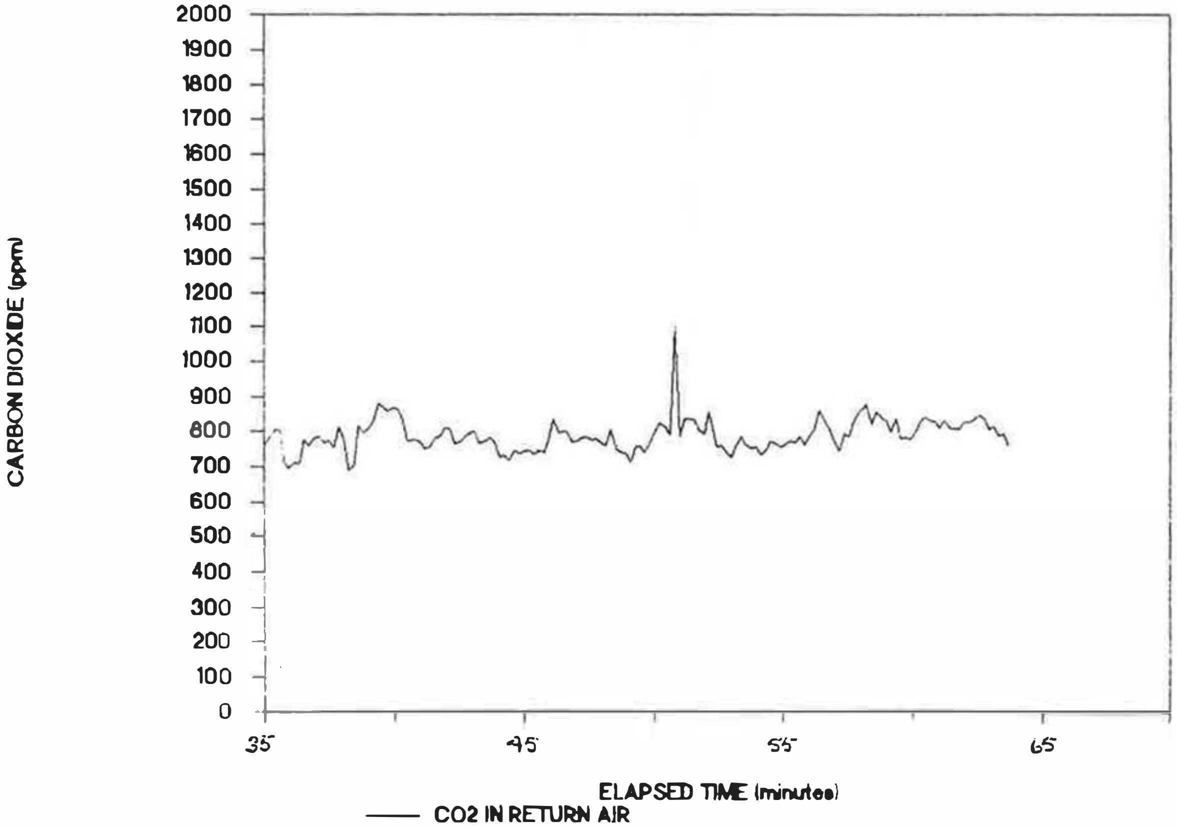
PROBLEM HOUSE FOLLOW-UP, MAY 1986



GRAPH 4 - 1057

CARBON DIOXIDE MONITORING RETURN AIR

PROBLEM HOUSE FOLLOW-UP, MAY 1986



RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

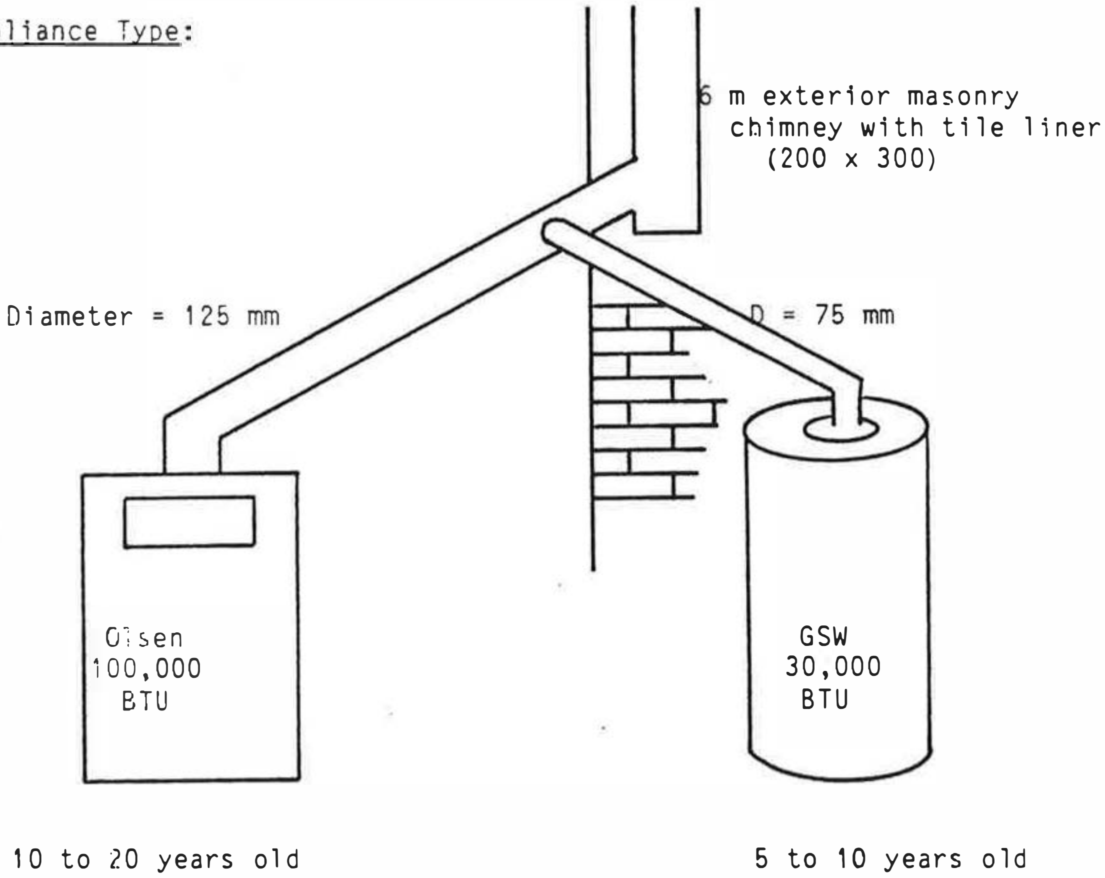
HOUSE NO: 1076 (VANCOUVER)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 54°C
DHW - 38°C

House Type: Two storey with full basement
1900-1945
Natural ELA @ 10 Pascals = 1715 cm^2
Natural ACPH @ 50 Pascals = 5.82

Appliance Type:



Competing Exhaust Systems:

1 - Bathroom fan
1 - Clothes dryer
Total exhaust fan flow measured - 109 L/s

Fireplace:

1 - Open brick fireplace

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted H.D. - 1 Pa
H.D. Limit for furnace - 5 Pa
House not prone to venting problems.

2) Inspection:

Ash clean-out missing; chimney dwarfed by nearby trees and houses; leaks in chimney.

3) Venting Systems Test:

H.D. from fans - 1 Pa.
H.D. from fans plus fireplace - 2 Pa.
Fans and fireplace did not exceed depressurization limit for either appliance.

4) Total Flue Draft:

Full Operation = 3-4 Pa.
Standby = 0 Pa.

5) Spillage Observations:

Furnace spilled for more than 30 seconds with an open house. Spillage quantity and duration was greater when house was depressurized (2 Pa).

6) Heat Exchanger Test:

No perceptible leakage.

7) Questioning of Occupant:

Occupant had been aware for five years that furnace spilled badly, especially at start-up.

