Residential Combustion Venting Failure - A Systems Approach

Project 1, Phase 1

Canada-wide Survey; Development and Testing
of Spillage Detectors

RESIDENTIAL COMBUSTION VENTING FAILURE

A SYSTEMS APPROACH

FINAL TECHNICAL REPORT

PROJECT 1, PHASE 1

CANADA-WIDE SURVEY;

DEVELOPMENT AND TESTING OF SPILLAGE DETECTORS

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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.

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RESIDENTIAL COMBUSTION VENTING FAILURE - A SYSTEMS APPROACH
COUNTRY-WIDE SURVEY: DEVELOPMENT AND TESTING OF SPILLAGE DETECTORS

This project was funded by the Canada Mortgage and Housing Corporation and the Panel for Energy Research and Development, but the views expressed are the personal views of the author(s), and neither the Corporation nor PERD accepts responsibility for them.

SUMMARY

This research has taken place as part of a project funded by Canada Mortgage and Housing Corporation on Residential Combustion Venting Failures - A Systems Approach. The objective of this phase of the research was to develop monitoring devices for installation in random houses across Canada. These devices were to provide evidence of significant combustion gas spillage from oil or gas furnaces and water heaters, and from wood fireplaces. By identifying spillage events in typical housing, the survey permits follow-up tests on houses experiencing problems and provides a statistical basis of evaluating frequency and severity of spillage problems.

The research budget required that total costs per house for survey devices not exceed $10.00 and that the materials be suitable for installation by untrained individuals. A wide range of devices were evaluated in laboratory and house settings, including: CO detectors, minimum/maximum thermometers, smoke detectors, heat sensitive materials and various types of switches and counters. Most of the technologies were quickly rejected due to high cost or inconvenient installation procedures.

For gas furnaces and water heaters, the most appropriate technology was found to be the use of heat sensitive dots mounted on a piece of heat resistant plastic and stuck to the top or bottom of the dilution air opening so as to intercept the flow of spillage gases. In preparation for the design and placement of prototype heat sensors, extensive testing was conducted in two test houses in Vancouver. Gas temperatures were mapped at many locations around the furnace and water heater while chimney spillage was induced by depressurizing the house or blocking the chimney. Prototype sensors were then developed and tested in situ under a variety of conditions, and were shown to successfully indicate spillage after about 15 seconds of operation under most conditions. Each detector incorporated a series of heat sensitive dots at different indicating temperatures, which made possible an assessment of the severity of spillage by counting the number of dots changing from white to black. The extensive testing approach was necessary in order to develop a data base for properly interpreting the results of this survey using detectors.

The greatest success with detecting spillage from oil furnaces was achieved with using conventional ionization-type smoke alarms hung above the barometric damper. Budget limitations precluded the use of smoke detectors during the survey, however. Instead, a spillage detector for oil furnaces was developed using a series of heat sensitive dots - similar to the detector for gas appliances. Extensive testing on one test house indicated that the swing plate of the barometric damper is the most suitable location for a heat sensitive detector. Field trials of

the dots on three additional houses showed that this approach was capable of detecting spillage or poor draft problems in conventional oil furnaces. The dots are mounted on foil tape with a peel-off adhesive backing. The detector is designed so as to be stuck to the upper exterior portion of the swing plate of a barometric damper.

Fireplace spillage detectors could not rely on heat sensitive materials because of the extreme temperature range that can be found in front of a fire under normal operating conditions. Locating heat sensitive materials above the fireplace was also unsuccessful, because when spillage occurs from a fireplace, the temperatures above the fireplace opening remain quite cool. Instead the fireplace spillage detectors utilize the smoke detectors found in conventional house smoke alarms, and carbon monoxide detectors. The smoke and CO detector are connected to a pulse counter, and a time totalizer (as opposed to an alarm) and mounted above the centre of the fireplace at the location of the mantle. Concentrations of smoke and CO correspond with spillage from the fireplace, and are recorded on the pulse counters.

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1.0 INTRODUCTION

DEVELOPMENT AND EVALUATION OF SURVEY TECHNOLOGY

This report describes the development and evaluation of spillage detection devices used during a Canada-wide survey of combustion venting hazards. The Canada-Wide survey was a component of: Residential Combustion Venting Failures - A Systems Approach, a research project funded by the Canada Mortgage and Housing Corporation.

As part of this research on Combustion Venting Failures, a survey of random houses across Canada is to be conducted for the purpose of assessing the frequency of combustion gas spillage events in Canadian housing, and for the purpose of identifying problem houses where the diagnostic and remedial measures developed during the project can be evaluated.

In preparation for the Canada-wide survey, it was necessary to undertake research into appropriate technologies for detecting spillage. The research project budget and design required that the total cost for detectors not exceed $10.00 per house, and that the technology be suitable for installation by untrained persons. In order for the results of the survey to be meaningful, the devices needed to be capable of leaving permanent evidence of any significant combustion gas spillage from oil or gas fired furnaces and water heaters and from wood fireplaces.

Because the focus of the overall research project is primarily on "Systems Failures", it was essential that detection devices be capable of identifying spillage due to house depressurization and wind downdrafts, as well as spillage resulting from failures with the venting system such as chimney blockage, poor chimney design, or heat exchanger leakage. It was also necessary that devices differentiate between significant spillage events and minor spillage. Previous experience with research on chimney performance in houses (Reference 1) had shown that short-term spillage at start-up was a common event in many houses, both for oil and gas fired appliances and for wood fireplaces. The objective was to develop devices that detected spillage in excess of the 15 or 30 second start-up period.

2.0 PROCEDURE

The research conducted into spillage detection devices was performed in two phases. Firstly, it was necessary to establish what the most appropriate detection strategy would be for each type of appliance; and second, it was necessary to thoroughly evaluate the performance of the selected technology in order to optimize design and installation procedures, and to provide an empirical basis for interpretation of the survey results.

An extensive review was carried out to identify all possible detection devices. This review included contacting groups who had previously developed or evaluated such technologies including APTECH Consulting, Co-Sensor International and the Canadian Gas Research Institute. In addition, reference was made to the findings of previous research into monitoring devices and the physics of spillage events as presented in previous reports on combustion ventilation safety produced by Sheltair Scientific for CMHC (References 1 to 6). Other documents were also found very useful in evaluating the suitability of different technologies. These included a report by APTECH Detectors Inc. on the Furnace Alert Combustion Backdraft Indicator (Reference 7), and unpublished data presented by the Canadian Gas Research Institute on the development of a spillage detector for gas furnaces (Reference 8).

The next step was to purchase or construct a series of prototype devices for evaluation in labs. Technologies considered and rejected during this process included minimum/maximum thermometers, disk and probe switches with counters, CO detectors, heat sensitive crayons and paints, heat sensitive vials and flow detectors. Each of these items was evaluated, but factors such as cost or safety, convenience, availability or accuracy prevented their use during the survey.

To better predict the performance of specific technologies in situ, it was necessary to conduct extensive testing on appliances operating in houses under various failure conditions. For this purpose, Sheltair selected four test houses in the Vancouver area for repeated field testing purposes. All four houses were occupied. Home owners were paid a monthly stipend to compensate for any inconvenience from repeated visits by field test personnel. The selection of appropriate houses was a difficult task, since it was desirable to have a range of conventional appliances, in reasonably tight housing stock. Assistance in this selection process was obtained from B.C. Hydro and from Imperial Oil.

Initial field testing involved the monitoring of temperatures in and around gas furnaces and gas water heaters during various failure modes. Temperatures were monitored by means of Sciemetrics Instruments 8082A Electronic Data Acquisition System, connected to 11 Type E thermocouples. An IBM compatible micro-computer was used to simultaneously log temperatures in various locations during each spillage event, and these temperatures were, subsequently, graphed and mapped to provide extensive information on the relative temperatures at different times and locations for each type of failure condition. Type E thermocouples have an operating range of 0 to 900°C, and were chosen especially because of their response characteristics and high resolution (+/-1.7°C). (A beaded 18 gauge thermocouple has a time constant of approximately 2.7 seconds). The use of a Sciemetric data logger for mapping temperatures greatly facilitated the research on appropriate detectors since extensive data could be collected and analyzed in a relatively short period of time. The data was stored on floppy discs, and later imported into a Symphony spreadsheet for graphical presentation.

Backdrafting conditions were simulated by depressurizing housing using a Retrotec door fan. Use of the door fan permitted repeated temperature monitoring at various intensities of backdraft. Chimney spillage was created by intentionally blocking the flue connector with sheets of aluminum foil. The foil was perforated in the center so as to minimize distortion in the gas flows. Blockage was typically calculated at 50%, 90% and 100% of the flue area. Oil furnaces were caused to backdraft and/or spill during temperature monitoring in a similar fashion to the gas furnaces and water heaters. In all cases, smoke pencils were used to better estimate the quantity of spillage occurring and the direction of flow.

The location of the thermocouples for temperature monitoring varied depending upon the appliance and the type of tests that were being conducted. Consequently, a Legend to temperature locations is provided on the graphs and tables in which the data is presented. Hand-held thermometers were used in conjunction with the data logging system to provide additional information on relative temperature in various locations and to suggest ways of designing a detector so as to increase sensitivity to low temperatures or short term spillage. For this purpose, a hand-held IMC Digital Thermistor Model 2200 was used for temperatures up to 140°C. A hand-held Taylor Model 9700 Type K thermocouple Digital Thermometer was used for temperatures above 140°C.

During fireplace monitoring, carbon monoxide levels were monitored in addition to temperatures and spillage flows, using an Interscan Digital portable CO Monitor connected to a Servodyne strip chart millivolt recorder.

In addition to the field testing in four test houses, prototype detector were evaluated in various other settings as seemed appropriate. Fireplace monitors were tested on houses where the spillage and noise created were not perceived as a problem. These tended to be the houses of research personnel. Oil furnace prototype detectors were evaluated on random houses while accompanying an oil furnace serviceman during his morning complaint calls.

To provide more detailed data on the response time of detectors, laboratory testing was conducted using propane burners and "facsimile" furnaces. A dilution air inlet was constructed out of cardboard and foil. A barometric damper was mounted on a flue connector T. These laboratory models permitted more controlled testing under a wide range of temperatures.

3.0 RESULTS

3.1 Survey Detection Strategy for Gas-Fired Furnaces

After a review of all possible detection strategies for gas furnaces, it was decided that the strategy with the greatest potential for success was to detect excess temperatures. Alternatives that were considered including detecting a rise in particle count, a rise in the concentration of combustion gases such as CO_2 and humidity, and a reversal in flow direction in the flue.

Detecting particles caused by spillage was rejected, primarily because natural gas is such a clean burning fuel. Previous field research on chimney backdrafting with gas furnaces had included locating a smoke detector directly in front of the dilution air inlet during backdraft spillage events. The smoke detectors had been found to melt before detecting any excess particle count in the spillage gases.

Detecting combustion gas concentrations was an approach rejected primarily because of cost. The easiest combustion gas to monitor would likely be carbon dioxide since it is always present in concentrations well above ambient. However, there are no low cost CO_2 detection methods that were both easy to install and capable of leaving permanent evidence of excess concentrations. Carbon Monoxide detectors cost less, but were not considered for gas furnaces. Previous testing had shown that the concentrations of CO combustion gases are extremely small, in most cases, and most spillage events would be overlooked by a strategy depending on Carbon Monoxide.

A flow detection system was another option rejected primarily on the basis of cost. Moreover, it would be necessary to interlock flow detectors with thermostats in order to detect flow reversal during furnace operation, since off-cycle backdrafting is a common event of less interest to the research project. The wiring of such a device in situ was felt to exceed the cost and installation limitations imposed on the detector design.

A variety of devices for detecting temperature were evaluated. Each of these is briefly described below:

Minimum/Maximum Registering Thermometers

Two different thermometers were obtained for evaluation: A Sybron Taylor Model 5458 - minimum/maximum registering thermometer and a Sybron Taylor maximum registering pocket thermometer - Model 21480-1.

The use of a thermometer offered the advantage of permanently recording the maximum temperature reached in the dilution air stream. Unfortunately, both these thermometers cost over $20.00.

The minimum/maximum thermometer, the cheapest of its type, was too large for our purposes. It was also difficult to read, difficult to zero and surrounded in a plastic case that was not designed for high temperature environments such as might be experienced during a spillage event. The staff engineers at Taylor Industries were consulted about temperature limitations. It was their opinion that if temperatures exceeded the range of a mercury thermometer, the possibility existed of the thermometer exploding with subsequent loss of mercury into the house - an unacceptable scenario.

The maximum registering thermometer offered a suitable temperature range and if purchased in open-faced armored cases should remain safe from explosion or other damage to temperature. Unfortunately, these armored case thermometers were extremely expensive, ranging from $60.00 to $100.00.

The $25.00 Blue Derlin pocket thermometers could have been allowable within the project budget (assuming major bulk/wholesale discounts). However, the temperature ranges were too limited for the furnace gases, and there was no guarantee that the thermometer would hold together during a serious spillage event, since the plastic and glue was only guaranteed to 124°C.

Disk and Probe Switches

Previous research work by Sheltair (Ref. 3) and by the Canadian Gas Research Institute (Ref. 7) had indicated that snap thermodiscs have good potential for use as spillage detectors on furnaces. The snap thermodiscs are bimetallic switches with factory-set operating temperatures. The disc housing has two terminals, and the switch is typically used to control such appliances as clothes dryers and electric baseboard heaters. Thermodiscs are available with probes, consisting of fluid-filled copper tubes of varying lengths, which permit the sensing of temperatures over greater areas, and at locations up to 1 meter distant from the thermodisc.

One advantage to the use of probes and discs is their low cost. Bulk orders of thermodisc can bring prices within the $2.00 to $3.00 range per unit. Discs and probes are available at temperatures as low as 44°C. The response time of the switches is typically delayed between 30 seconds and 3 minutes, which gives an adequate time buffer so as to avoid detection of the cold start-up spillage. A variety of temperature ranges of discs are widely available.

On the basis of previous research on spillage alarms, it was expected that a manual reset probe hung from the upper corner of a dilution air inlet could consistently detect significant combustion gas spillage. The manual reset button would leave a permanent indication of spillage since the button protrudes slightly from the disc following activation of the switch.

Some of the difficulties with the use of probes and switches for spillage detection in this project include: a long order time for temperature probes and disks; the difficulty that might be encountered by an uninitiated householder trying to determine whether the reset button is protruding; the need for several probes and switches on each appliance in order to determine varying intensities or severities of spillage; and the generally poor response time of disk and probes to slight quantities of spillage such as often occur during marginal failures.

An alternative application of a thermoprobe or thermodisc is to connect the switches to a counter and power source, thereby permitting the counting of spillage events. This approach was felt to hold considerable potential for use during the survey, except that the cost exceeded the $10.00 budget by a factor of three. The lowest cost pulse counter that could be obtained on the market was a Hecon non-zeroing mechanical counter, priced at approximately $22.00. In addition, the devices would have required fasteners, wiring, battery, and probe. It was felt that this approach was best used as a follow-up measure for installation in houses where some indication already existed that spillage was occurring. Thus, the added information obtained from counting the spillage events would be worth the extra expense of purchasing a counter.

With sufficient lead time, electronic counters could be used in place of mechanical counters, and could monitor the thermodiscs, using a solid-state technology and a battery powered, push-button LED readout. Cost estimates for 9V DC solid state counters again exceeded the budget; solid-state thermodisc counters ranged from $50.00 to $17.00 a piece.

Heat Sensitive Crayons & Chalk

Heat sensitive crayons and chalks were purchased and evaluated. At a preset temperature this material turns dark, drips, and becomes glossy. There were two difficulties encountered. The first was the application of the chalk or crayon to the furnace - since it is difficult to write on metal with this material. Secondly, the interpretation of a spillage event requires knowing the difference between melted and unmelted materials.

A heat sensitive paint was obtained for evaluation. The paint type was Omegalaq at an indicating temperature of 66°C. The paint is applied to a surface as a thin smear, using an applicator brush and allowed to dry thoroughly. When exposed to a temperature above the indicating temperature, the paint liquifies in a similar manner to the crayons and chalk. Thereafter one can determine if the temperature has been exceeded by noting that the paint has dripped and has become darker and glossier than when originally applied. Although this type of indicating paint was very low cost, and easier to interpret than the crayons, it still presented problems of interpretation and application for untrained persons.

Heat Sensitive Dots

The most appropriate material for indicating a temperature rise caused by spillage from a gas furnace was found to be temperature sensitive labels or dots. The use of dots for this purpose was already being promoted by a company consulting on this project - APTECH Detectors Inc. APTECH had recently developed a stick-on plastic detector with a single dot indicator for purposes of alerting home owners to backdraft incidents in houses. A review of APTECH Detectors Inc.'s field testing and monitoring performance validation (Ref. 6), and discussions with Mike Monette, the President of APTECH, indicated high potential for the use of the APTECH

Detectors as part of the Canada-wide survey. Consequently, a large number of APTECH Detectors were purchased from APTECH Detectors Inc., and evaluated in the field test houses and laboratory tests by Sheltair.

In addition to the APTECH Detectors, a variety of heat sensitive dots were obtained from different manufacturers over a range of temperatures. A series of prototype detectors were made up to explore all possible alternatives. As a result of extensive testing on furnaces and on detector designs, some significant variations were made to the APTECH Detector design and application procedures. Eventually, a custom detector, more appropriate for research use, was produced for use during the survey.

The final design chosen for use in the Canada-wide survey is illustrated in Figure 1. The detector consists of a thin, rigid plastic strip, 100 mm long, 20 mm wide. The upper 37 mm of the strip has a peel-off self-adhesive backing which allows for easy application to the front of the furnace. The detector is designed to hang down into the flow of air through the dilution air inlet at approximately the upper centre of the inlet opening. On the cold side of the detector, away from the heat source, are four stick-on heat sensitive labels each containing a dot that turns from light grey to black when the specified temperature is exceeded. The dot indication temperatures are 38°C, 50°C, 71°C, and 121°C. The lower temperature dots are on the uppermost portion of the detector. In addition, a second 38°C dot is applied on the uppermost portion of the hot side of the detector.

The remainder of this section of the report describes the research undertaken for the purpose of optimizing detector design, and correlating dot changes with various degrees of combustion spillage.