They had a combustion air feed installed by B.C. Hydro, but problems did not disappear. At times she would have to open basement door to backyard to improve draft.

Failure Event Description and Simulation: House 1076

A very weak chimney in House 1076 resulted in partial gas spillage for prolonged periods. Although chimney draft was poor by design, the major contributing factor was a missing ash clean-out, which creates a very leaky chimney. The chimney was an exterior, masonry chimney, held away from the house with metal brackets. The chimney was dwarfed by nearby houses and trees, and also appeared to be suffering from occasional wind downdrafts. Slight house depressurization increases the severity of the spillage event considerably. Two Pascals of depressurization created virtually continuous spillage. Persistent equipment problems, and lack of time, prevented a failure event simulation in this first test house in Vancouver.

Conclusions and Comments: House 1076

o The outdoor, ground-level, ash clean-out door was missing, but a large panel of wood had been laid across the opening and obscured the hole. The chimney also appeared to have many leaky cracks in the mortar. The combination of these leaks caused the draft to be very low at the furnace. A measurement of the chimney draft triggered a careful search for leaks, which lead to finding the missing door.

o A second storey had been added on to this house within the last two years. At this time the chimney was not extended. The result was that the chimney top was wedged between two tall roofs and extremely susceptible to down drafts when winds blew from the south, east, or west.

o The exhaust fans and open fireplace caused the house to be depressurized to two Pascals. This had the effect of increasing both the quantity and duration of spillage from the appliance. Spillage would have been much worse if a large combustion air feed had not been installed.

o Extending the chimney and tightening up the chimney system should elimnate spillage from this appliance.

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

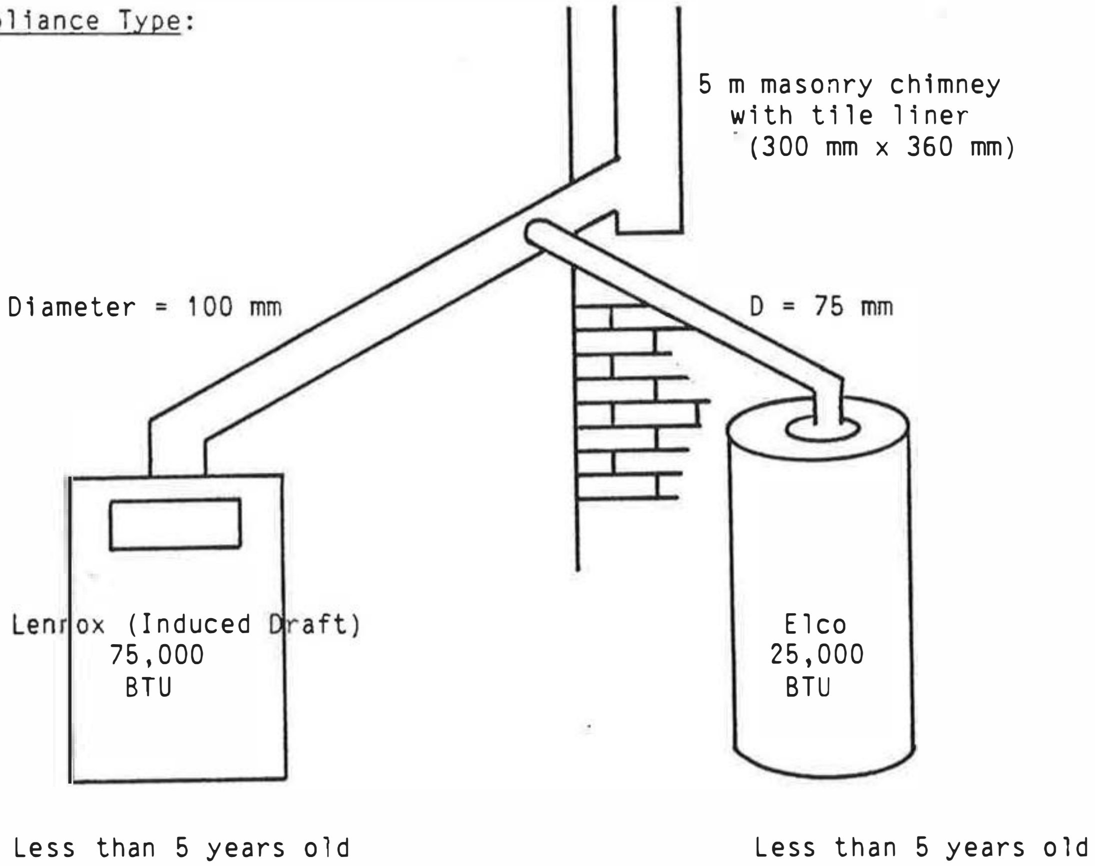
HOUSE NO: 1142 (VANCOUVER)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 54°C
DHW - 0

House Type: One storey with full basement
1900-1945
Natural ELA @ 10 Pascals = 1520 cm²
Natural ACPH @ 50 Pascals = 10.0

Appliance Type:



Competing Exhaust Systems:

1 - Kitchen range hood fan
1 - Clothes dryer
Measured flow - 187 L/s

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted H.D. - 4 Pa
H.D. Limit for furnace -15 Pa
H.D. Limit for DHW - 4 Pa
House prone to venting failure.

2) Inspection:

Large holes in chimney where previous oil furnace had been connected.

3) Venting Systems Test:

H.D. from fans - 3.5 Pa
Exhaust fan operating in house did not exceed H.D. Limit for either appliance.

4) Total Flue Draft:

Full Operation = 17 Pa.
Standby = 3-4 Pa.

5) Spillage Observations:

Less than 30 seconds of spillage with exhaust fans operating in a tight house.

6) Heat Exchanger Test:

No perceptible leakage.

7) Questioning of Occupant:

Occupant unaware of any problems.

Conclusions and Comments: House 1142

o This was the only gas-heated house where the reasons for combustion gas spillage remained a mystery. The fans were powerful (total exhaust = 187 litres/second) but the house envelope was not particularly tight (ELA = 1520 cm^2). The house had new windows installed and no fireplace and, from experienced judgement, should have been much tighter than what was measured. A thorough search and questioning of the occupant did not uncover any overlooked holes in the envelope.

o The furnace only spilled briefly at start-up. There were two 38°C dots on the DHW heater, and a 54°C dot on the furnace. The two dots on the DHW heater had turned since the Canada Wide Survey in May. The appliance had definitely spilled at one point, but the researchers were unable to determine the failure mechanism.

o Without a definite cause, a failure event simulation was not considered.