Table 1

DESCRIPTION OF TEST HOUSES AND APPLIANCES
USED FOR EVALUATION OF SPILLAGE DETECTION TECHNOLOGIES

	House 1	House 2	House 3
Construction Date	1910	1930	1920
Number of Stories	1	2	1
Volume (M3)	585	450	600
Envelope Area (M2)	454	350	500
Floor Area (M2) (including basement)	234	160	250
Chimney Type	Masonry/ Clay Tile	Masonry/ Clay Tile	Masonry/ Clay Tile
Chimney Vertical Height	7 m	7 m	10 m
Chimney Internal Dimensions	150 X 275 mm	150 X 275 mm	150 X 275 mm
Furnace Make	Olsen Gas	Airco	Lennox
Furnace Size	110,000 BTU	Not Known	90,000 BTU
Furnace Age	2 years	12 years	17 years
DHW Heater Types	Giant	Sears and Giant	J. Wood
Fireplace Type	Woodstove	Open, Wood	Open, Wood

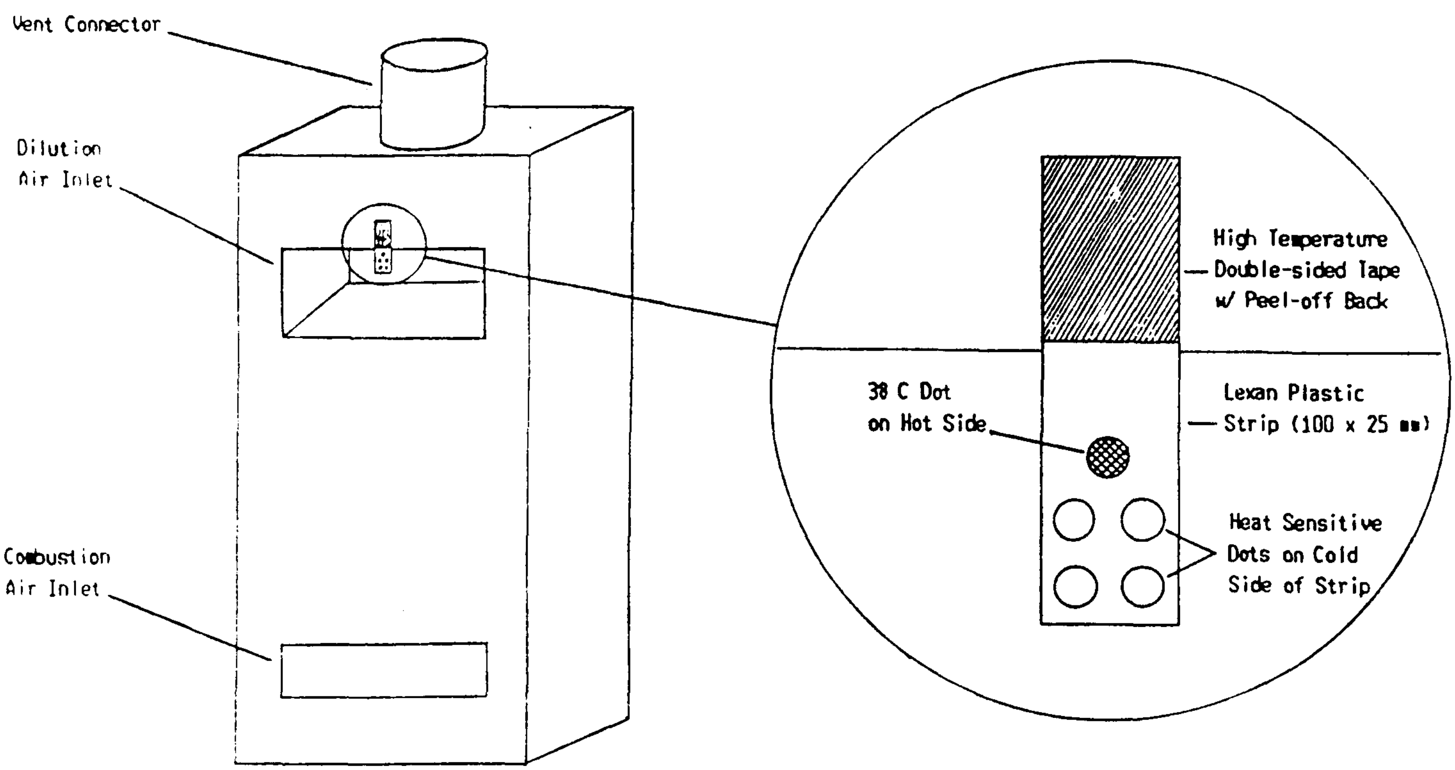


FIGURE 1: Dot Detector for Gas-Fired Furnaces

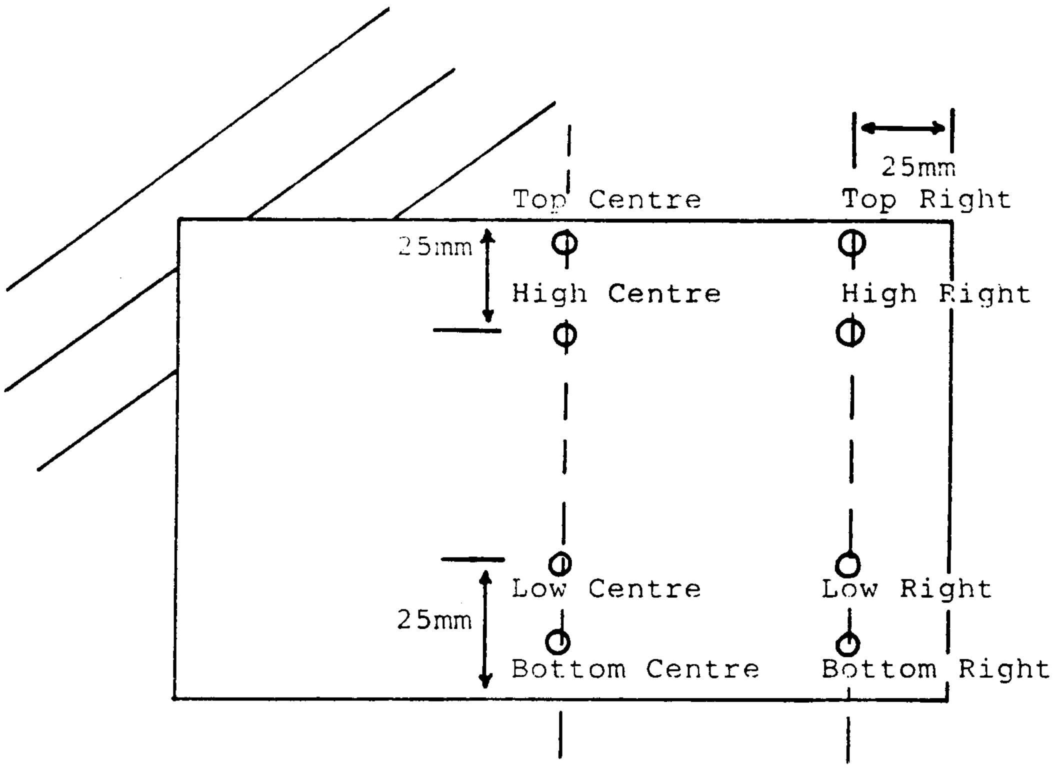


FIGURE 2: Location of Thermocouplers at the Face of the Dilution Air Inlet of a Gas Furnace

Test House No. 1

Backdraft at 10 Pascals House Depressurization
Temperature Indoors = 17.3° C
Temperature Outdoors = 0° C

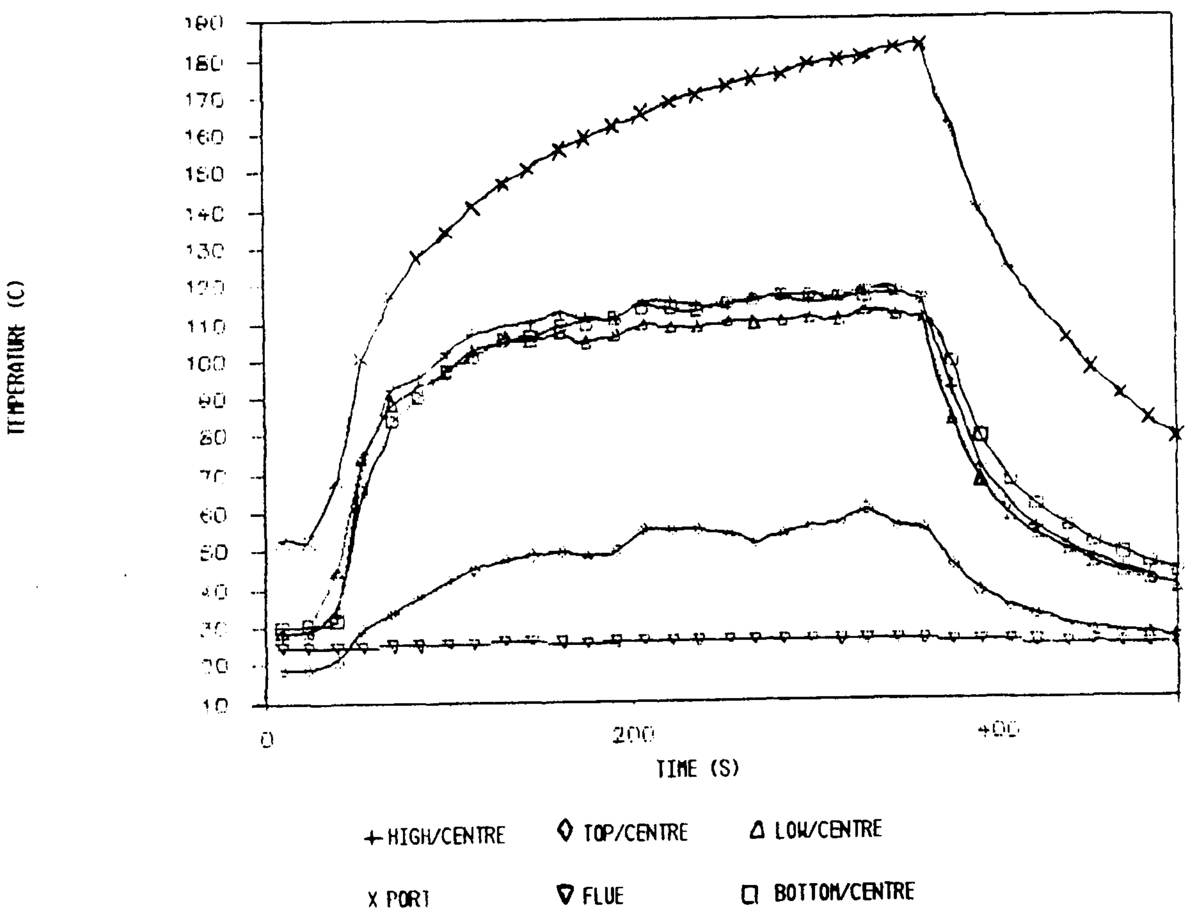


FIGURE 3: Typical Gas Temperatures for Backdrafting Gas Furnaces

Test House No. 1

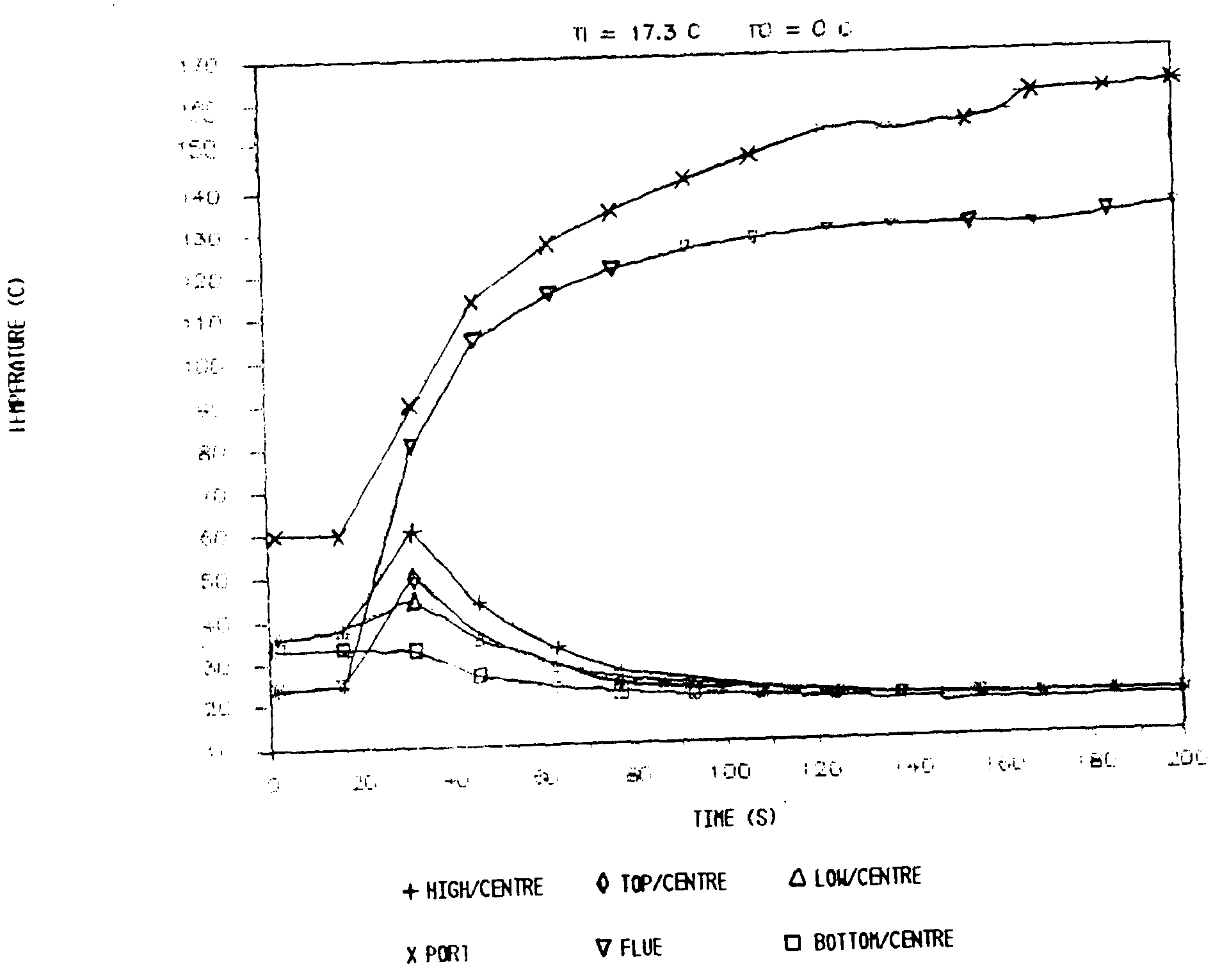


FIGURE 4: Gas Temperatures for a Gas Furnace that was Backdrafting and then Re-Established Proper Venting

less interest in the survey, and which is therefore important to distinguish from more continuous or severe spillage. Note that, under these conditions, the high/centre and top/centre are both hotter locations than any other on the dilution air inlet vertical centreline. Weak backdrafts and temporary backdrafts therefore tend to reach their peak temperatures at the upper portion of the inlet, whereas the stronger backdrafts, illustrated in Figure 3, reach peak temperatures at the lower portion of the inlet.

Figure 5 illustrates gas temperatures during spillage caused by approximately 80% blockage of the flue connector. Note that, even under partial blockage, the spillage gases reach a higher temperature than the flue connector. Under these conditions, the most extreme temperatures are those at the upper portion of the inlet. The spillage, due to blockage, causes very low temperature rises or no temperature rise at all at the lower portions of the dilution air inlet.

Table 2 presents a comparison of temperatures at key locations around the dilution air inlet after a period of 64 seconds of furnace operation. The key locations are high/centre, high/right and low/centre.

Test House No. 1

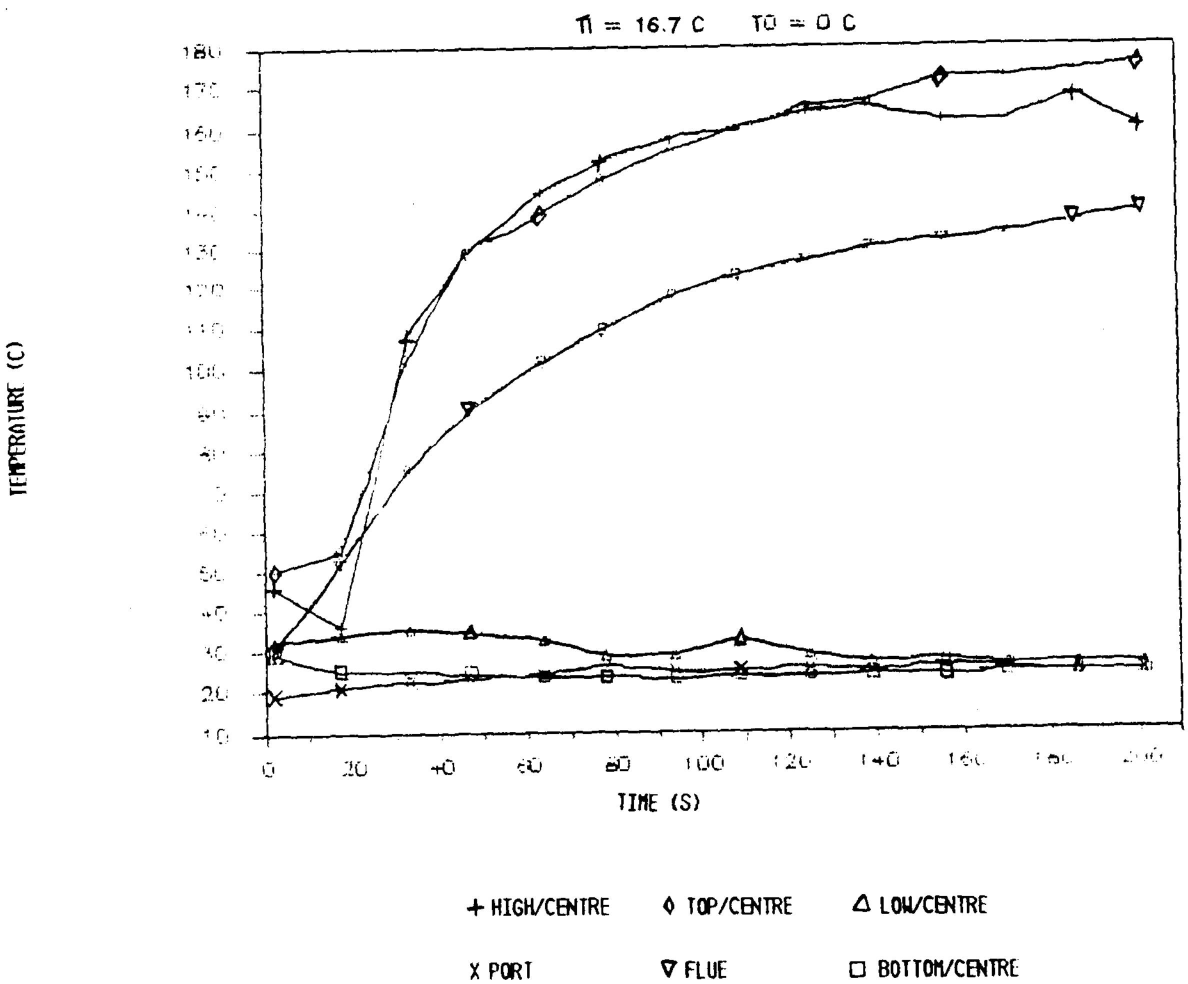


FIGURE 5: Gas Temperatures During Spillage Due to 80% Blockage of the Flue Connector

Table 2

A COMPARISON OF TEMPERATURES AT KEY LOCATIONS
AROUND DILUTION AIR INLET AFTER 64 SECONDS
OF FURNACE OPERATION
IN TEST HOUSE NUMBER 2

	Temperature (°C) Under Various Failure Modes						
Location	Back-draft (8 Pa)	Back-draft (15 Pa)	Short-term backdraft (5 Pa)	Backdraft (6 Pa) Leading to Partial Spillage	Full Block	90% Block	50% Block
High Centre (25 mm from top)	72	69	55	52	102	67	52
High Right (25 mm from top)	42	73	34	30	59	34	35
Low Centre	84	80	31	34	71	39	28

Temperatures are indicated for various failure modes. A comparison of the temperatures demonstrates that the high centre location is the best location for identifying all types of spillage occurrences. Although the temperatures at high/centre are less than those at low/centre during stronger backdrafts (8 Pa and up), the high/centre temperatures are still sufficiently high to indicate that a significant spillage event is occurring. Under weaker backdrafts and under blockage conditions, the high/centre is much preferred to a side location or a low location in every case (at least for Test House No. 2). Note that after approximately one minute of operation all failure modes have caused a temperature rise at the high/centre to exceed approximately 52°C. In all cases these temperatures will continue to rise as the furnace heats up during a longer operating cycle.

Although Table 2 is based on Test House No. 2, much of the data on Test House No. 1 confirms these conclusions. An exception is the responsiveness of the high/right location to marginal spillage incidents. In Test House No. 1, marginal spillage is first indicated at the top corner of the dilution air inlet. It is assumed the reason for this variation is due to the configuration of the overflow vestibule on these furnaces. In Test House No. 1, the overflow vestibule is connected directly with the dilution air inlet opening on the face of the furnace. In Test House No. 2, the overflow vestibule is constructed as a box within a box, and much of the initial marginal spillage is lost up the interior cavity of furnace and first appears around the exterior of the flue connector at the collar of the furnace. Because of the high temperature around the flue connector at the collar, it is not possible to consider placing a temperature detector at this location. It must be assumed, however, that the use of a detector on a dilution air inlet is more effective for those types of furnaces that do not have an interior over-flow cavity. In Test House No. 1, the only advantage to a side location was during very minor spillage events, and often the temperatures during such spillage events would be insufficient to cause the temperature sensitive dots to change colour.

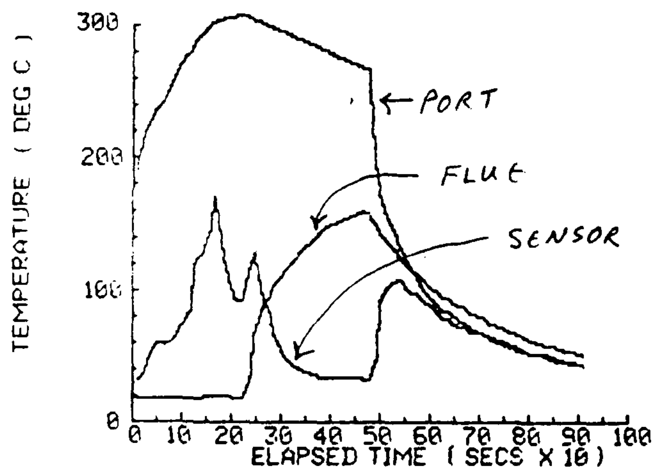
Although the high centre location appeared to be generally the best for detecting all types of spillage events, this was not true on furnaces with flue dampers. Figure 6 contains two graphs which illustrate the sensitivity of high centre and low centre locations to heat spillage caused by the closing of the flue damper on the furnace. These graphs were extracted from a report prepared by APTECH Detectors Inc. (Ref. 6). The upper graph in Figure 6 shows the response of the temperature sensor to a forced backdraft. Note the sudden rise in temperature at the high/centre location once furnace shuts down. This rapid and extreme rise in temperature would suggest combustion gas spillage is occurring, when in reality all that has occurred is heat spillage from convection flow through the furnace combustion chamber immediately following furnace shutdown. The lower graph in Figure 6 illustrates how a low/centre location avoids such misinterpretation. The low/centre sensor is not exposed to any of the heat spillage after shut-off, and is therefore to be specified for furnaces with flue dampers.

Repeated backdraft testing on Test House No. 1 allowed for comparison of temperatures at various locations under varying intensities of backdraft.

Chimney backdrafting was induced at pressures of 6 Pa, 8 Pa, 10 Pa, 14 Pa and 16 Pa. The results of this temperature mapping have been summarized in Figures 7a, 7b, 8, and 9. Figure 7a illustrates the combustion gas temperatures at a high/right location. Outdoor temperatures during all of these tests were constant at 3°C. Figure 7a indicates that marginal backdrafts created fairly erratic temperature movements, but that temperatures are otherwise extremely consistent, with a slight decrease in combustion gas temperatures with increasing depressurization.

Figure 7b illustrates the temperatures during the same backdraft tests but at a location on the cold side of spillage detector. The thermocouple was immersed in a conductive cream so as to accurately represent temperatures that would be experienced by a temperature sensitive dot located on the detector surface. From the shape of the curve it is easy to see that the effect of the detector is to drastically lower the temperatures that are experienced by the dot, to increase the time period with which the dot will respond to temperature increases, and to smooth out any erratic changes in surrounding gas temperature.

OLSEN MINIMAX FORCED BACKDRAFT TESTS
INDOOR TEMP (C): 19
SHALLOW HIGH CENTER OUTDOOR TEMP (C): 7



SHALLOW LOW CENTER OUTDOOR TEMP (C): 7

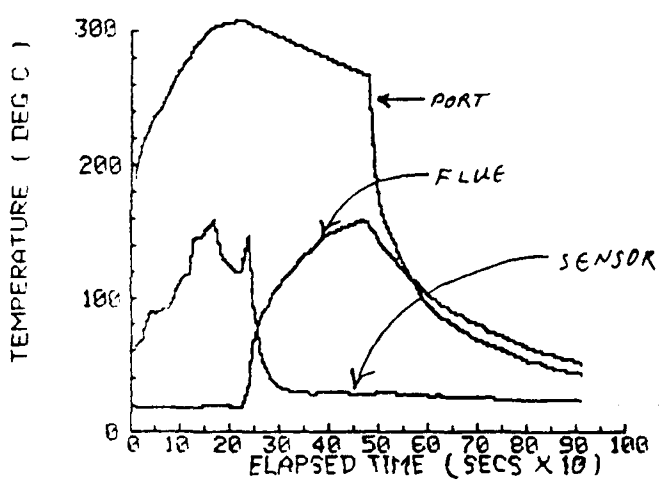
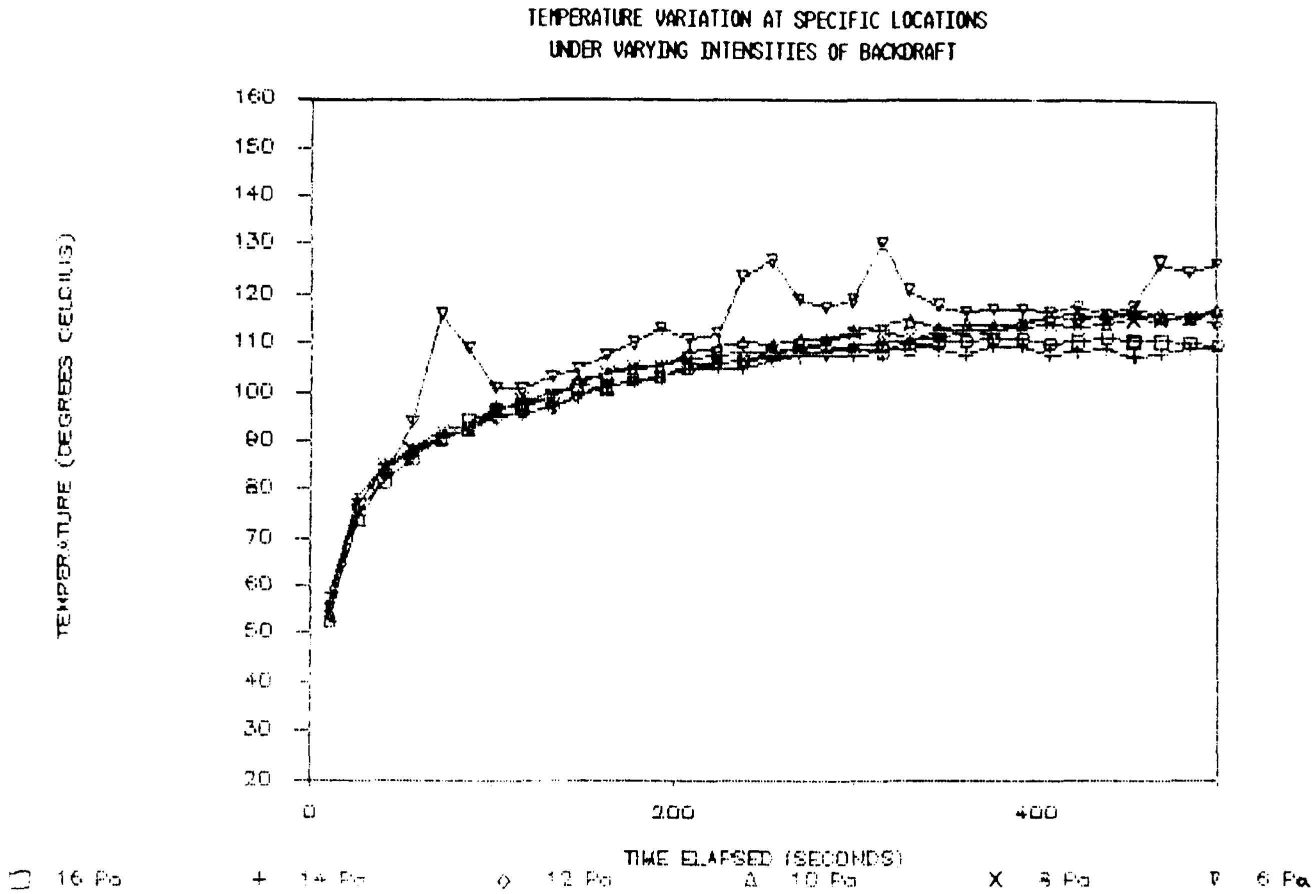


FIGURE 6: Sensitivity of High Centre and Low Centre Locations to Heat Spillage Caused by Closing Flue Damper (Extracted from "Furnace Alert Backdraft Indicator")