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

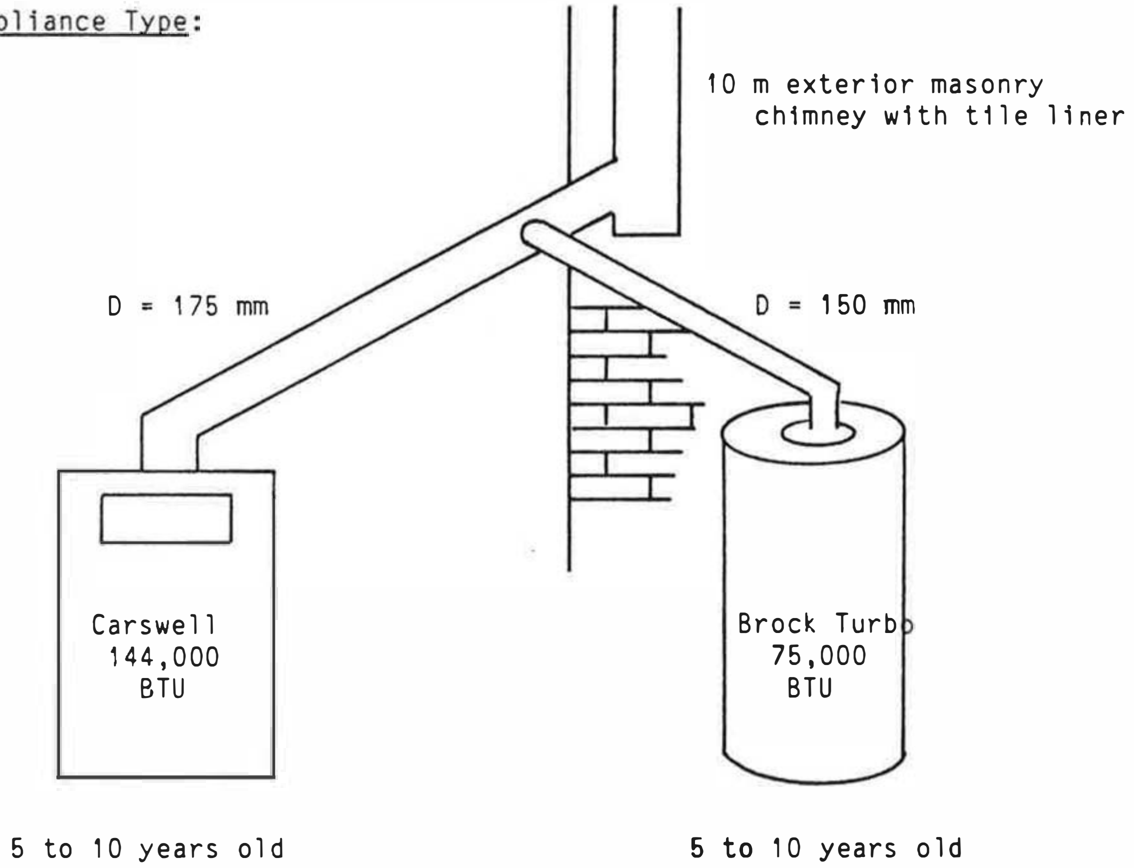
HOUSE NO: 4004 (OTTAWA)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 71C
DHW - 121°C

House Type: Two storey with full basement
Post - 1975
Natural ELA @ 10 Pascals = 891 cm^2
Natural ACPH @ 50 Pascals = 4.10

Appliance Type:



Competing Exhaust Systems:

1 - Kitchen range hood fan
3 - Bathroom fans

Fireplace:

1 - Open brick fireplace

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted H.D. - 6.4 Pa
H.D. Limit - 4 Pa
House prone to venting problems.

2) Inspection:

Ash clean-out (moisture accumulation, broken lining, creosote excessive, metal lining required); flue connector slope inadequate; flue odours present; warm air register missing.

3) Venting Systems Test:

H.D. from fans - 3 Pa
H.D. from fans plus fireplace - 6 Pa
Fans plus fireplace exceeded H.D. Limit for furnace and DHW.

4) Total Flue Draft:

Full operation = 20 - 30 Pa.
Standby = 0 Pa.

5) Spillage Observations:

DHW heater spilled for less than 30 seconds with house tight and fans on.

6) Heat Exchanger Test:

Major leakage detected.

7) Questioning of Occupant:

Occupant aware of cracked heat exchanger and of chimney problems.

Failure Event Description and Simulation: House 4004

This oil-heated house in Ottawa offered a first opportunity to try out the test equipment and procedures on an oil furnace.

The house had a history of problems, including a deteriorating tile liner that had previously blocked the chimney and a suspected cracked heat exchanger. The safety checks confirmed both these problems, and identified excess home depressurization and creosote build-up, and icing, as further problems.

The detectors on both the furnace and DHW indicated signs of chimney failure, with dot temperatures of 71°C and 121°C respectively. Spillage could have occurred for a variety of reasons, and for varying durations.

Simulating a failure event was not an obvious task. In addition to the spillage identified by the detectors, further spillage may have been occurring as a result of the leaky heat exchanger.

With the house depressurized to 6 Pascals, the DHW heater and furnace were started. The appliances were cycled on for 20 minutes, off for 15 minutes. Graph 1 - 4004, shows flue and inlet temperatures during the event. Despite considerable spillage at start-up, the inlet (barometric damper) temperatures are much less than what was recorded on the detector.

Although there was considerable spillage at start-up, Graph 2 - 4004, shows that the carbon dioxide concentrations as measured in the return air system were unaffected by chimney spillage or heat exchanger spillage. As well, when the furnace was fired there was no rise in CO2 levels.

o Chimney spillage had no apparent effect on the indoor air quality during the failure event simulation.

Conclusions and Comments: House 4004

o The homeowner was aware that the oil furnace had significant leakage. He had chosen to keep the summer switch operating at all times to reduce the contamination of indoor air at start-up.

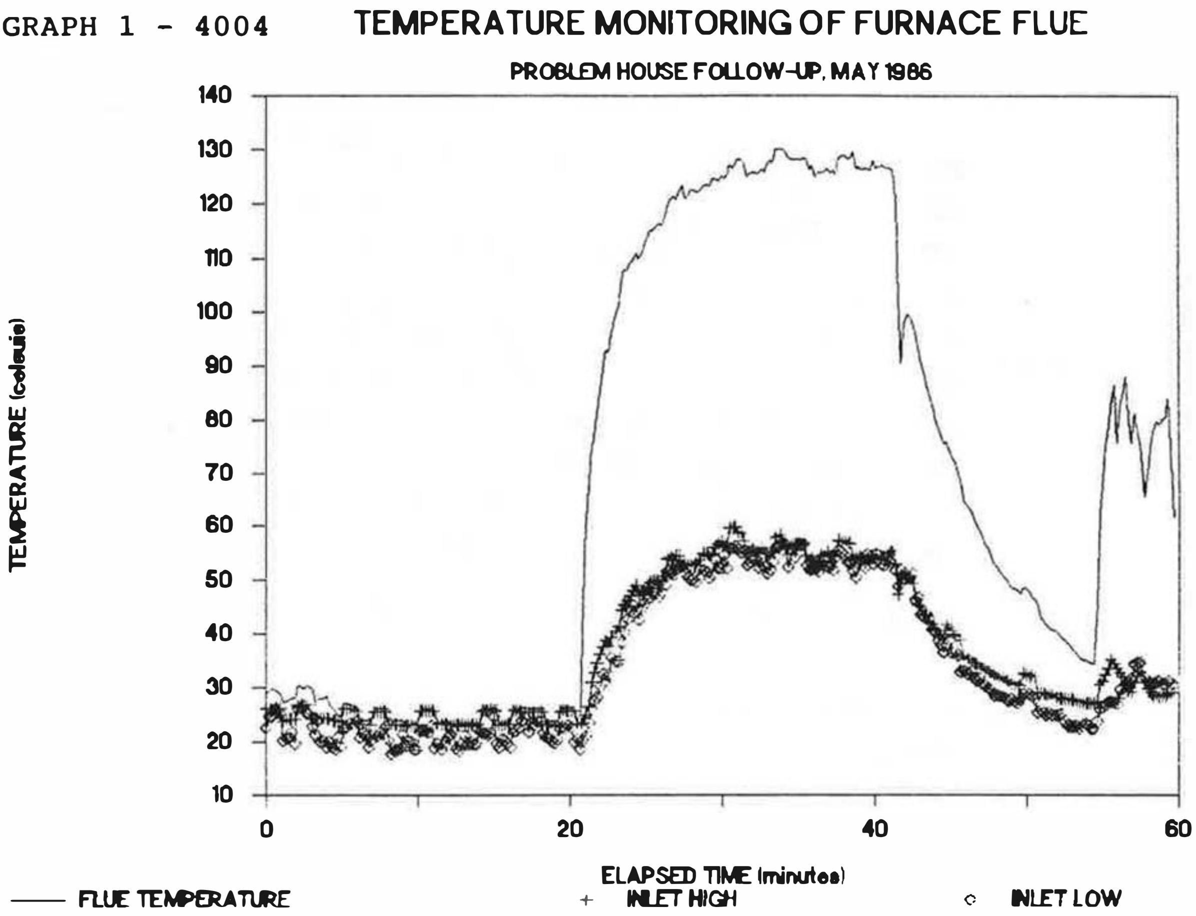
o It was equally likely that the detector dots had been set off by a chimney blockage caused by ice blockage or by a piece of tile lining, or that the house was depressurized by fans and fireplaces and a strong downdraft was established in the 10 meter exterior masonry chimney. The DHW heater only spilled for 20 seconds against a 6 Pascal house depressurization.

o It was thought that there was little to learn from blocking the chimney of these oil appliances, other than determining the extent to which homeowners will sacrifice air quality in the name of science.

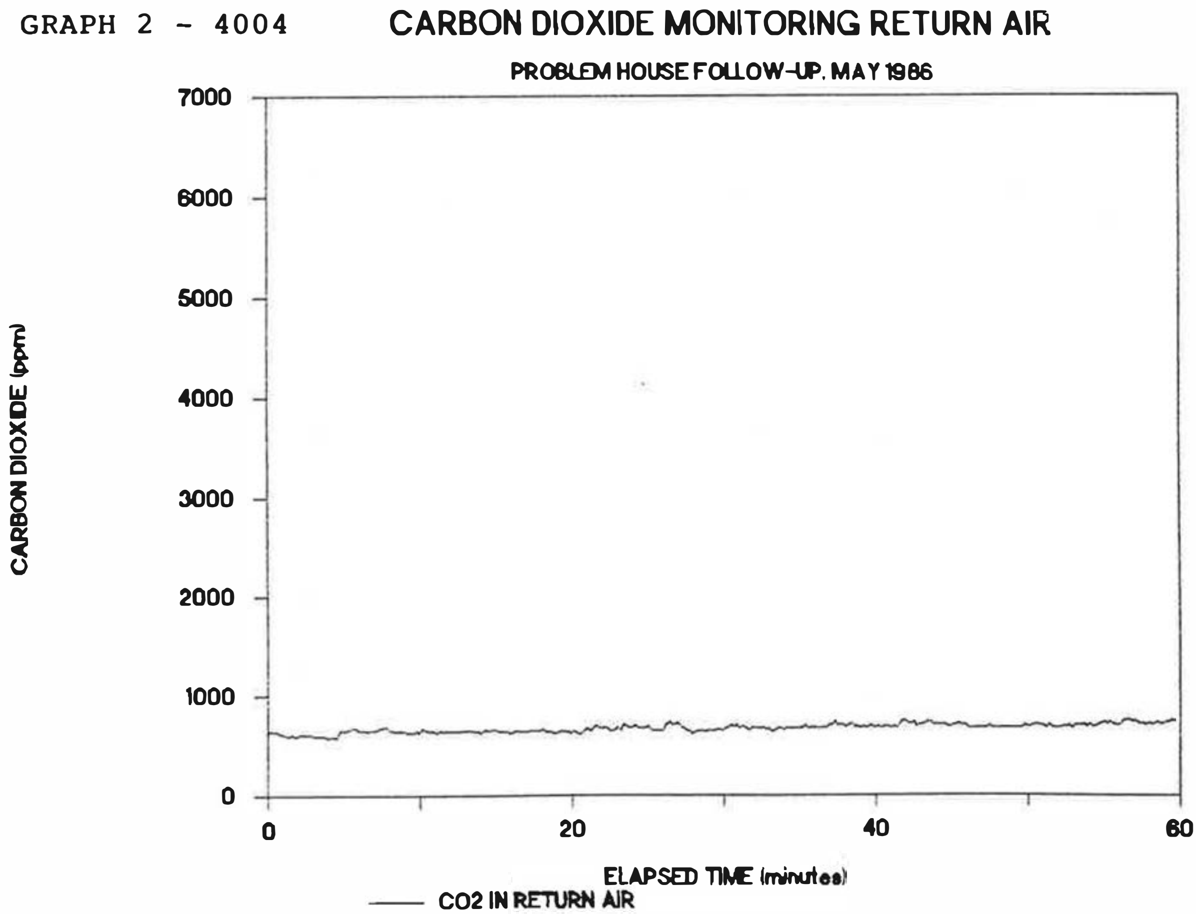
o If more time had been available in the house, it would have been interesting to cycle the appliances with and without the house being depressurized.

o This house showed the difficulties in simulating a failure event in an oil-fired appliance in summer. Once the appliance has been fired, both the mass of the chimney and the mass of the heat exchanger retain their heat for long periods, and no easy means exists for cooling. The safety check and diagnostic procedures involved firing the appliances, and hence precluded the simulation of an accurate failure event.

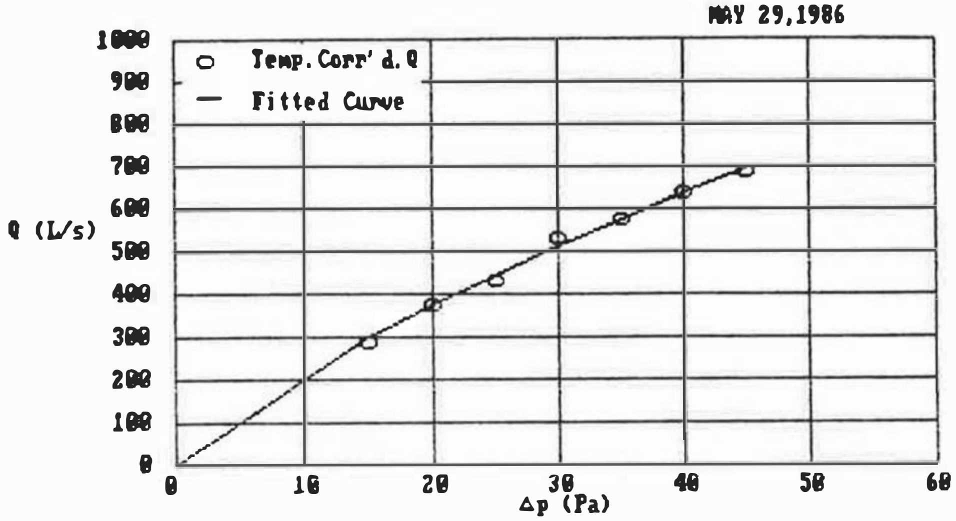
GRAPH 1 - 4004



GRAPH 2 - 4004



AIR LEAKAGE PROFILE   HOUSE NO. 4004



AIRTIGHTNESS TEST RESULTS
(AS PER CGSB DRAFT 12)

May 30/86

Ext.Temp. = 26 C   Wind Speed = 0 km/h

Envelope Area = NOT AVAILABLE   Volume = 672 m^3

PRESS. (PA)	TI (C)	FLOW(L/S) MEAS'D.	ADJ'D.	FITTED	RELATIVE ERROR(%)
15.0	22.0	281.90	293.08	302.29	3.15
20.0	22.0	365.40	379.89	376.49	0.89
25.0	22.0	417.60	434.16	446.37	2.81
30.0	22.0	513.30	533.65	512.99	3.87
35.0	22.0	556.80	578.88	577.02	0.32
40.0	22.0	616.00	640.42	638.90	0.24
45.0	22.0	662.90	689.18	698.98	1.42