- COLD SIDE OF SENSOR - HIGH/RIGHT
Test House No. 1

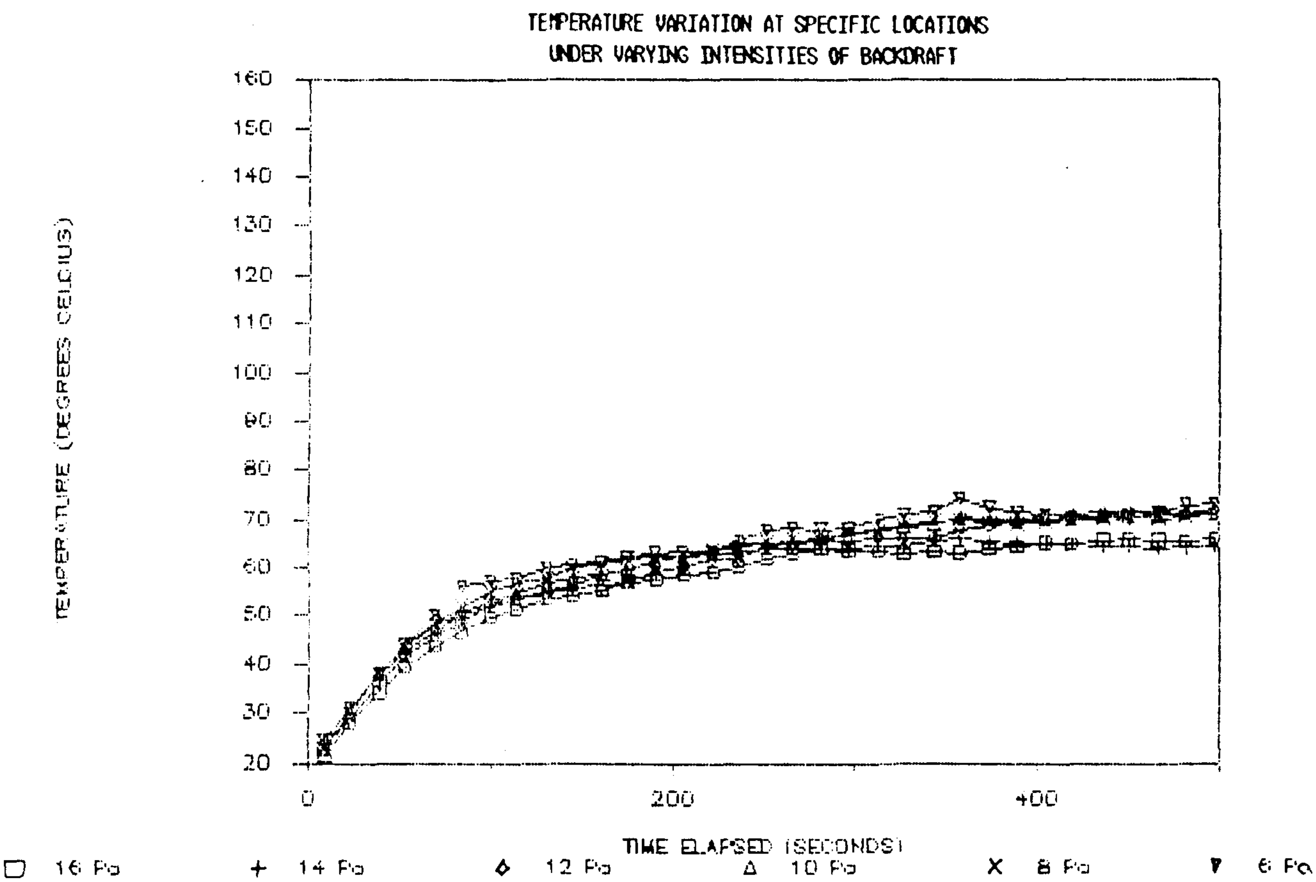


FIGURE 7 - GAS TEMPERATURE - HIGH/RIGHT
Test House No. 1

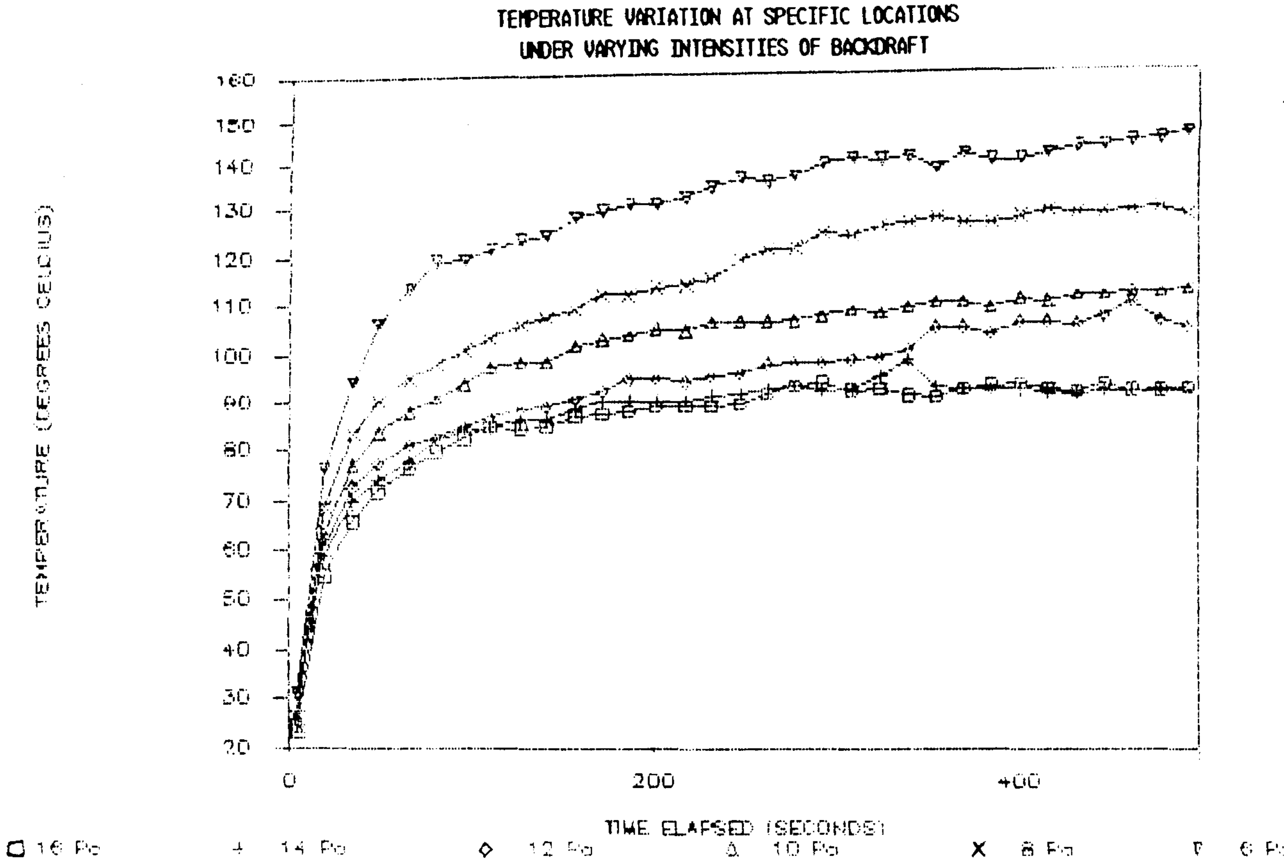


FIGURE 8 - GAS TEMPERATURE - LOW/CENTRE
Test House No. 1

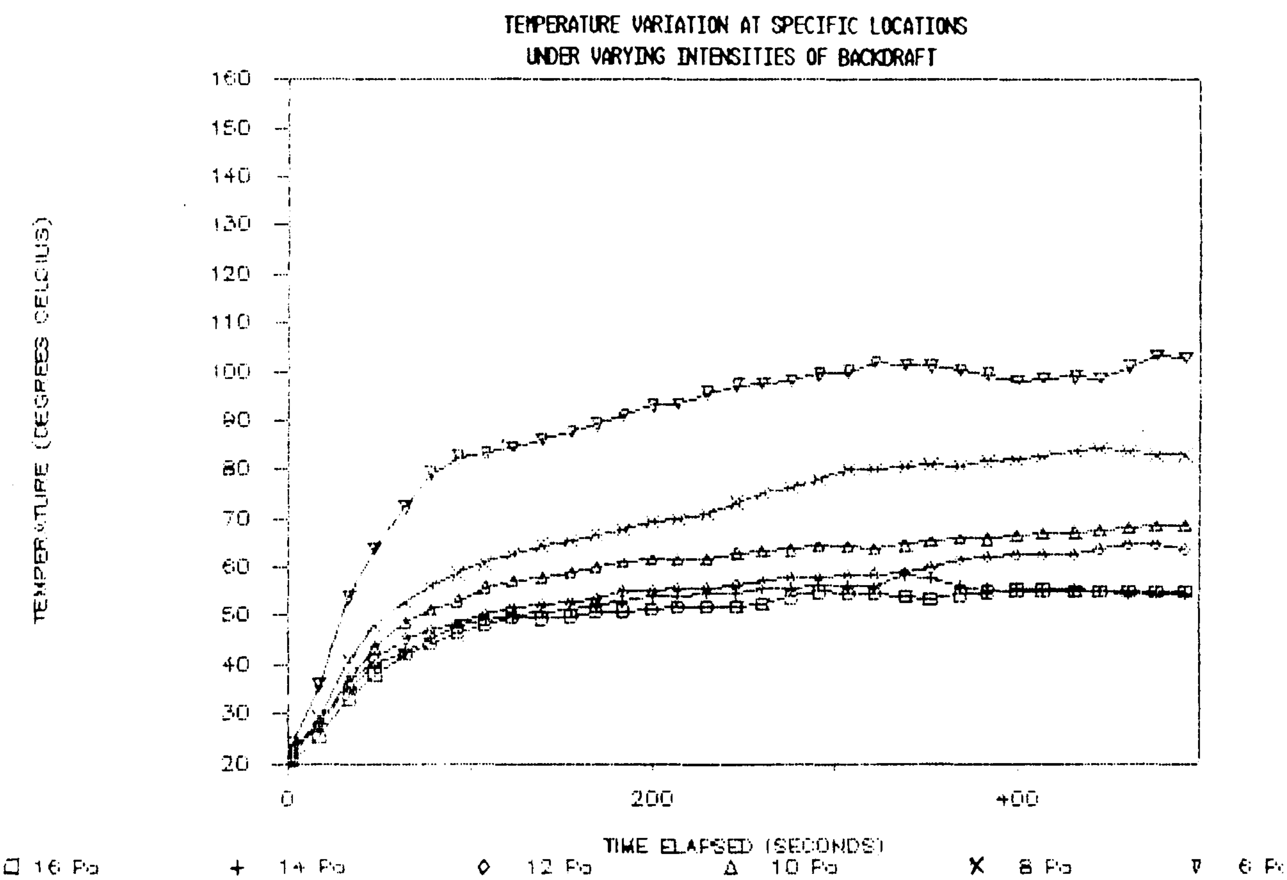


FIGURE 9 - COLD SIDE OF SENSOR - LOW/CENTRE
Test House No. 1

Also note that the relationship between temperatures for varying intensities of backdraft remains fairly constant for the cold side of the temperatures of the detector.

Figure 8 illustrates combustion gas temperatures at the low/centre location during varying intensities of backdraft. The temperatures are much more varied for this location, because the weaker backdraft pressures result in much higher temperatures, but at stronger backdraft pressures the temperatures drop to a level consistent with the upper side location.

Figure 9 shows a similar relationship for the cold side of the sensor at a low/centre location.

Figures 7a, 7b, 8, and 9 illustrate several phenomena that are important to interpreting the results of using temperature sensitive dots for combustion gas spillage detection. The use of a plastic detector strip on which to place the dot, introduces both a temperature reduction, and a time buffer. Analysis of temperatures around the detector and on the surface of the detector showed a consistent drop in temperature at the surface due to the air film and shielding effects. After the initial time delay, the temperatures on the cold side of the detector averaged approximately 95% of the surrounding combustion gas temperature (°K). On the hot side of the detector, the temperatures averaged approximately 98.7% of the surrounding gas temperatures (°K). These relationships are illustrated in Figure 10. The initial time delay caused by the use of the detector was found to vary depending on the rate of temperature rise of the combustion gases. For the test illustrated in Figure 10 the time delay is approximately 10 seconds. This is the time at which the cold side of the detector achieves the 95% temperature of the surrounding combustion gas.

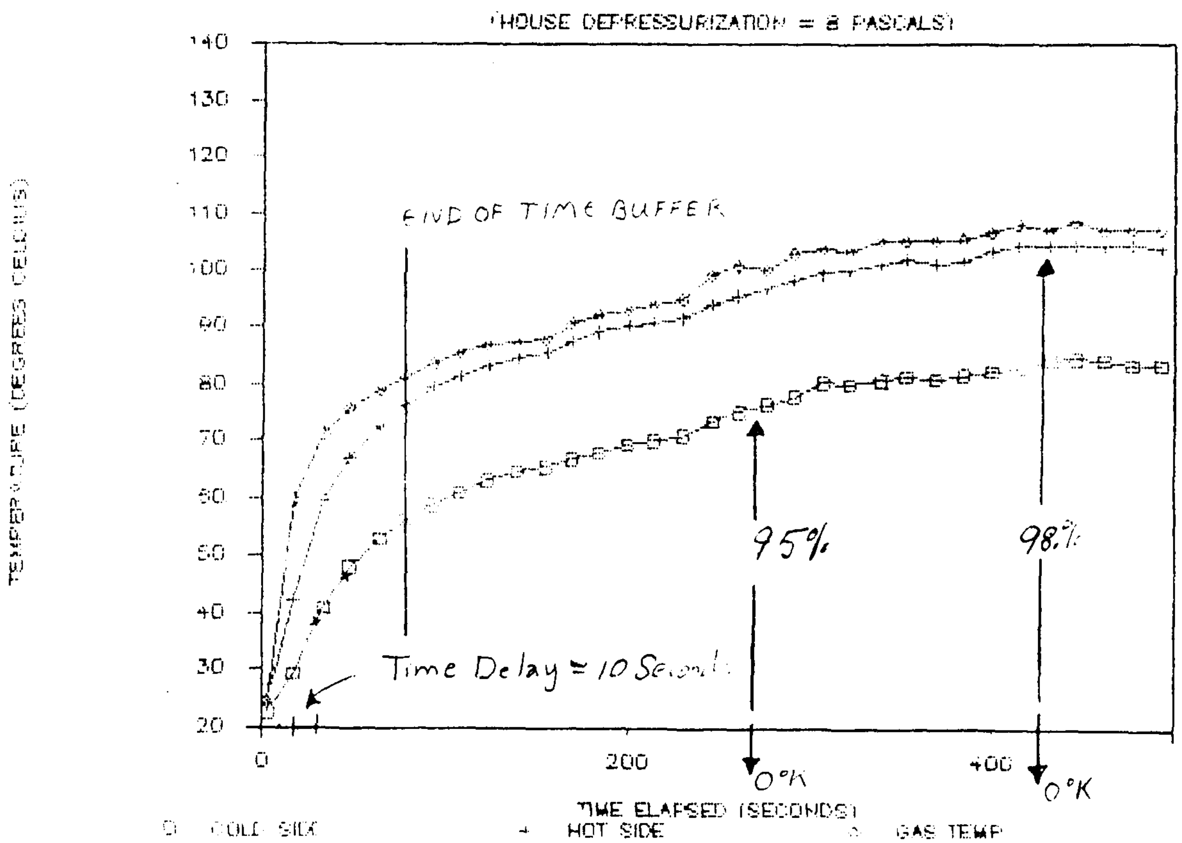


FIGURE 10: Temperature and Time Buffer of Sensor

Further testing was conducted on Test House No. 1 to confirm that the temperature sensitive dots would actually begin to turn black when the surface temperatures reached the specified temperature rating.

The time at which the dots of a specified temperature rating began to turn black was noted during a backdraft event. The times and dot temperatures were compared with both the combustion gas temperatures, and the temperatures on the cold side of the detectors, on which the dots were located. The results of these dot sensitivity evaluations are presented in Figures 11, 12, and 13. Each subsequent figure represents backdraft at increasing house depressurization and consequently with lower and slower temperature rises. In Figure 11, a weak backdraft of 6 Pa causes a rapid temperature rise for the detector, and in this situation, there is a significant delay in the time in which the dots change temperature. For example the 38°C dot does not begin to turn black until cold side temperatures on the detector have reached 50°C, and the 52°C dot doesn't begin to turn until the detector has achieved a surface temperature of approximately 83°C. The delays increase with the dot temperature, from approximately 10 seconds to approximately 100 seconds. These delays may provide an additional time buffer for the dots, in cases where temperature rise is rapid.

Figures 12 and 13 illustrate how the time buffer of the dot itself becomes less and less a factor at a lower temperature rise. In fact, in Figure 13, it is apparent that there is no delay whatsoever under these relatively low temperatures, and the dots change colour precisely at the indicated temperature. From these tests it was concluded that delays in response of the dot were caused by a sudden, rapid temperature rise. For this reason spillage detection ability was only affected during the start-up period.

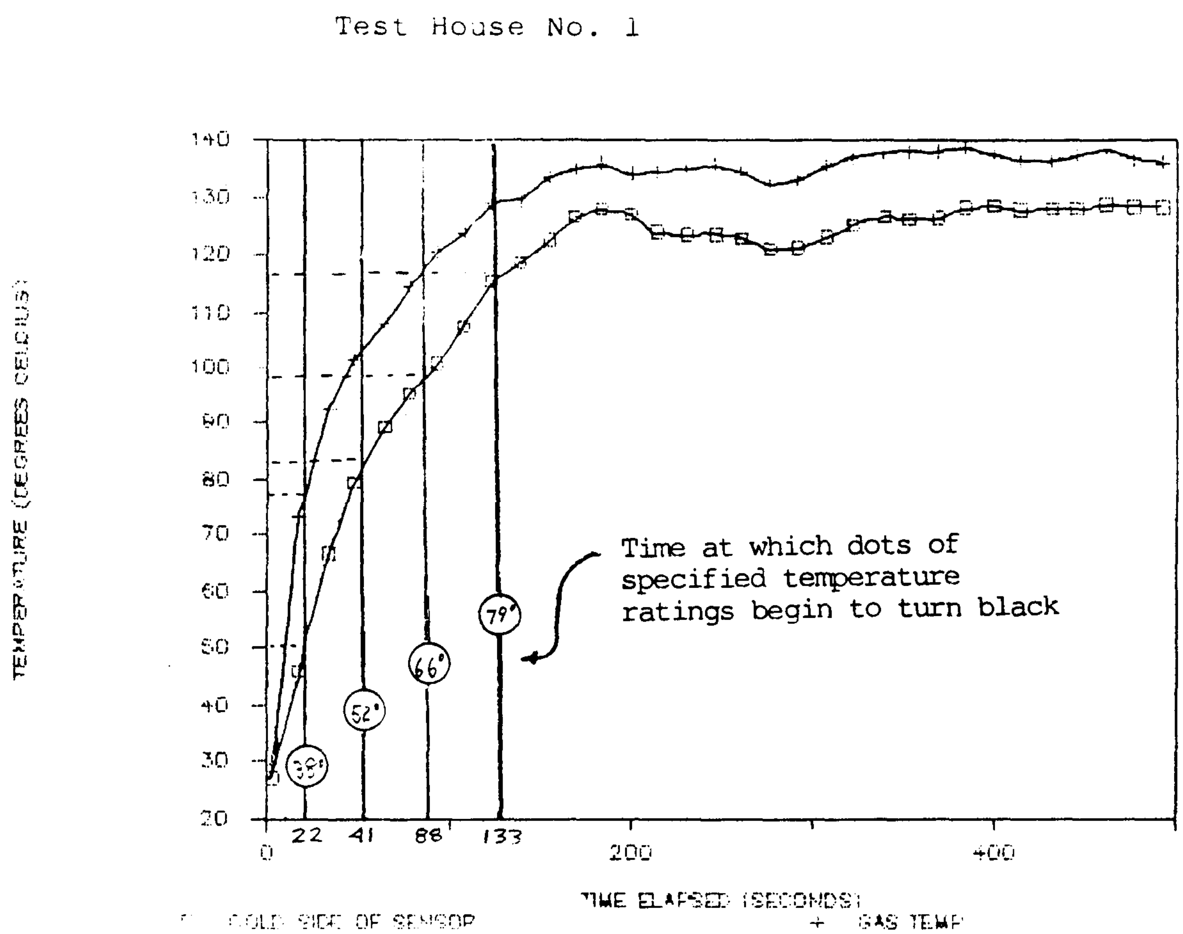


FIGURE 11: Dot Sensitivity During Backdraft at 6 Pa. of House Depressurization

8 PASCAL HOUSE DEPRESSURIZATION

(TIME CALIBRATION OF HEAT DOTS)

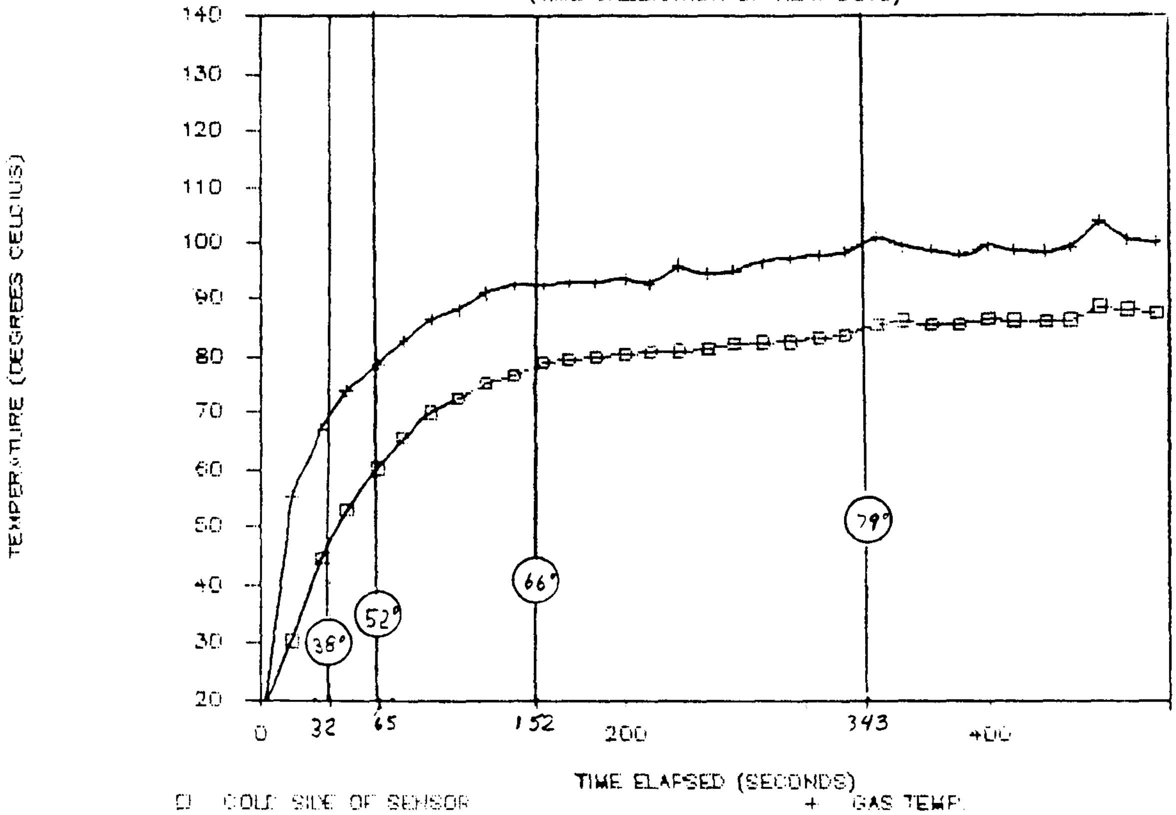


FIGURE 12

Test House No. 1

16 PASCAL HOUSE DEPRESSURIZATION

(TIME CALIBRATION OF HEAT DOTS)