C = 38.29097   n = .762979

E.L.A. = 0.0891 m^2   N.L.A. =NOT AVAILABLE

Q @ 10Pa = 221.86 L/S   Q @ 50Pa = 757.49 L/S

Air Change per Hour @ 50Pa = 4.058

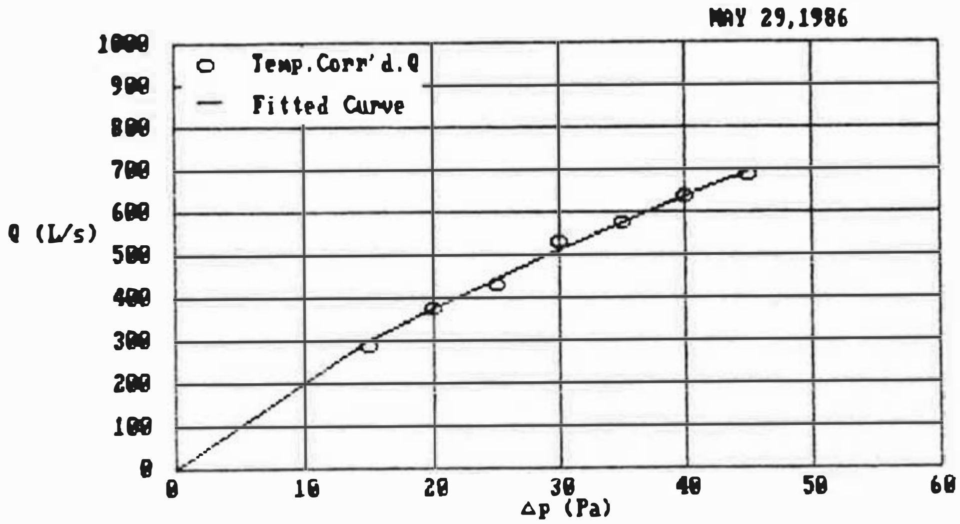
SXX= 3.238884E+11   SXY= 2.4712E+11

SYY= 1.900523E+11   SYX= 12.50849

Correlation Coefficient= .9960329

Relative Standard Error = 3.79%

AIR LEAKAGE PROFILE   HOUSE NO. 4004



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Relative Standard Error = 3.79%

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

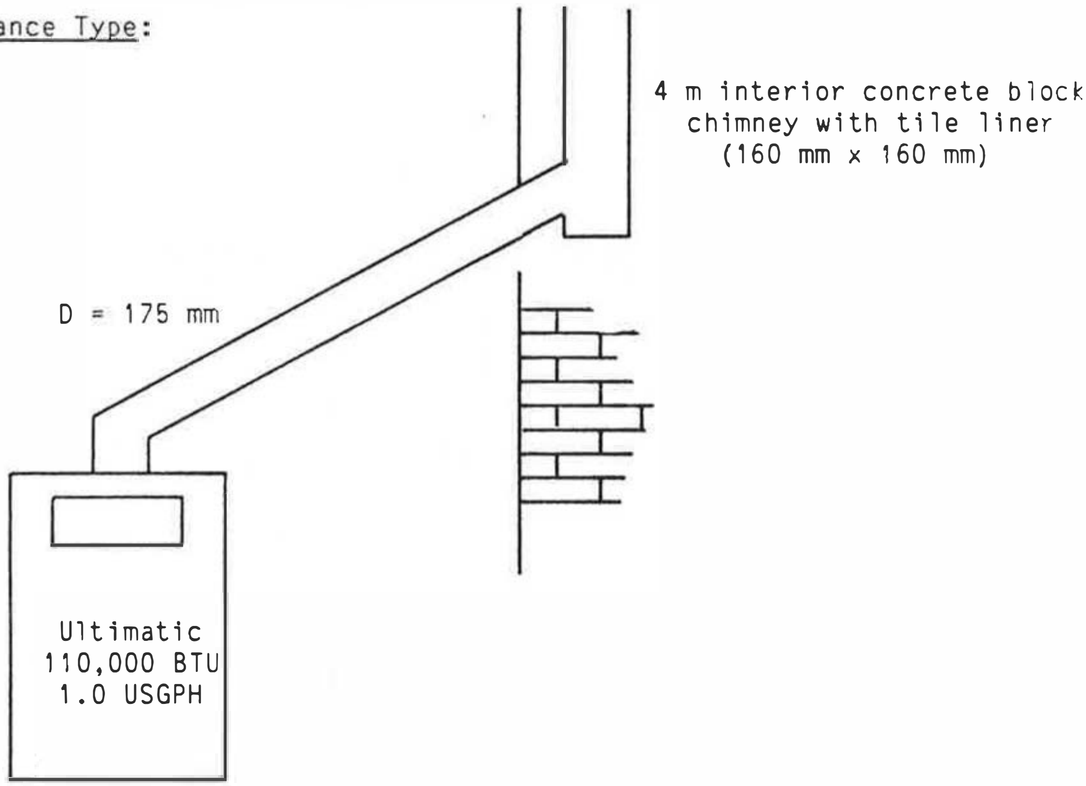
HOUSE NO: 1128 (VANCOUVER)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 71°
DHW - 0

House Type: One storey with full basement
1960-1975
Natural ELA @ 10 Pascals = 1259 cm²
Natural ACPH @ 50 Pascals = 9.15

Appliance Type:



More than 20 years old

Competing Exhaust Systems:

1 - Stove top barbecue fan
1 - Clothes dryer

Fireplace:

2 - one open brick

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted H.D. - 9.7 Pa
H.D. Limit - 5 Pa
House prone to venting problems.

2) Inspection:

Extremely yellow flame; rumbling at start-up; puffing causing spillage at barometric damper.

3) Venting Systems Test:

H.D. fans - 2.7 Pa
H.D. fans plus fireplace - 6 Pa
Fans plus both fireplaces caused house depressurization to exceed H.D. Limit for oil furnace.

4) Total Flue Draft:

Full Operation = 17 Pa.
Standby = 3 Pa.

5) Spillage Observations:

Furnace spilled for less than 30 seconds with fans operating in a tight house.
Continued to puff and spill for several minutes sporadically.

6) Heat Exchanger Test:

Moderate leakage detected.

7) Questioning of Occupant:

Unaware of any problems.

Failure Event Description and Simulation: House 1128

Researchers were unable to simulate conditions that would cause the chimney to spill during start-up, at least the duration and quantity of spillage necessary to change a 71°C dot on the detector. Levels slightly increased during start-up, but quickly dissipated. Depressurization of the house to 6 Pascals did not increase back puffing or spillage.

A recurrent problem with simulating failure events in oil-heated houses was keeping the appliance and chimney cool. The safety checks required the firing of the appliance. Once the interior chimney is warmed it takes hours to cool down. It was not possible to wait for the cooling down process before trying a simulated failure event. Neither is it possible to simulate a failure without first diagnosing the problem.

Conclusions and Comments: House 1128

o This house appeared to have both a restrictive chimney and an over-pressurized combustion chamber. A 175 mm in diameter flue connector joined a 160 by 160 mm concrete block chimney at right angles. The rumbling and backpuffing for the first several minutes of operation were likely due to restriction of the chimney and excess air supply to the furnace by the burner fan.

o Once the appliance was turned off, the barometric damper would swing from a down position to the horizontal position indicating that the burner fan was pressurizing the flue pipe.

o The temperature of the barometric damper swing plate never exceeded 54°C during a 20 minute operation. This would suggest that in colder weather the back puffing may have been aggravated and caused the 71°C dot to be changed.

o A careful tuning of the appliance may reduce the rumbling by reducing the burner fan supply. If the chimney cannot handle the flow from this furnace, then the nozzle size could be reduced and air supply cut back further.