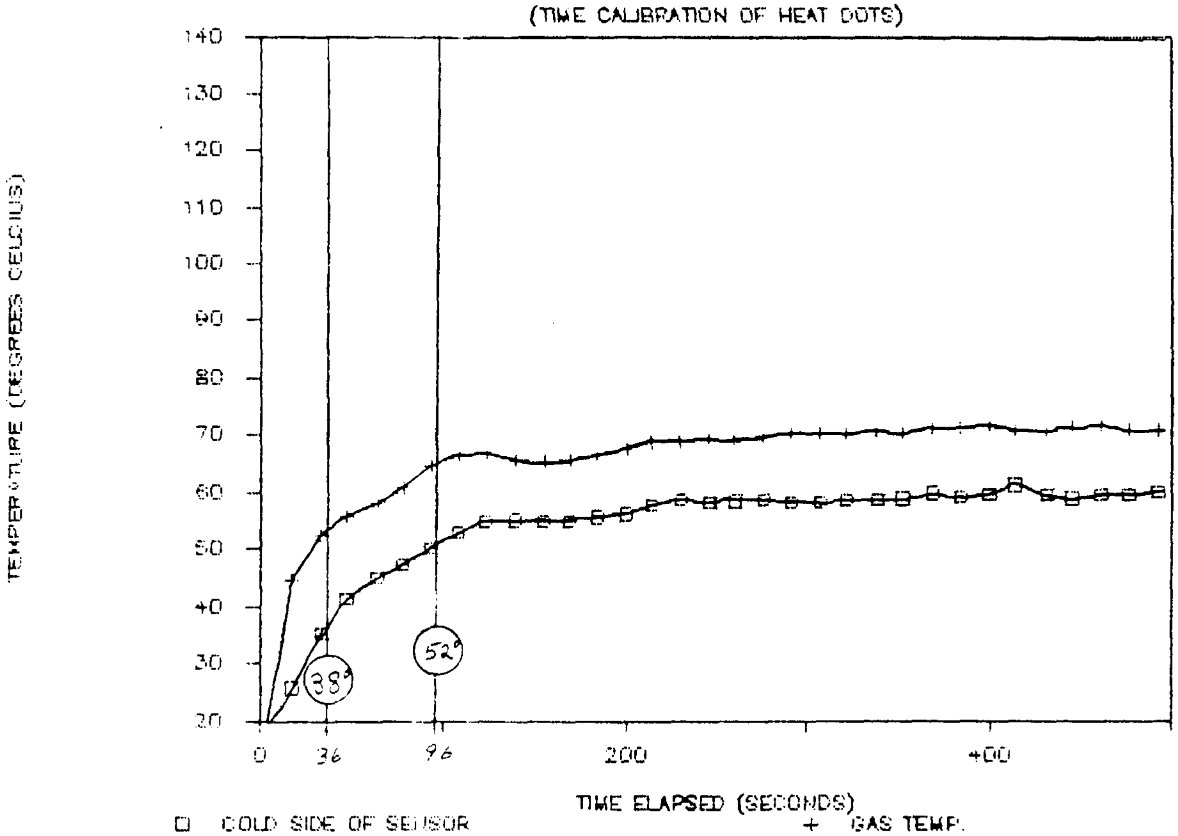


FIGURE 13

Test House No. 1

Further testing was conducted on Test House No. 1 to determine if a repeated marginal backdrafts would produce higher temperatures (due to the warm furnace) and make short term spillage appear severe. Figure 14 is illustrative of the test results, and indicates that temperature rise is not significantly higher with a warm start as opposed to a cold start during a marginal backdraft failure.

3.3 Selection of Dot Temperatures

Laboratory testing was conducted to determine the sensitivity of dots to temperatures in relation to their location on the detector. For this purpose, a full-scale mock-up of a gas furnace dilution air inlet was constructed from cardboard and foil, and a detector was mounted in the optimum location for detecting spillage and backdrafting (i.e. top centre of inlet). A series of propane burners were used to simulate combustion gas spillage through this inlet. The thermocouples were mounted in a conductive cream on the surface of the detector at various locations, and used to monitor the combustion gas temperature around the detector.

Figure 15 illustrates the surface temperature of the detector at various locations over the period of 200 seconds, and also provides a map for identifying the location of the thermocouples during the test. The test data demonstrated that the cold side temperatures on the detector followed quite closely the combustion gas temperatures around the detector. The relative location of the dots on the detector did not have a major impact, and even a dot located above the upper lip of the dilution air opening spillage temperatures approaching the combustion gas temperature. The ability of the plastic to conduct temperatures fairly uniformly over the surface helps to compensate for any major variations in combustion gas temperature around the detection location. For this reason, the precise location of each temperature dot on the detector was not felt to be a crucial factor. However, to optimize sensitivity to marginal backdrafting and slight spillage, it was clearly advisable to

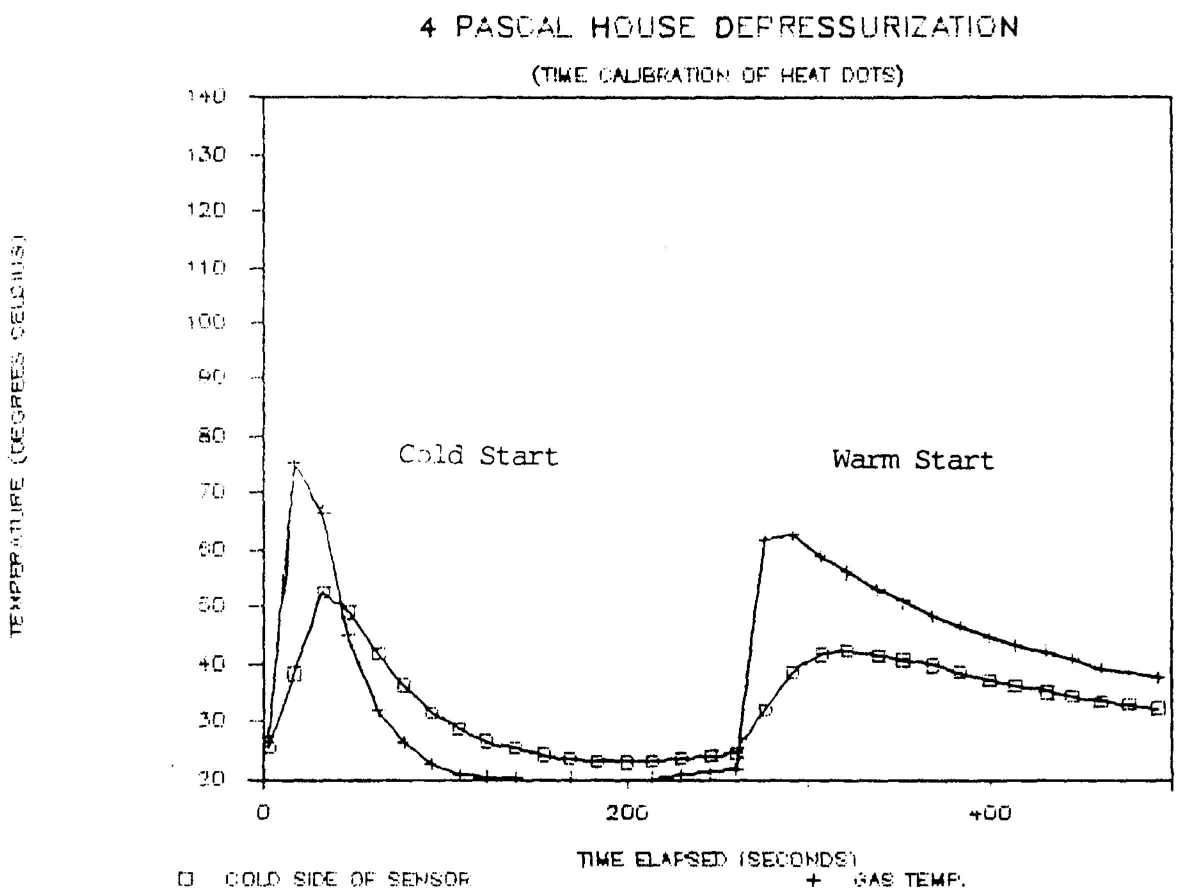
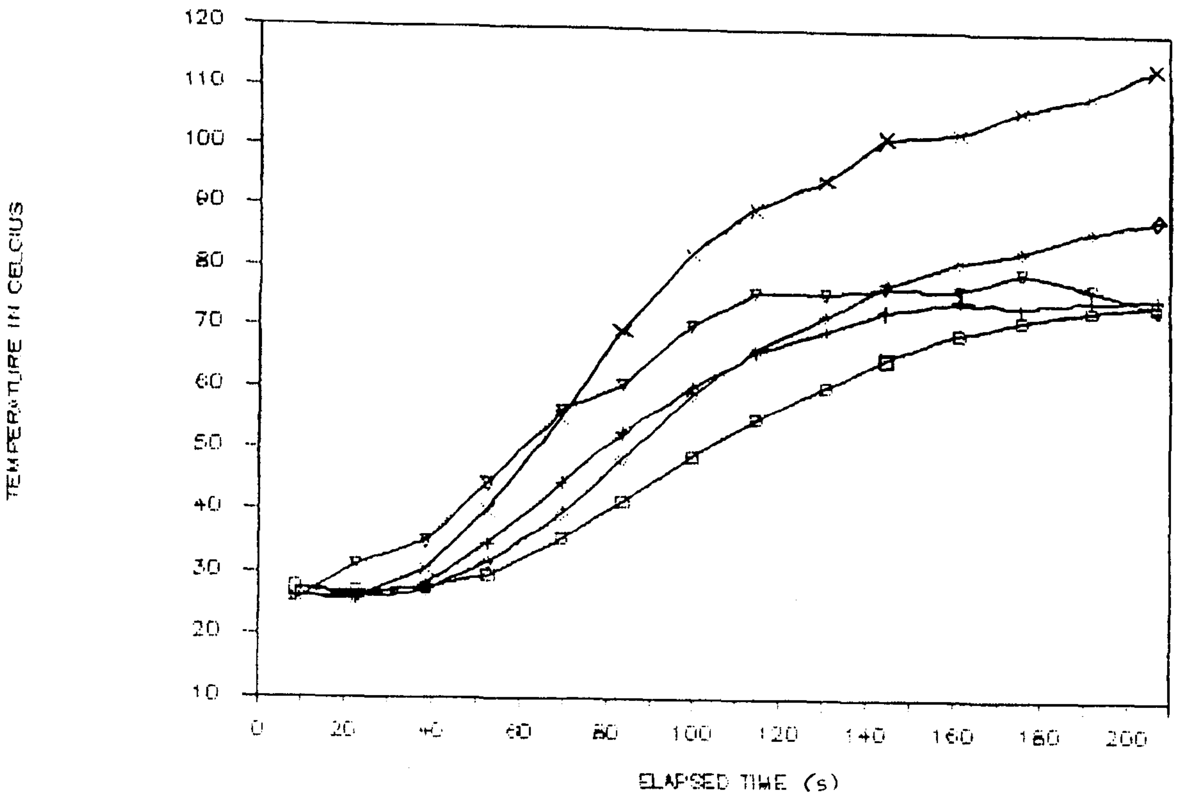


FIGURE 14: 4 Pascal House Depressurization



Legend: Location of Sensors on Plastic Strip and in Dilution Inlet

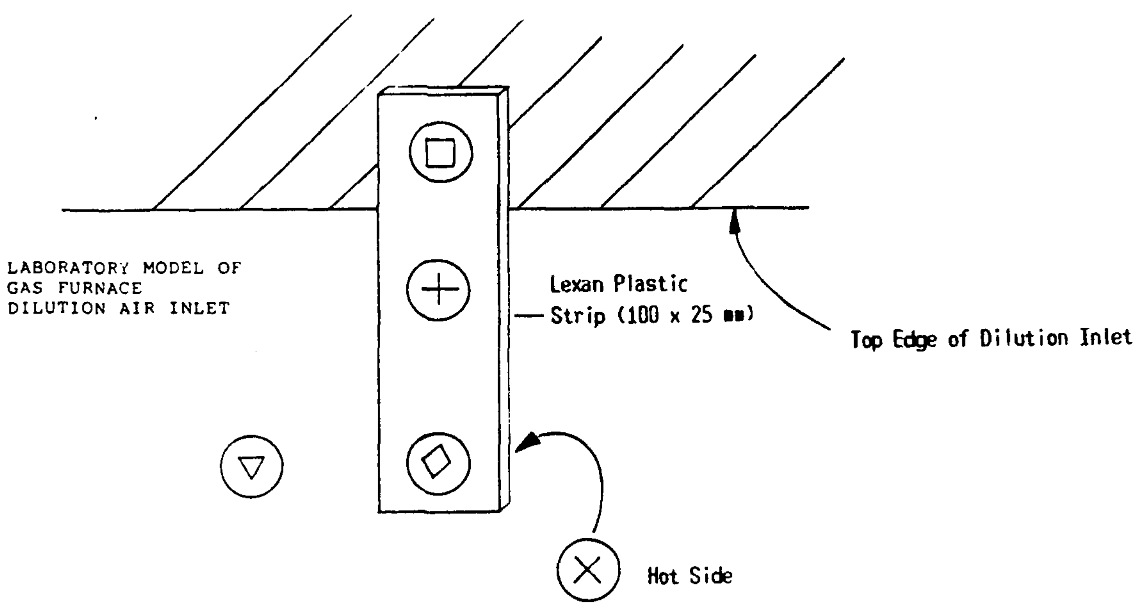


FIGURE 15: Surface Temperatures of Detector at Various Locations

locate the lower temperature (i.e. more sensitive) dots on the upper portions of the detector and the higher temperature dots on the lower portion. In addition, it was felt useful to extend the detector at least 50 mm to the dilution air opening so as to reach the high temperature locations during high velocity backdraft and spillage events. For reasons of cost, it was not possible to produce a detector using more than five dots. The final choice of dot temperatures and locations for the detector is briefly described and explained below:

Interpretation of Black Dot Spillage Detectors for Gas-Fired Appliances

1. A 38°C DOT ON THE HOT SIDE, 13 mm BELOW TOP OF INLET

   This is the most sensitive dot available and is designed to detect SHORT TERM, START-UP SPILLS of about 15 seconds, or marginal spillage for prolonged periods. The dot is glued face down to the hot side of the detector so that the dot colour can be observed through the clear lexan plastic. The temperature buffer (i.e. insulating effect of air film and plastic) for this location is relatively insignificant, and results in dot temperatures of about 98.7% of gas temperature (°K). The time delay is also insignificant. The detector is located so as to catch the slightest spills at the upper lip.

2. A 38°C DOT ON THE COLD SIDE, 30 mm BELOW TOP OF INLET

   This dot is designed to detect start-up spillage and/or possible failures. cold weather backdrafting, or spills of approximately 15 to 60 seconds will be detected. The dots will typically have a temperature buffer that produces dot surface temperatures equivalent to 95% of spillage gas temperatures (°K), and a time buffer of at least 15 seconds. An additional time delay of 20 or 30 seconds may exist if the furnace itself is still warming up. Colour change of this dot can indicate start-up against a temporary cold backdraft of one or two minutes duration, or prolonged start-up spillage.

3. A 54°C DOT ON THE COLD SIDE, 30 mm BELOW TOP OF INLET

   This dot is indicative of a PROBABLE FAILURE. A 54°C dot temperature translates to combustion gas temperature of 71°C, which occur after at least one minute of continuous backdraft or blockage, under most operating conditions.

4. A 71°C DOT ON THE COLD SIDE, 42 mm BELOW TOP OF INLET

   This dot indicates a DEFINITE FAILURE, in which the furnace has likely experienced a backdraft for at least one full cycle, or a major spillage incident due to blockage or other factors. Some cooler furnaces, however, may never cause a 71°C DOT to change, despite continuous spillage or long term backdrafting episodes.

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

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

3.4 Gas Domestic Hot Water Heater Spillage Detectors

The characteristics of combustion gas spillage from DHW heaters are, in many ways, similar to spillage from gas fired furnaces. Consequently, the detection strategy is not significantly different. Extensive field monitoring of two different styles of DHW heaters was conducted in order to determine what kind of detector design best suited a hot water heater.

The proposed design of the DHW heater spillage detector is illustrated in Figure 16. The temperature sensitive dot ranges and the dimensions of the detector are identical to the gas furnace detector. The detector is placed so as to bridge the gap between the lower rim of the dilution air hood, and the upper surface of the hot water heater. The detector is securely held in place at both ends with a strip of high temperature tape. The backing of the tape is peeled off just prior to application.

The temperature mapping of gas DHW heaters was conducted in Test House No. 2. The house contained two water heaters side by side, a Giant water heater (DHW1) and a Sears water heater (DHW2). The height of the dilution air inlet on the Sears Model (#2) was approximately 30 mm, whereas the Giant (#1) had a larger opening with approximately 60 mm. The assistance of two DHW heaters in the same house with varying designs provided a convenient method of comparing the effect of water heater design on temperature profiles. The location of the thermocouples on both water heaters is illustrated in Figure 17.

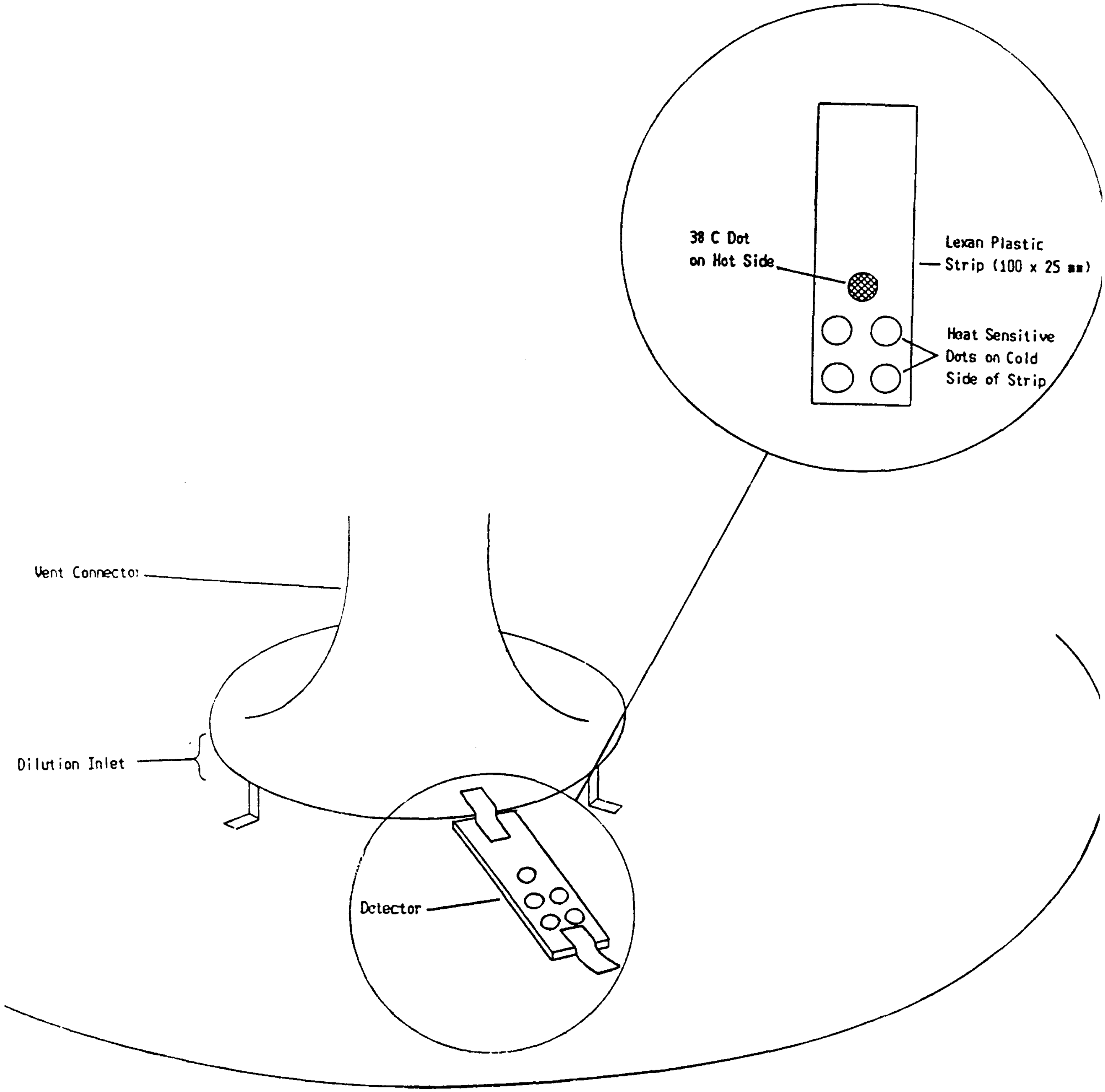


FIGURE 16: Proposed Design of the DHW Heater Spillage Detector

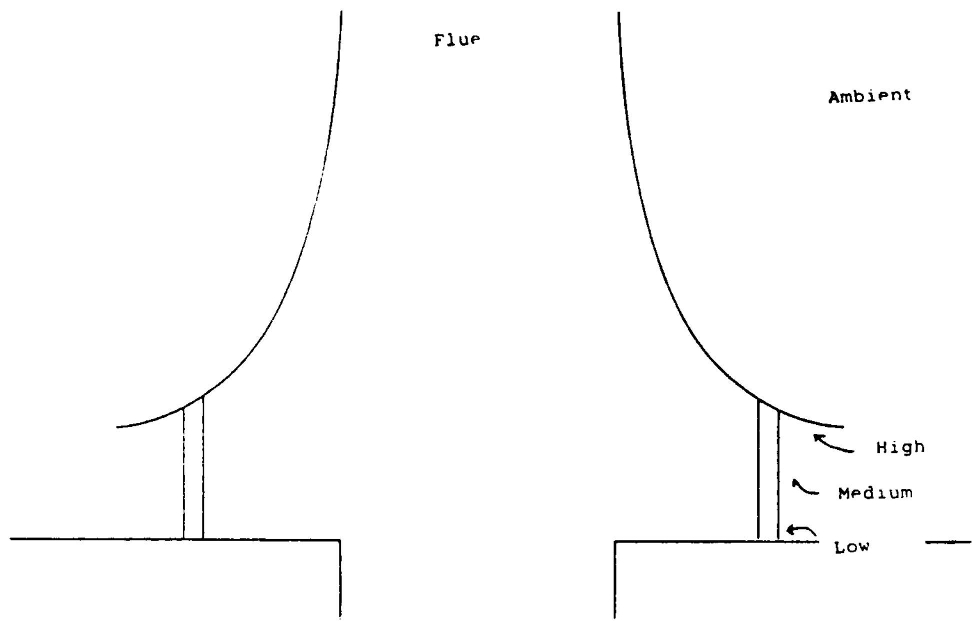
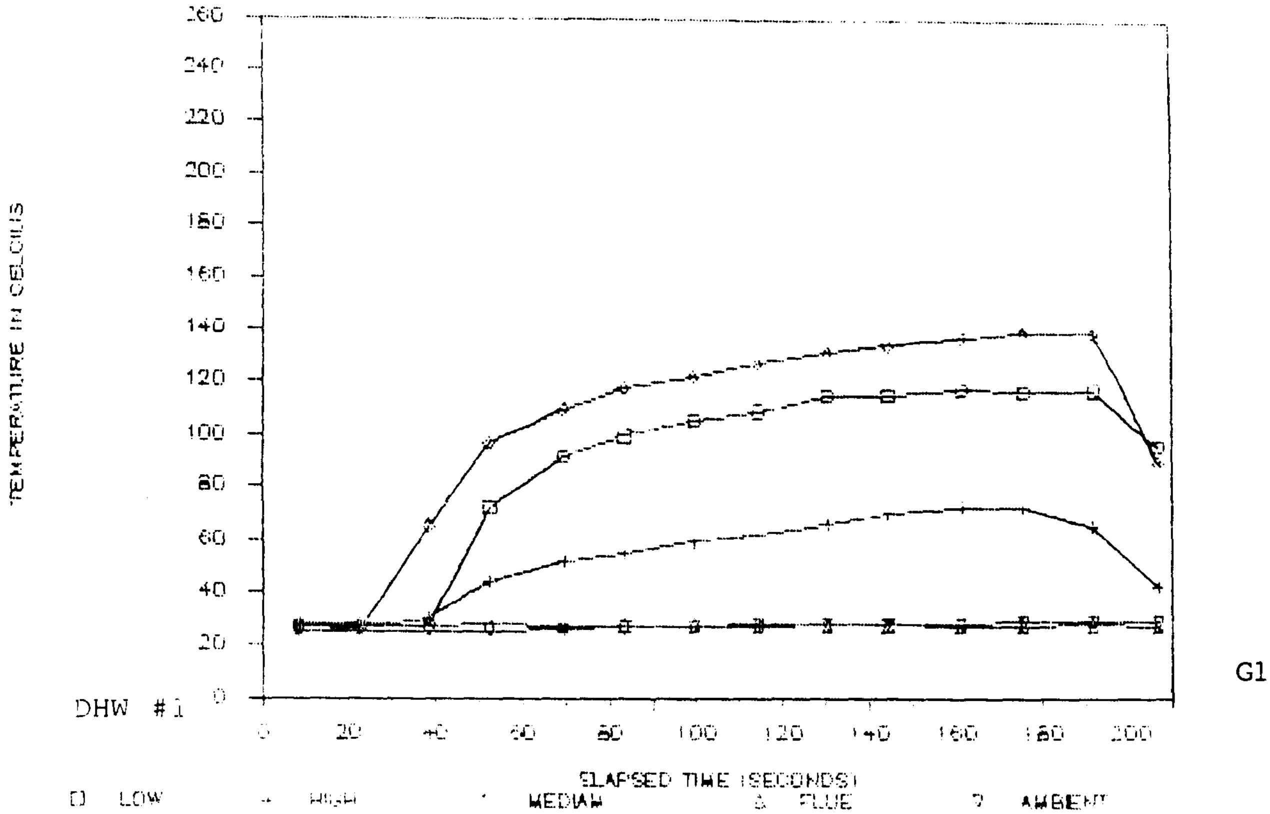


FIGURE 17: Location of Thermocouples During Temperature Mapping of DHW Heaters



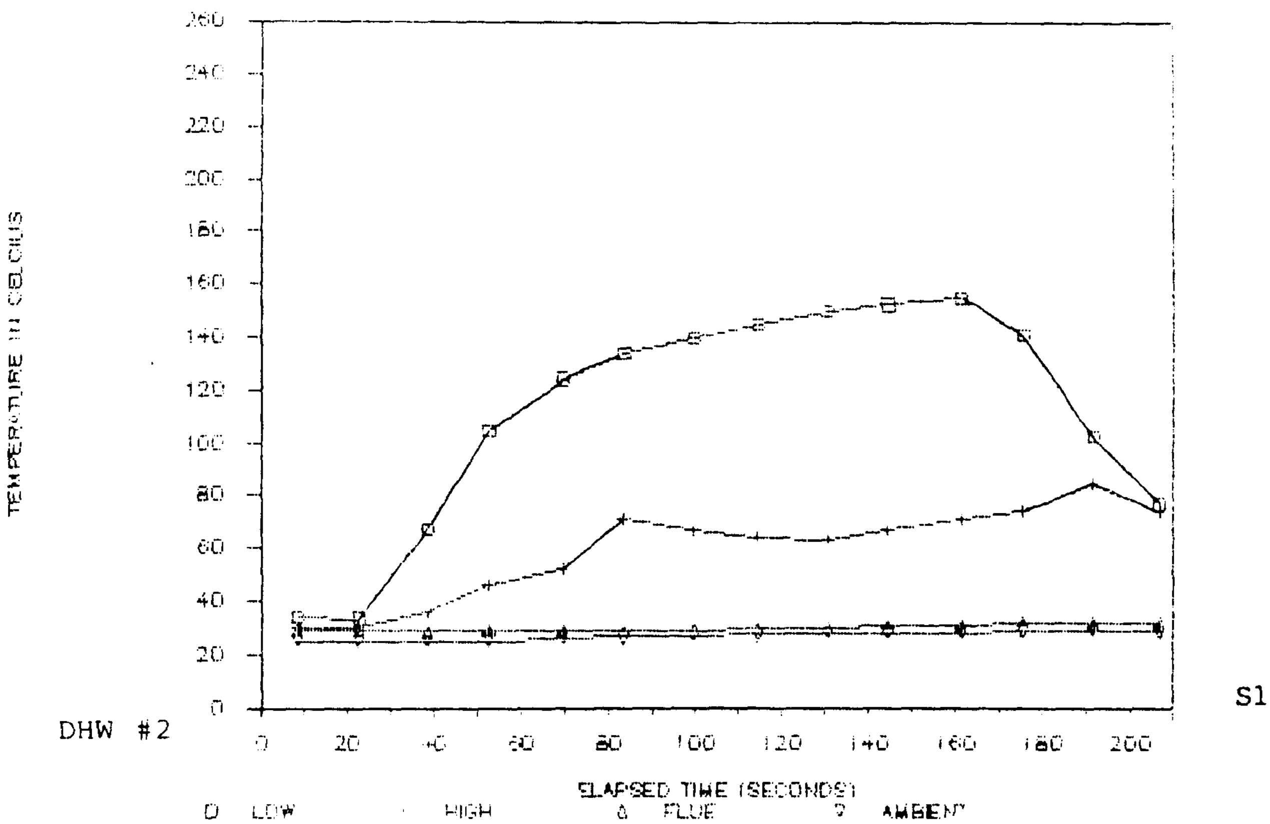
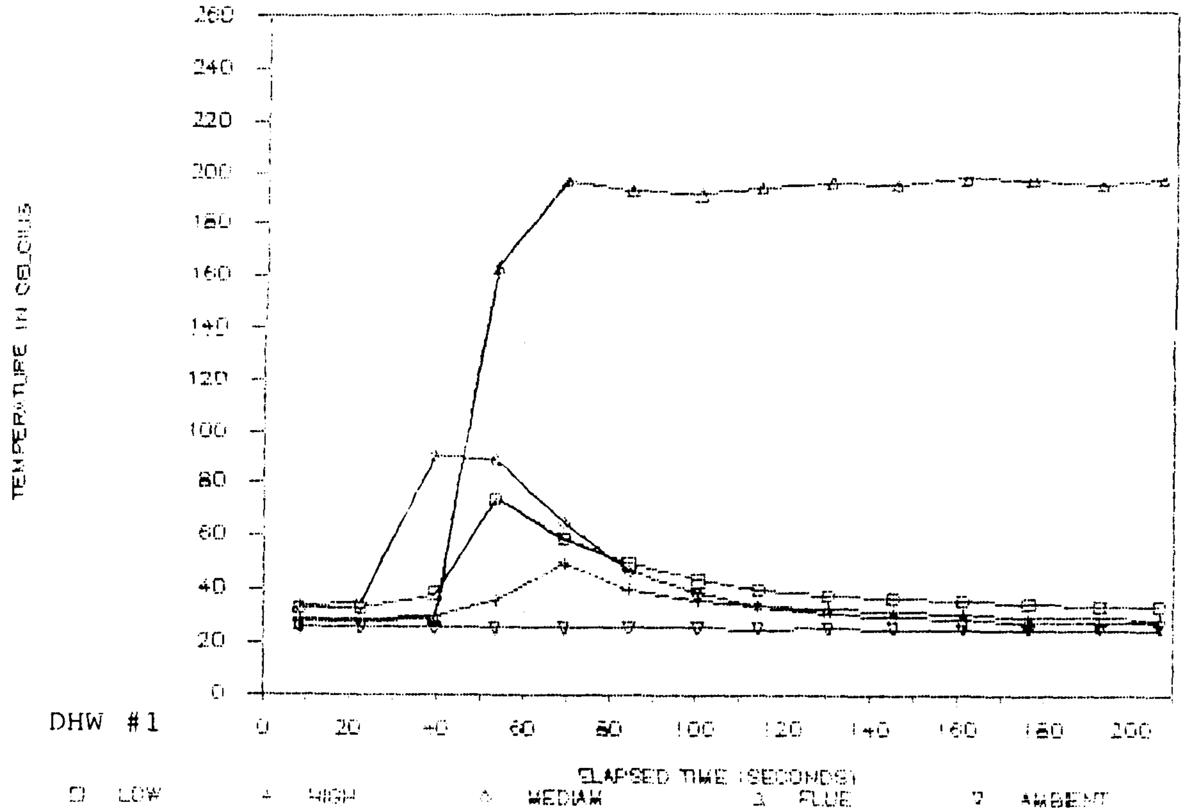
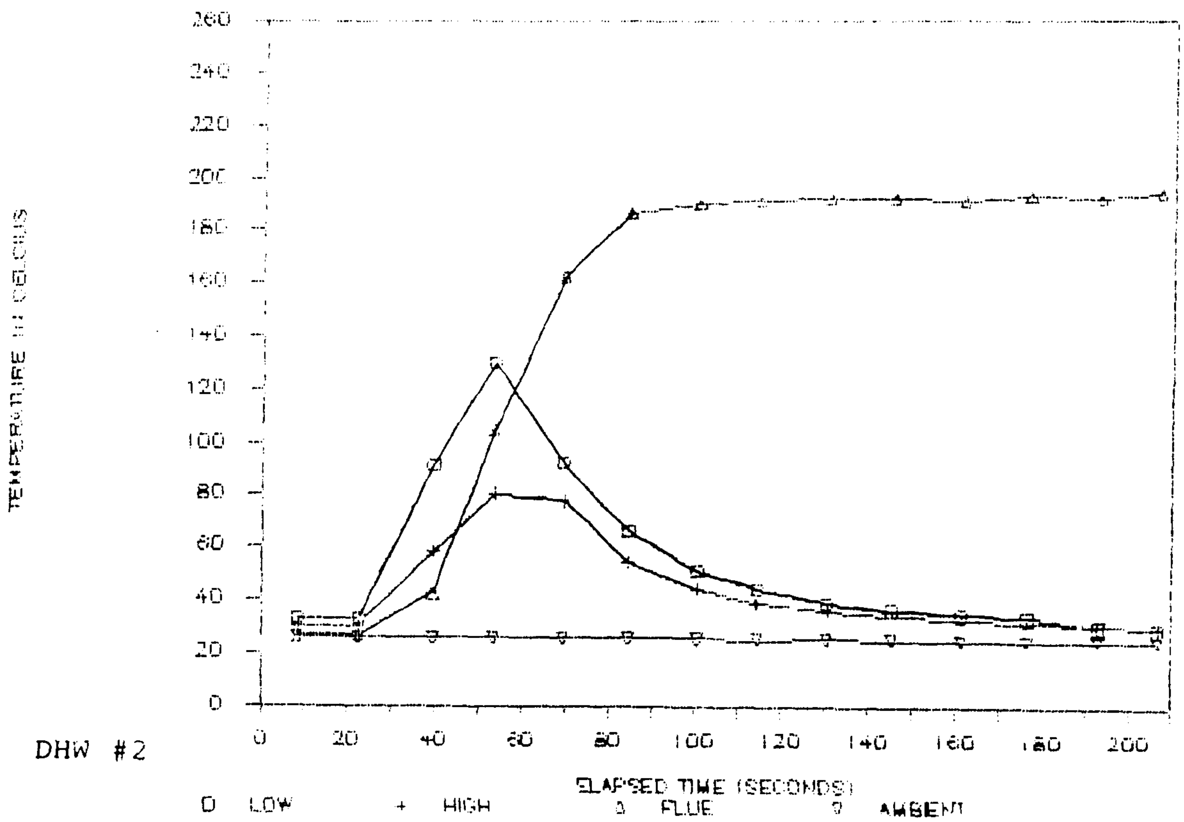