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

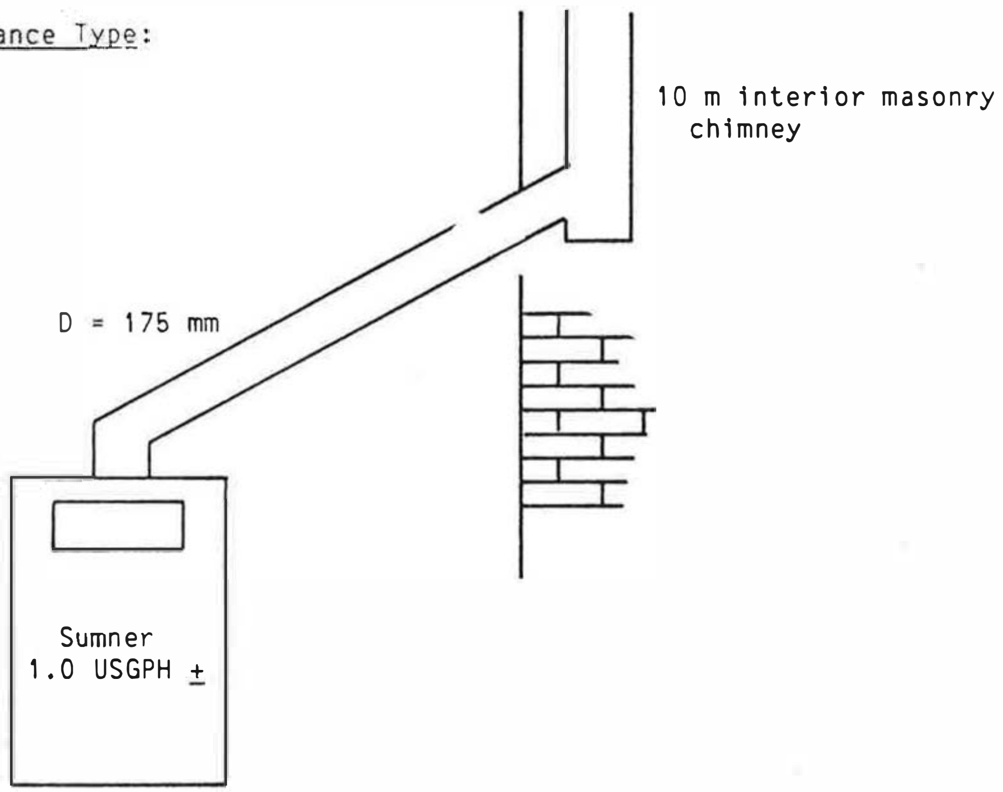
HOUSE NO: 5071 (PEI)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 121°C
DHW - 0

House Type: Two storey with full basement
1900-1945
Natural ELA @ 10 Pascals = 1510 cm^2
Natural ACPH @ 50 Pascals = 10.25

Appliance Type:



Less than 5 years old

Competing Exhaust Systems:

1 - Kitchen range hood fan
1 - Bathroom fan
1 - Clothes dryer

Fireplace:

1 - Open brick fireplace

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted H.D. - 6.4 Pa
H.D. Limit - 7 Pa
House is prone to venting problems.

2) Inspection:

Fuel odours present; damper imbalanced; soot covering appliance, surrounding walls and ceiling; some build-up of soot in chimney.

3) Venting Systems Test:

H.D. fans - 1.5 Pa
H.D. fans plus fireplace - 3.5 Pa
Depressurization caused by fans and fireplace exhaust does not exceed H.D. Limit for appliance.

4) Total Flue Draft:

Full Operation = 30- Pa.
Standby = 12 Pa.

5) Spillage Observations:

No spillage observed.

6) Heat Exchanger Test:

N/A

7) Questioning of Occupant:

Sooting and spillage likely caused by a delivery of oil with water contamination.
Freezing of oil line caused puffing and sooting during winter.

Conclusions and Comments: House 5071

o The Venting Systems Test did not uncover a problem in this house. However, discussions with the homeowner uncovered a likely cause of spillage. A delivery of water contaminated oil during the winter had caused the appliance to malfunction with major back puffing. The homeowner commented that he had noticed the appliance spilling during this period, although he had not noticed when the dots on the detector had turned.

o This house had removable wooden storm windows that had been removed for the summer. It is expected that the house would have been much tighter and hence more prone to venting failure if the windows had been on. This raises the question of whether it is valid to test a house without the storm windows in place.

o If the amount of soot in the basement was an indication of the amount of spillage that occured, it must have been considerable.

o The exterior portions of the masonry chimney were in extremely poor condition.

o It was difficult to determine what rooms to include in the envelope, and what rooms to exclude.

o This appliance had a short flue connector (.75 meter) which appeared to be tight. The standby draft was 12 Pascals, which emphasized the difference between forced air oil furnaces with exterior chimneys, and an oil boiler with an interior chimney. The current H.D. Limit of 5 Pa is probably too low for this kind of system.

o A short simulation was carried out in this house to determine whether the appliance was spilling into the house. No signs of spillage were recorded and the simulation was aborted.

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

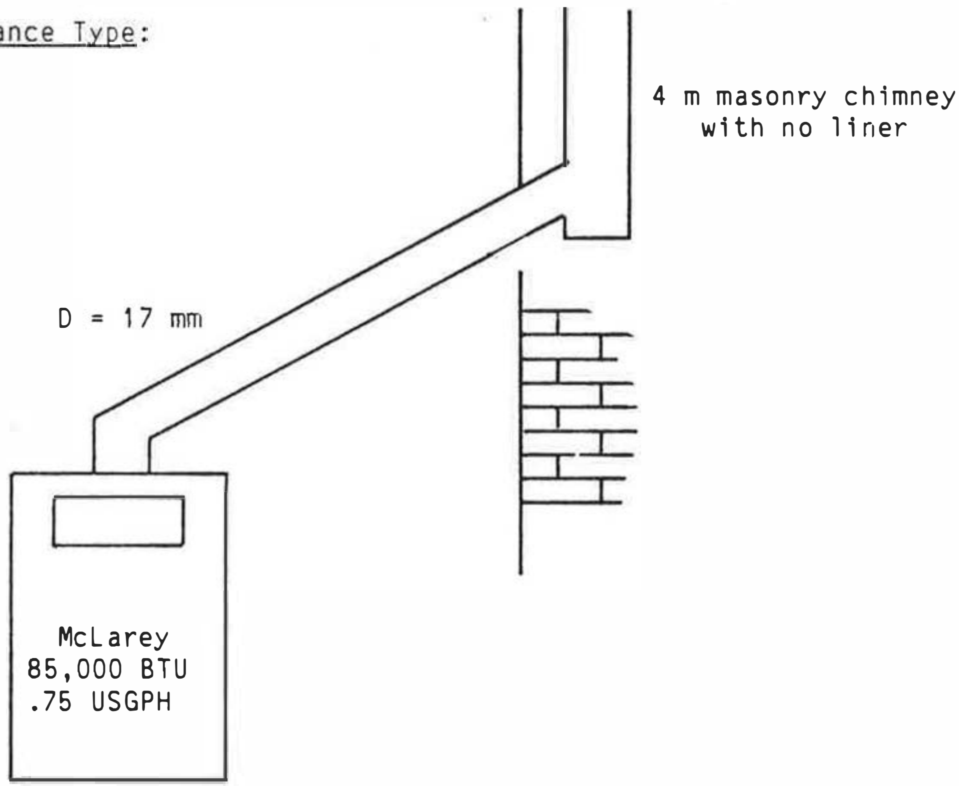
HOUSE NO: 5027 (PEI)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 121°C

House Type: One storey with full basement
1945-1960
Natural ELA @ 10 Pascals = 670 cm^2
Natural ACPH @ 50 Pascals = 7.5

Appliance Type:



More than 20 years old

Competing Exhaust Systems:

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

H.D. Limit - 4 Pa
Not prone to venting failure.

2) Inspection:

Furnace rusted on base; inspection port plugged with tin foil; completely deteriorated tile liner; no down-sizing of furnace flue connector with addition of energy-efficient burner; chimney cracked and falling apart.

3) Venting Systems Test:

No fans or fireplace.

4) Total Flue Draft:

Full Operation = 8 Pa.
Standby = 0 Pa.

5) Spillage Observations:

Slight spillage at start-up.

6) Heat Exchanger Test:

Major leakage.

7) Questioning of Occupant:

Occupant had noticed smoke alarm being set off.
Also remembered that she had been told furnace had a cracked heat exchanger three years ago.