FIGURE 18: Backdraft at 15 Pascal Depressurization in Test House No.2



DHW #1



DHW #2

FIGURE 19: Backdraft at 8 Pascal Depressurization in Test House No.2

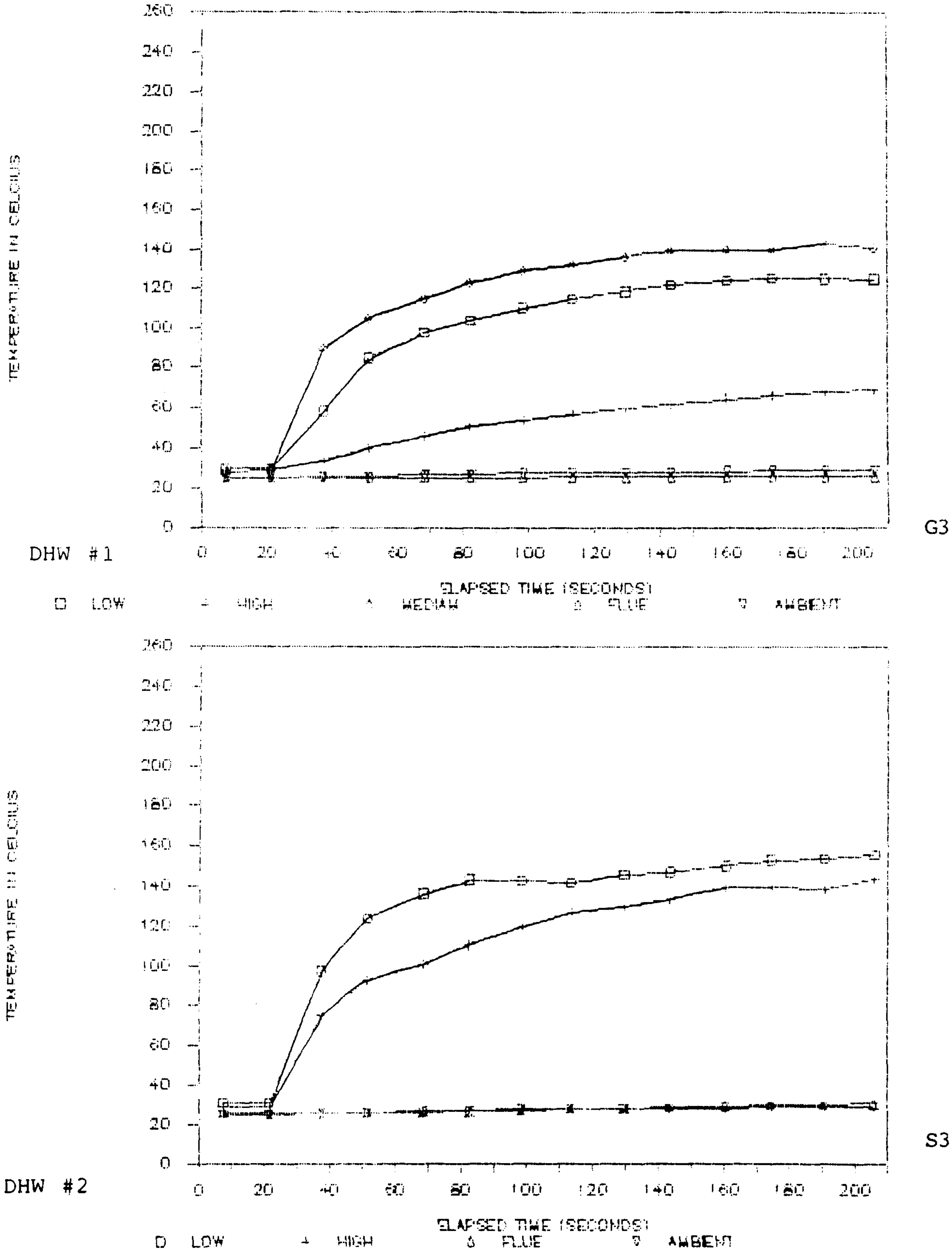
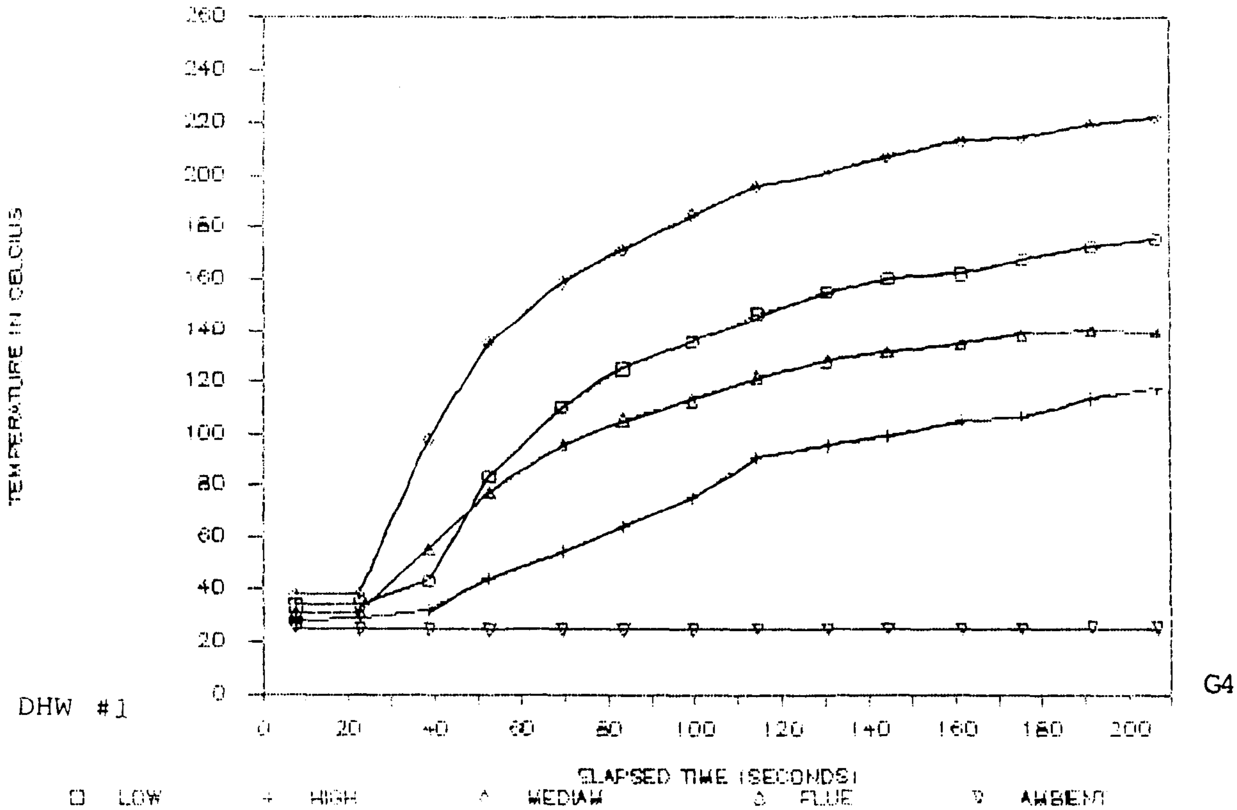


FIGURE 20: Backdraft at 10 Pascal Depressurization in Test House No.2



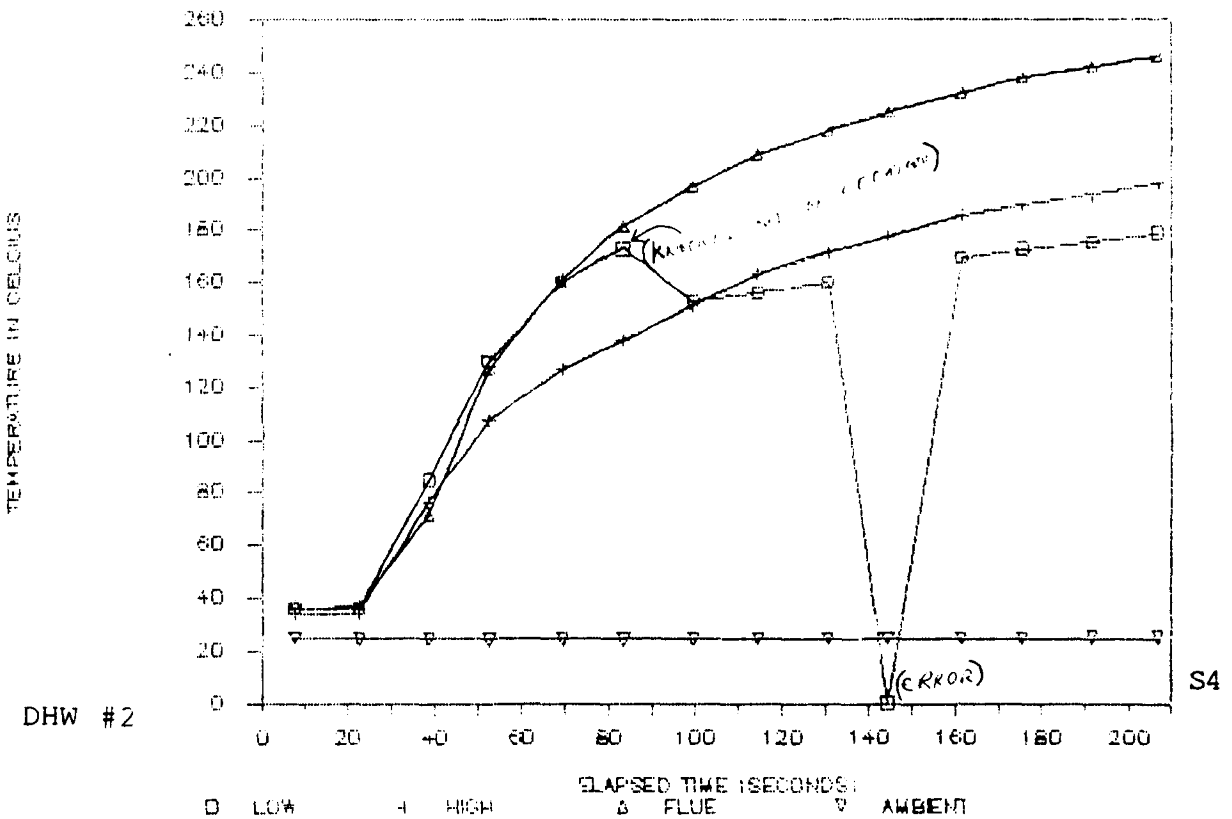
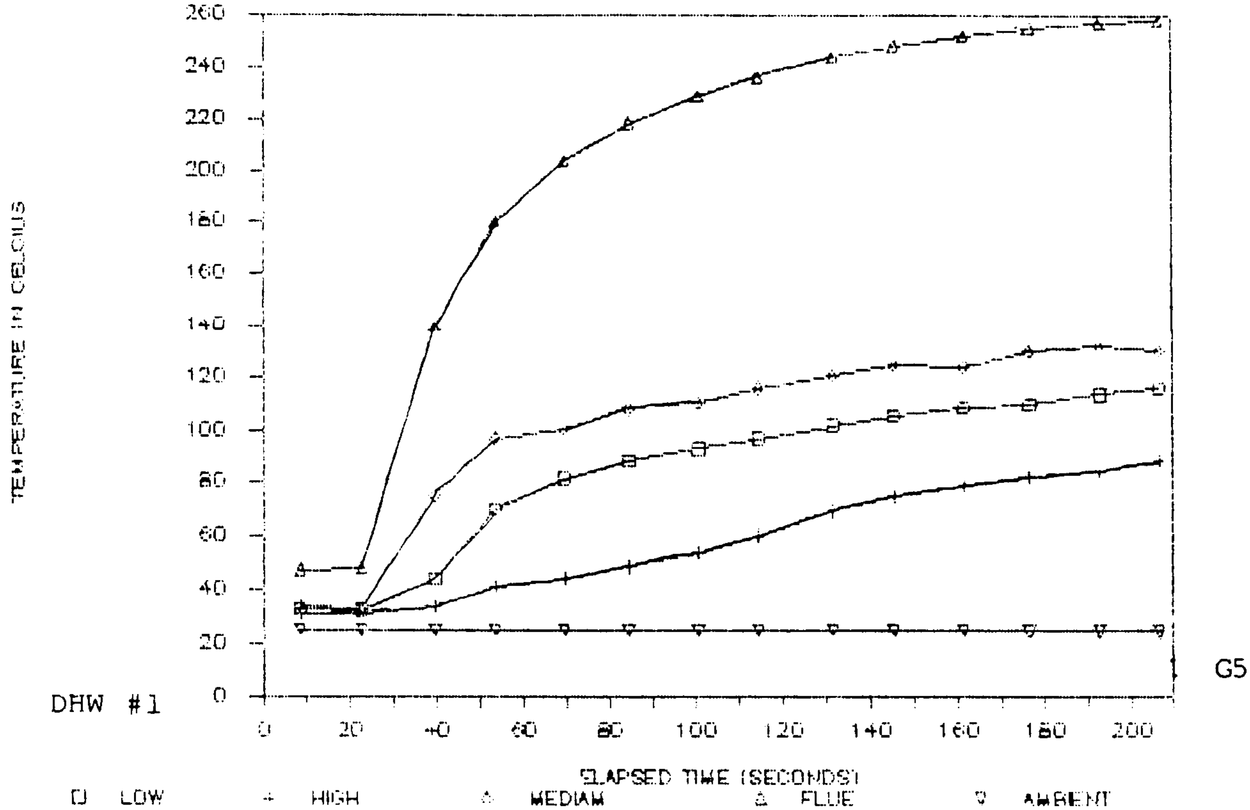


FIGURE 21: Full Blockage of Chimney in Test House No.2



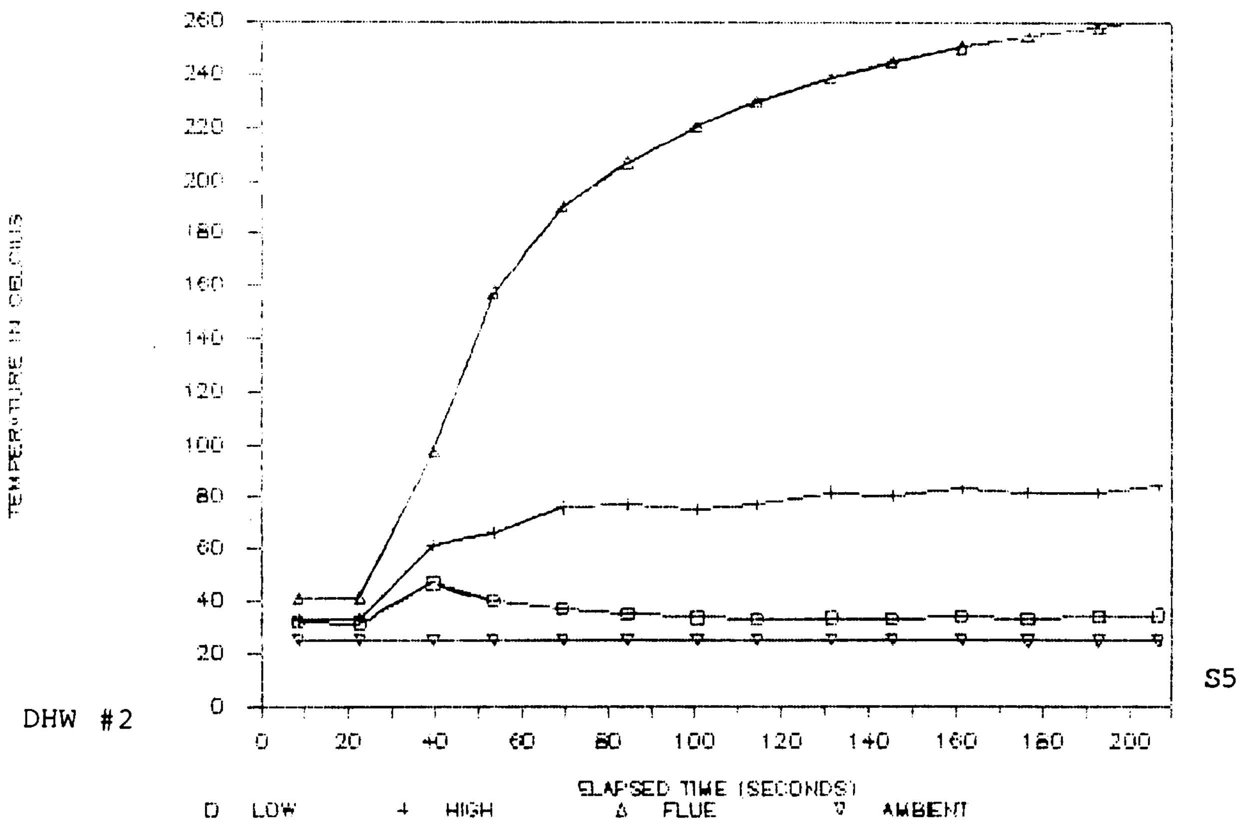
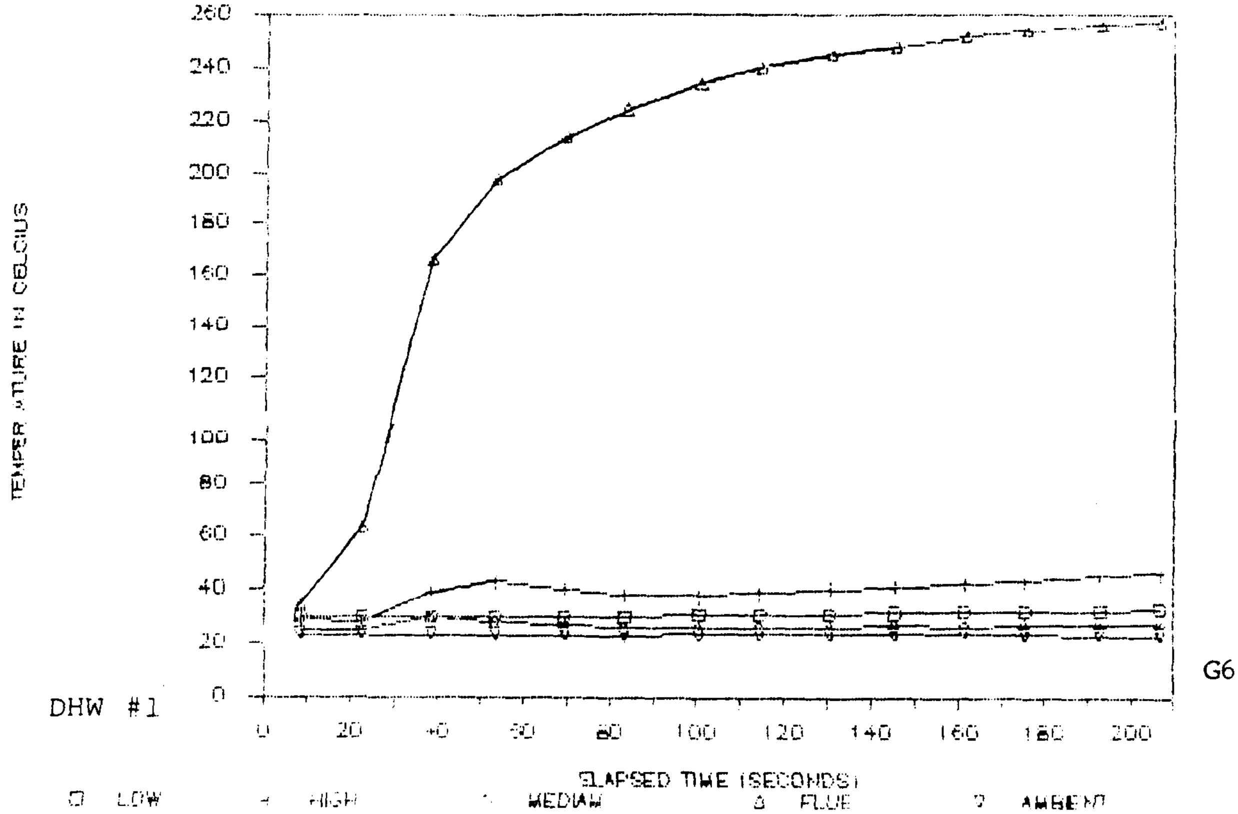