Conclusions and Comments: House 5027

o The exterior masonry chimney had a vertical crack extending for 90% of the total length. A furnace technician, who was present to comment on the usefulness of the checklists, suggested that it could have been a lightning strike (it had that appearance). A far more plausible explanation is that a drastic temperature difference between the side closest to the house and the side exposed to frigid temperatures had caused the chimney to split down the centre.

o The furnace technician had visited the house on a yearly maintenance call and had found the chimney 75% blocked with fine red dust. They had removed 5 gallons of this dust from the chimney. The top of the chimney indicated that the chimney had a tile liner. The majority of this liner must have crumbled due to temperature differences and icing and this is what must have been removed from the chimney by the furnace technician.

o The oil furnace had a two year old Riello burner. The Riello is an energy efficient burner that was retrofitted to the furnace under a government grant program and installed by a firm specializing in energy conservation measures. The furnace technician discovered that the burner had not been set up properly. In particular, the flue connector had not been down-sized to match the lower temperatures and flow from this energy efficient burner. After several minutes of appliance operation, a hand could still be comfortably placed on the flue connector. Not only was the output temperature of the flue gas low, but the heat loss must have been considerable form this large (175 mm) flue pipe.

o The low flue gas temperature, combined with an exterior chimney location, would cause an abnormal amount of condensation in the chimney. This would explain why the chimney was falling apart; the chimney was probably unsafe to stand beside. (ESSO has recently announced that it will not be allowing the installing of efficient burners (Reillo type) without flue liners.)

o The furnace heat exchanger had a major leak. With the furnace cold and the house circulating blower operating, a steady blast of air was leaving the inspection port. The furnace technician plans to strip the appliance and find the leakage.

o The furnace technician intended to line the chimney with a flexible steel liner (single-walled). It is standard practice not to insulate between the liner and the masonry chimney in PEI. The technician also intended to re-mortar the chimney.

o Part of the problem with House 5027 can be traced to installing an energy efficient burner on an appliance that is over 20 years old without checking the heat exchanger for cracks, or down-sizing the flue connector. It appears that the retrofit in this house led to blockage of the chimney.

o A smoke alarm alerted the occupant to the presence of a spillage problem. (The value of smoke alarms in detecting spillage from oil furnaces was noted during the design phase of the Canada Wide Survey.)

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

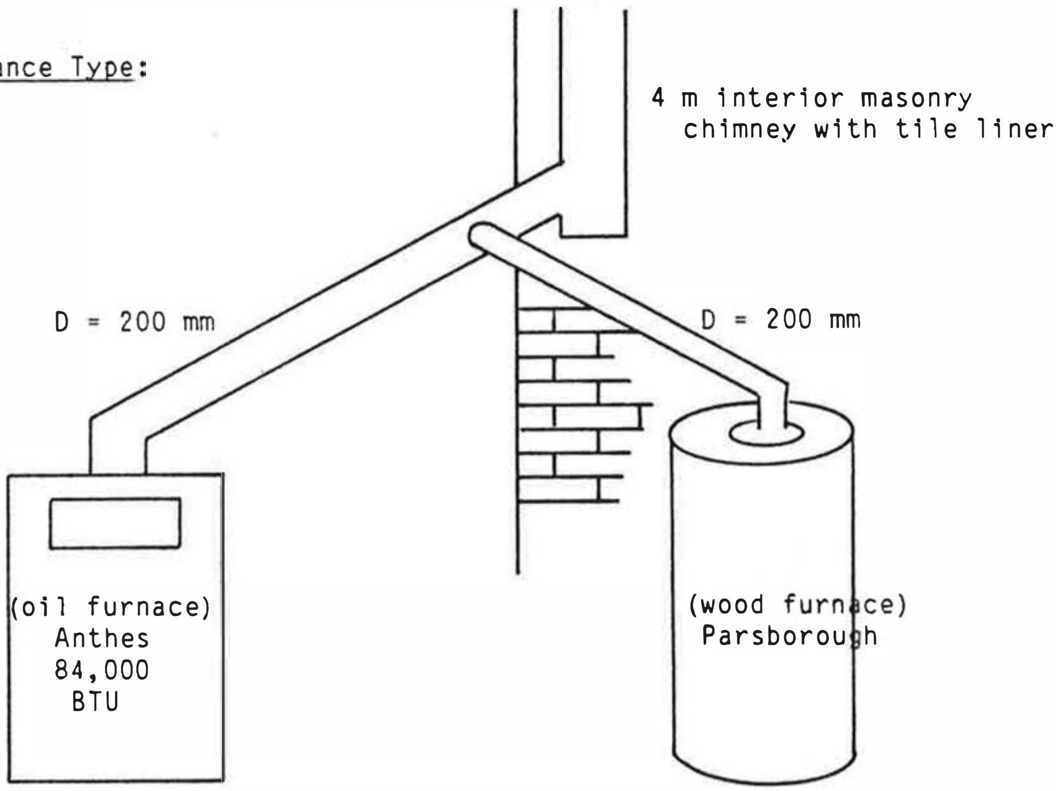
HOUSE NO: 5107 (PEI)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 71°C

House Type: One storey with full basement
1960-1975

Appliance Type:



10 to 20 years old

Competing Exhaust Systems:

1 - Kitchen range hood fan

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

H.D. Limit - 5 Pa
No fans or fireplace.

2) Inspection:

Imbalanced dampers on both appliances.
Soot build-up on barometric plates.

3) Venting Systems Test:

No fans or fireplace.

4) Total Flue Draft:

Full Operation = 30 Pa
Standby = 4 Pa

5) Spillage Observations:

No spillage of combustion gases in a tight house.

6) Heat Exchanger Test:

N/A

7) Questioning of Occupant:

Unaware of any problems.

Conclusions and Comments: House 5107

o This house did not appear to have a spillage or backdrafting problem. The dots on the detector had been set off because the plates of the barometric damper were not balanced. Both plates were badly sooted, which indicated neglect.

o The majority of the PEI oil houses that were visited had dampers that looked like they had never been adjusted. This would suggest that the furnace technicians in this area of the country do not believe that the adjustment of dampers is important. This, unfortunately, meant that many of our detectors were not indicating spillage in houses, but instead revealed only the malfunctioning of barometric dampers.

o The surface temperatures of the barometric plates were measured during the investigation; temperatures were found to exceed 71° Celsius.

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

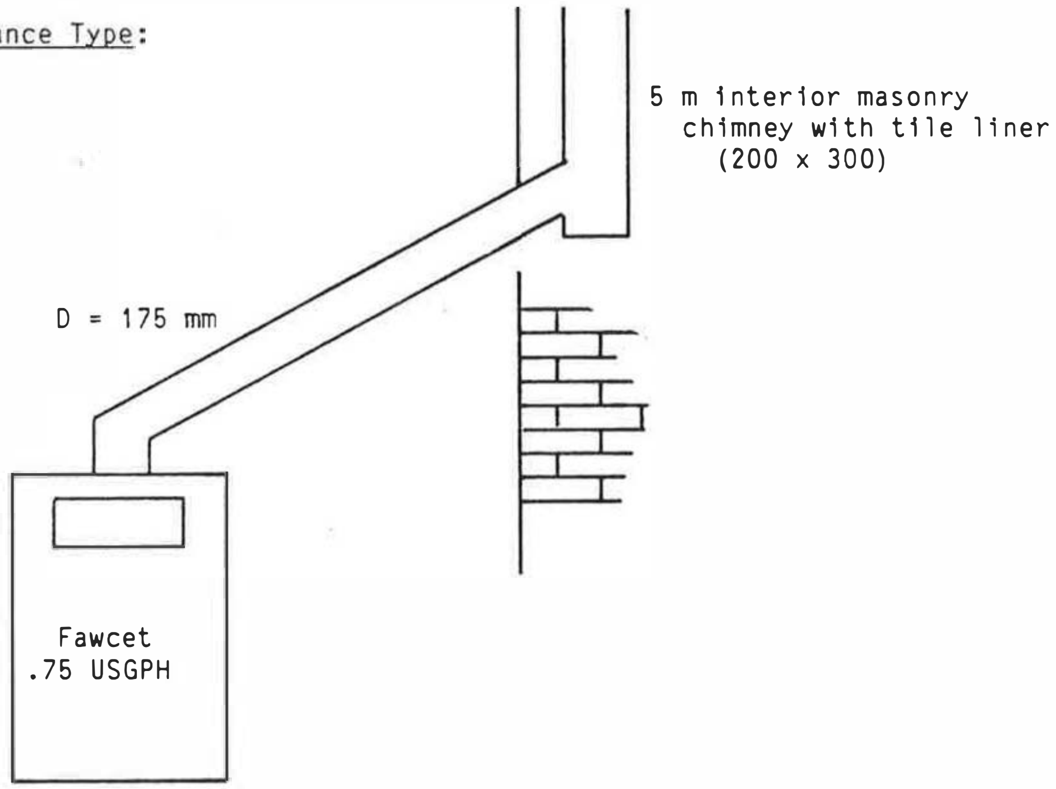
HOUSE NO: 5146 (PEI)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 121°C
DHW - 0

House Type: One storey with full basement
1945-1960
Natural ELA @ 10 Pascals = 800 cm^2
Natural ACPH @ 50 Pascals = 8.57

Appliance Type:



10 to 20 years old

Competing Exhaust Systems:

1 - Clothes dryer

Fireplace:

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted H.D. - 1 Pa
H.D. Limit - 4 Pa
House was not prone to venting failures.

2) Inspection:

Soot stains around inspection port.
Rubble in fire box interfering with flame.

3) Venting Systems Test:

Clothes dryer did not cause house to exceed H.D. Limit.

4) Total Flue Draft:

Full Operation = 12 Pa.
Standby = 30+ Pa.

5) Spillage Observations:

No spillage with a tight house.

6) Heat Exchanger Test:

Major leakage detected.

7) Questioning of Occupant:

Occupant not aware of any problems.

Conclusions and Comments: House 5146

o There was no obvious reason why this appliance might have experienced spillage of combustion gases around the barometric damper. During a 20 minute cycle the plate of the barometric damper never exceeded the temperature of the 54°C dot. The only possible explanation was downdrafting due to winds. The house had a short chimney (0.5 meters above roof at ridge) and tall trees surrounding the house.

o This is one of the few PEI houses that had a properly balanced barometric damper.

o A close inspection of the firebox revealed that rubble was interfering with the flame. In combination with a cracked heat exchanger, this caused sooting around the inspection port.

o The heat exchanger test was found to work the best with a cold heat exchanger. It would be an advantage for users of the test to request that householders turn off the furnace several hours before testing time.

o The smoke pencil showed obvious leakage through the heat exchanger.

o If the spillage detectors can be trusted to indicate spillage problems, as opposed to faulty dampers, it would allow the furnace technician to identify a spillage problem between annual service visits to the house. In cases where spillage had occurred, with no obvious cause, a down wind would be suspected and a possible retrofit might be a specially designed chimney top.

o The occupant was informed about the cracked heat exchanger and was advised to watch for signs of an increase in house dust, or sooting deposits on baseboards. This would be an appropriate time to replace this appliance.

RESIDENTIAL COMBUSTION VENTING FAILURES -
CASE STUDIES OF PROBLEM HOUSES

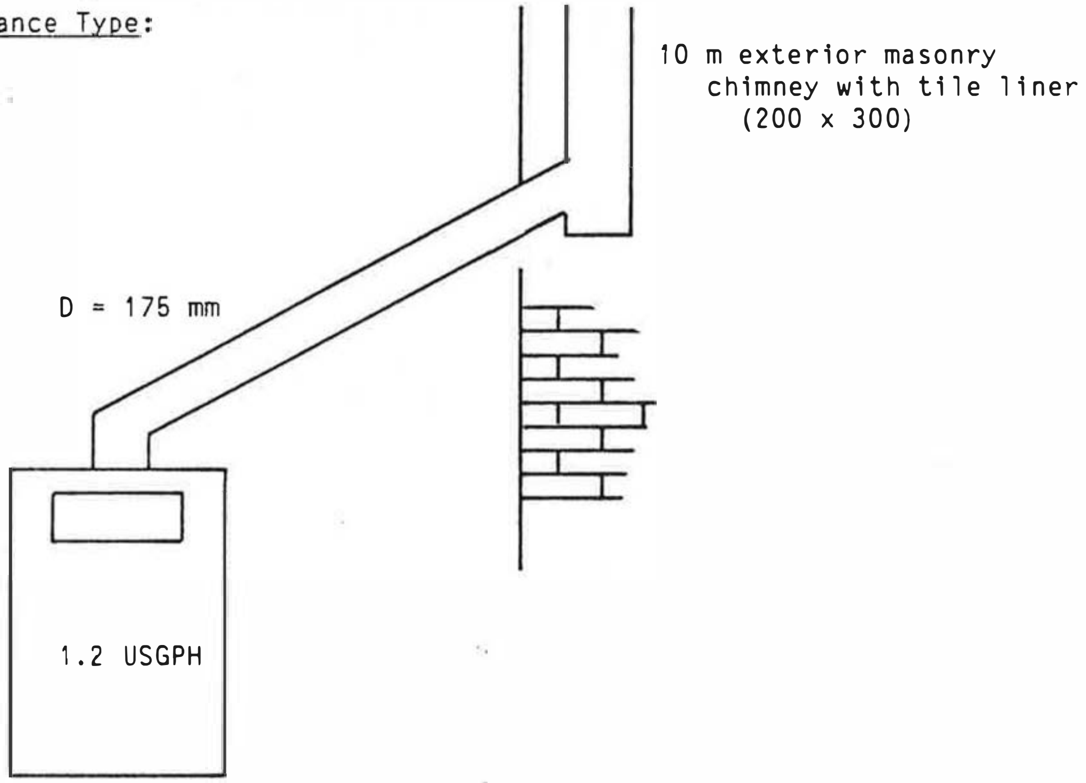
HOUSE NO: 5007 (PEI)

HOUSE PARTICULARS:

Spillage Detector Results: Furnace - 121°C
DHW - 0

House Type: One and a half storey with full basement
Post - 1975
Natural ELA @ 10 Pascals = 800 cm^2
Natural ACPH @ 50 Pascals = 4.4

Appliance Type:



5 to 10 years old

Competing Exhaust Systems:

1 - Kitchen range hood fan
1 - Clothes dryer

Fireplace:

RESULTS OF SAFETY CHECK

1) Preliminary Assessment:

Predicted H.D. - 2.6 Pa
H.D. Limit - 4 Pa
Not prone to venting problems.

2) Inspection:

Soot build-up in flue connector.

3) Venting Systems Test:

H.D. fans - 4.5 Pa
With all fans operating, house depressurization exceeds H.D. Limit for appliance.

4) Total Flue Draft:

Steady State = 7 Pa.

5) Spillage Observations:

Slight spillage for more than 30 seconds with fans operating in a tight house (spilled for 10 minutes).

6) Heat Exchanger Test:

No perceptible leakage.

7) Questioning of Occupant:

Occupant unaware of any problems.

Conclusions and Comments: House 5007

o This oil furnace had an especially weak chimney. After 10 minutes of operation the total flue draft was only 7 Pascals. This tall exterior masonry chimney was prone to problems.

o The appliance spilled for 10 minutes when started up against a 4.5 pascal house depressurization. Most of the spillage occured at the barometric damper.

o A very brief failure simulation was run on this appliance. Carbon dioxide levels rose very slowly and dropped off quickly indicating that the quantity of spillage was small. Maximum levels reached were 1800 ppm CO_2.

o A possible remedial measure for this house would be a chimney liner and sealing of the flue connector. This would strengthen the chimney system.

o The CO_2 levels were quite high in this house the way it was found (1000 ppm). The house had a small volume (443 m^3) and a relatively small ELA (800 cm^2). The burning of pilot lights on a propane burning stove during the day when the house was closed up and not occupied, may have caused CO_2 levels to reach 1000 ppm.

RESIDENTIAL COMBUSTION VENTING FAILURE

A SYSTEMS APPROACH

PROJECT 6

CASE STUDIES OF PROBLEM HOUSES:

A FOLLOW-UP TO THE CANADA WIDE SURVEY

APPENDIX B

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

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_2, 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 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.