FIGURE 22: 90% Blockage of Chimney in Test House No.2



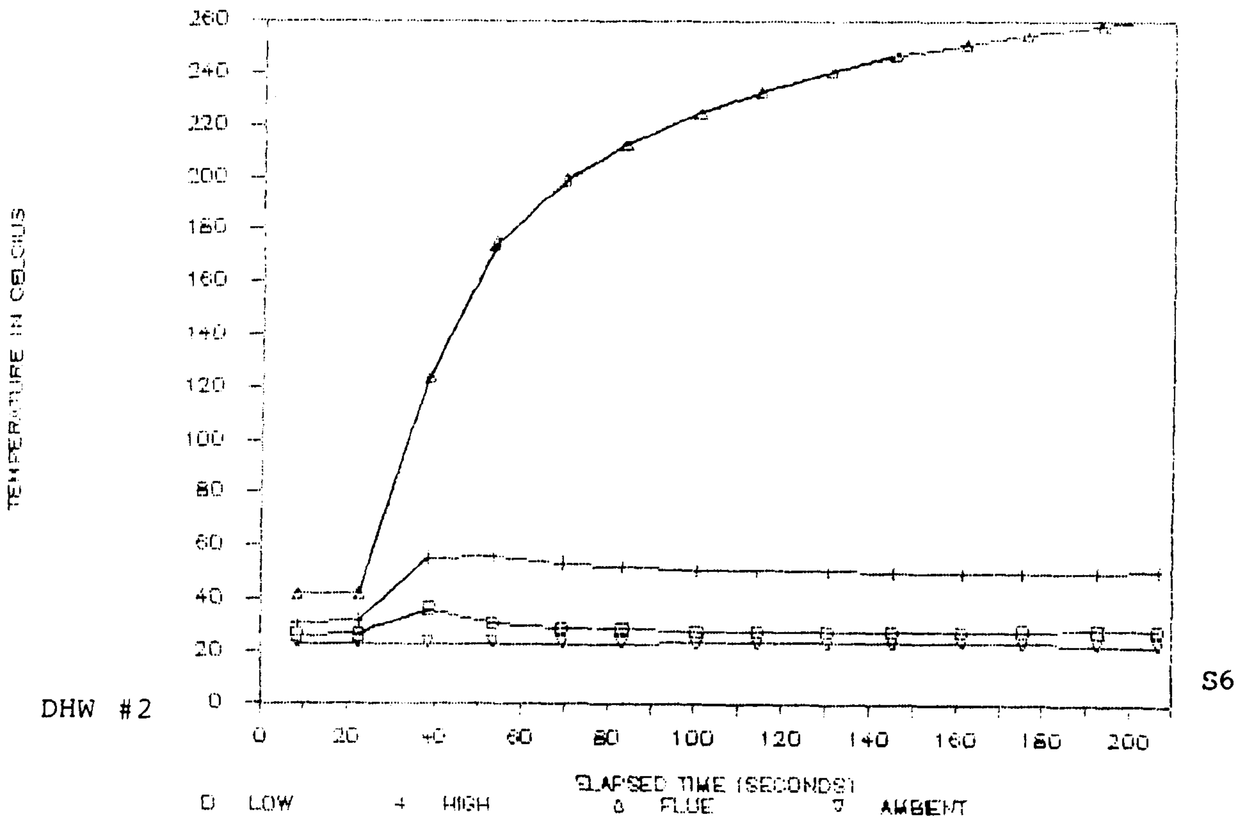


FIGURE 23: 50% Blockage of Chimney in Test House No.2

Figures 18 to 23 illustrate the time temperature profiles for each location on each DHW heater. Failure modes including: 15 Pa House depressurization, 10 Pa house depressurization, 8 Pa house depressurization, full blockage of chimney, 90% blockage of chimney and 50% blockage of chimney.

An analysis of the temperature/time data on DHW heaters has led to the following conclusions:

1. The range of temperatures in the spillage gases is similar to gas furnaces, although significantly higher during blockage events.

2. A more rapid rise in temperatures can be expected during marginal failures, requiring a correlation of significant spillage events with higher recorded temperatures.

3. A low location is always preferable to a high location for detecting backdraft events.

4. A low to medium location is better at detecting full blockage events, whereas a high location is preferable for detecting slight spillage due to partial blockage.

5. A mid-location is preferable for detecting all types of failures on the large dilution inlet of DHW No. 2 (except for the slight blockage scenario).

6. An optimum design would be to bridge the low and high locations with the plastic thereby ensuring the surface temperatures approximate the combustion gas temperatures under conditions of minor and major blockage or backdrafting.

7. The most sensitive (i.e. low temperature) indicating dot is best located at the uppermost portion of the detector in order to ensure detection of slight blockage or marginal backdraft. On the other hand, if the purpose is to ensure detection of very strong backdrafts in cold weather, the best location of the more sensitive dot is at the lower-most portion of the detector.

8. In order to leave permanent evidence of a minor spillage caused during cold backdrafting at start-up, or very slight spillage, the optimum location for a dot is on the hot side at the top of the detector. For all other types of failure events, the optimum location is the cold side of the detector, to ensure adequate temperature and time buffers for excluding minor start-up spillage.

9. A temporary backdraft resulting in re-establishment after 60 seconds could result in a black dot for both 38°C and 52°C indicators. Thus with DHW heaters, the only sure sign of a major, prolonged spillage event would be the darkening of the 71°C dot.

3.5 Oil Furnace Spillage Detector Design

Two different detector strategies were considered for oil furnaces. The first was to detect an increased particle count in the air around the furnace using smoke detectors. The second was to use temperature indicating materials in a similar fashion to gas fired appliances. Because of the large variation in operating temperatures and design features in oil furnaces, it was necessary to corroborate findings on Test House No. 3 with short field tests conducted on random houses in the company of an oil furnace serviceman. Figure 24 shows the final detector design.

Initial testing with smoke detectors around an oil furnace indicated high potential for this type of technology. Smoke detectors mounted at the ceiling level above the inspection port and above the barometric damper were found to sense combustion gases even when these gases were spilling at very low temperatures and for periods as short as 10 to 15 seconds. Connecting smoke detectors in these locations to pulse counters in place of the sonic alarm appeared to offer an excellent technology. An experiment was conducted in Test House No. 2 to see if smoke alarms were sufficiently responsive to typical spillage gases from an oil furnace. Temperature probing and the flue of a spilling oil furnace indicated that the only suitable location for mounting a detector was directly above the barometric damper. A minimum distance of 150 mm was felt necessary to avoid melting the housing of the smoke alarm. A more convenient location would be on the ceiling, directly above the dampers. Both these locations were tested, by timing the response of a smoke alarm to varying quantities of spillage. Spillage quantities were varied from 2% to 50%, by varying the crack opening of the barometric damper and blocking the flue pipe. At the same time, the air intake of the oil burner was adjusted from open to closed, to alter the soot (particle) concentration of the spillage gases. The results of this testing is presented in Table 3.

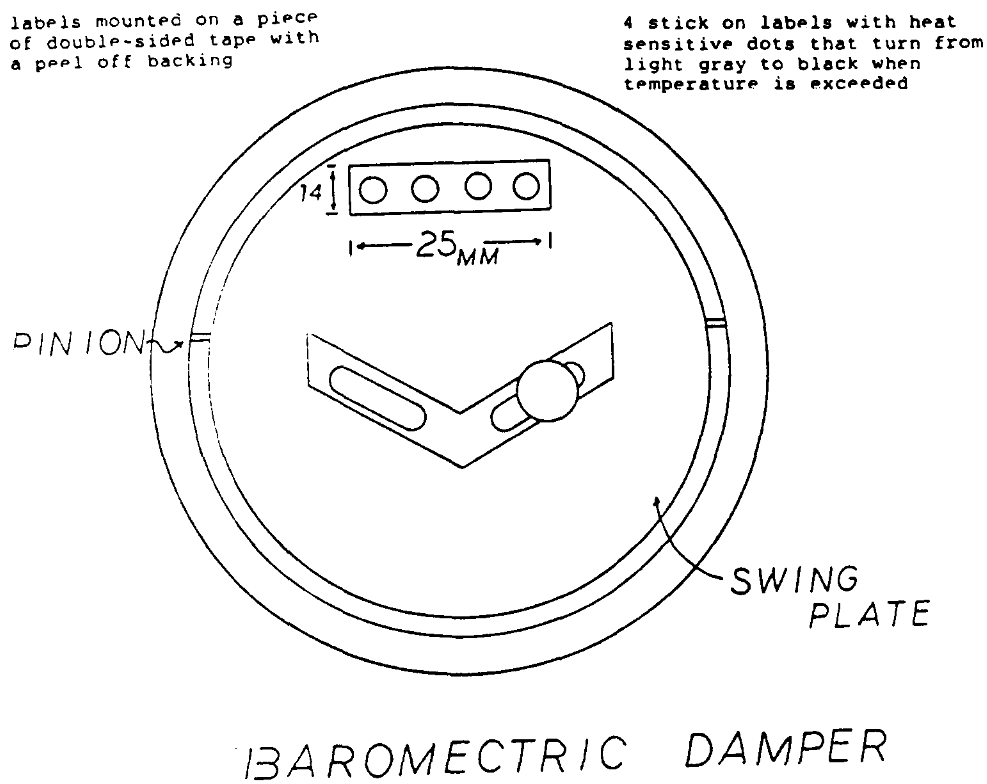


FIGURE 24: Proposed Design of Spillage Detector for Oil Furnaces

Tables 3

RESPONSE TIME OF SMOKE DETECTOR TO OIL FURNACE SPILLAGE

Air Intake Adjustment on Burner	Vertical Distance Separating Smoke Detector and Barometric Damper	Response Time in Seconds Approximate Spillage Quantity As a Percentage of Total Flue Gases 2%	5%	25%	50%
Furnace As Found	150 mm	*	15	14	12
	600 mm (ceiling)	*	24	21	19
Close Off Air Supply	150 mm	*	10	7	5
	600 mm	*	19	19	18
Open Wide Air Supply	150 mm	52	12	8	6
	600 mm	*	17	17	16

* No Response

Table 4

RESPONSE TIME FOR DOTS MOUNTED ON SWING PLATE OF BAROMETRIC DAMPER

House No.	Location of Dots on Barometric Damper	Response Time in Seconds for Each Dot Temperature (°C) 38	43	49	54	60	66	71
1	Top	76	76	194	8	8	*	*
2	Top	5	5	5	5	5	*	*
3	Top	*	*	95	131	160	185	209
4	Bottom	*	*	80	95	120	*	*

* Dot detectors were not used for these temperatures

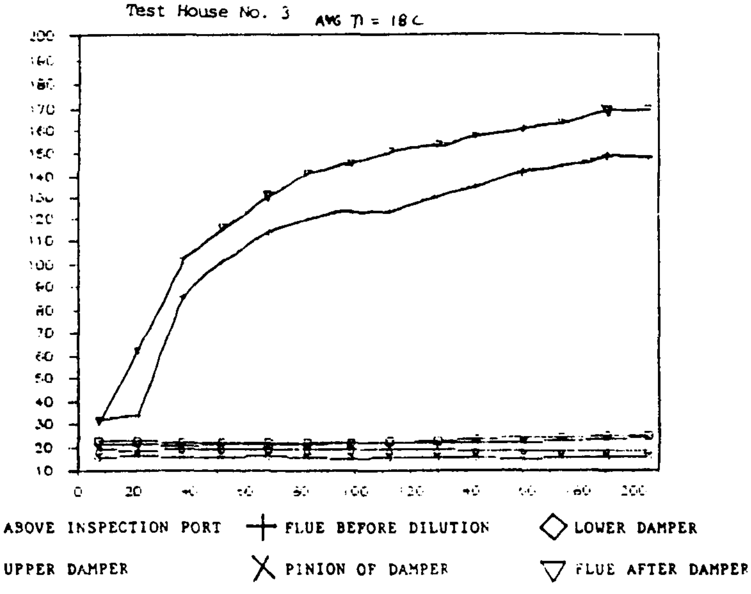
Both the ceiling location and the location 150 mm above the damper appeared suitable. However, the 150 mm distance produced a consistently faster response time, averaging only 10 seconds delay between the start of spillage and sounding of the alarm. Adjusting the air intake on the burner, and altering the quantity of spillage gas, produced insignificant changes to response time. An exception is the 2% spillage condition, which was generally undetectable. A location 150 mm above the damper was felt preferable, since this could avoid exposing the detector to humid air, which sometimes collects at the ceiling level (eg. during clothes washing).

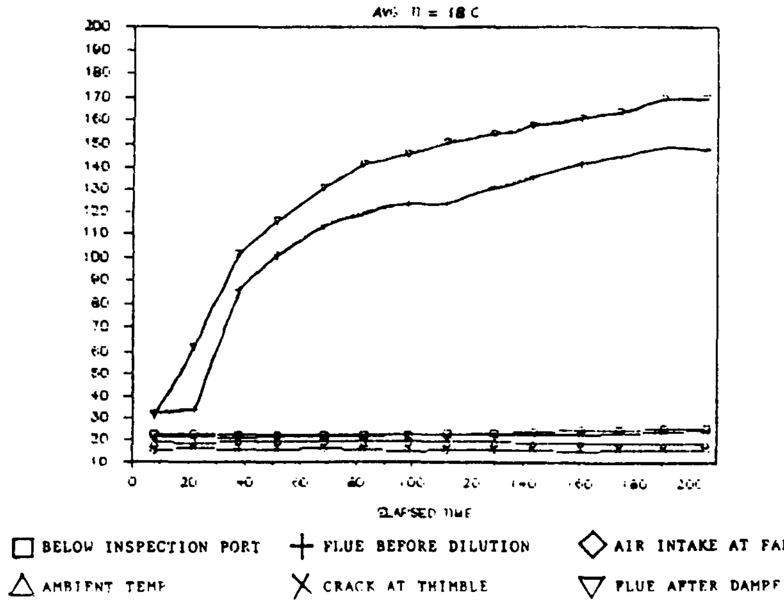
Although the smoke alarm performed extremely well as a spillage detector, (at least for this brief experiment), the concept was eventually rejected on the basis of cost. A converted smoke alarm appeared to entail equipment costs in the range of $30.00 to $40.00, considerably above the $10.00 allocation in the budget. The smoke alarm and counter technology seemed to be more appropriate for follow-up investigations on furnaces where some type of spillage was known to be occurring. The smoke detector seemed particularly well suited for detecting spillage from backpuffing at start-up which commonly occurs at the inspection port or at the barometric damper.

To explore the possibility of using heat sensitive dots for detecting spillage from oil furnaces, a series of tests were conducted on Test House No. 3 so as to map the temperature profiles over time at various locations around an oil furnace undergoing spillage.

A Legend is provided for Figures 25 to 29, indicating the location of thermocouple sensors during this temperature mapping. Figure 25 shows the normal operating temperature range of the oil furnace (surprisingly low due to the large mass and high efficiency of this particular model).

URE 25 OIL FURNACE TEMPERATURES DURING NORMAL OPERATIONS
Test House No. 3





LEGEND FOR FIGURES 25 to 29
LOCATION OF SENSORS DURING TEMPERATURE MAPPING OF OIL FURNACES

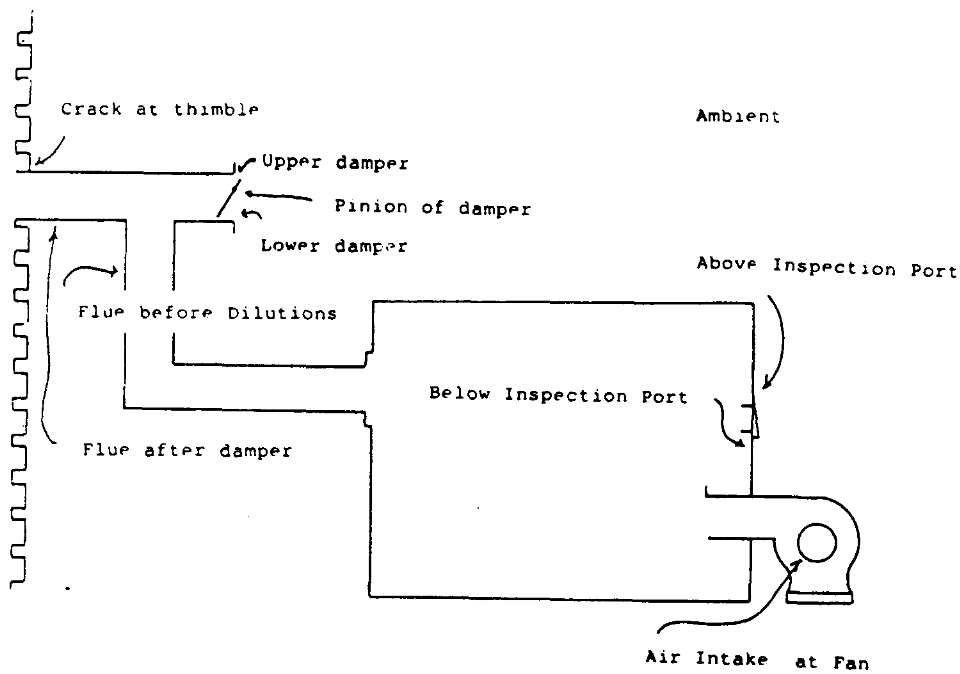
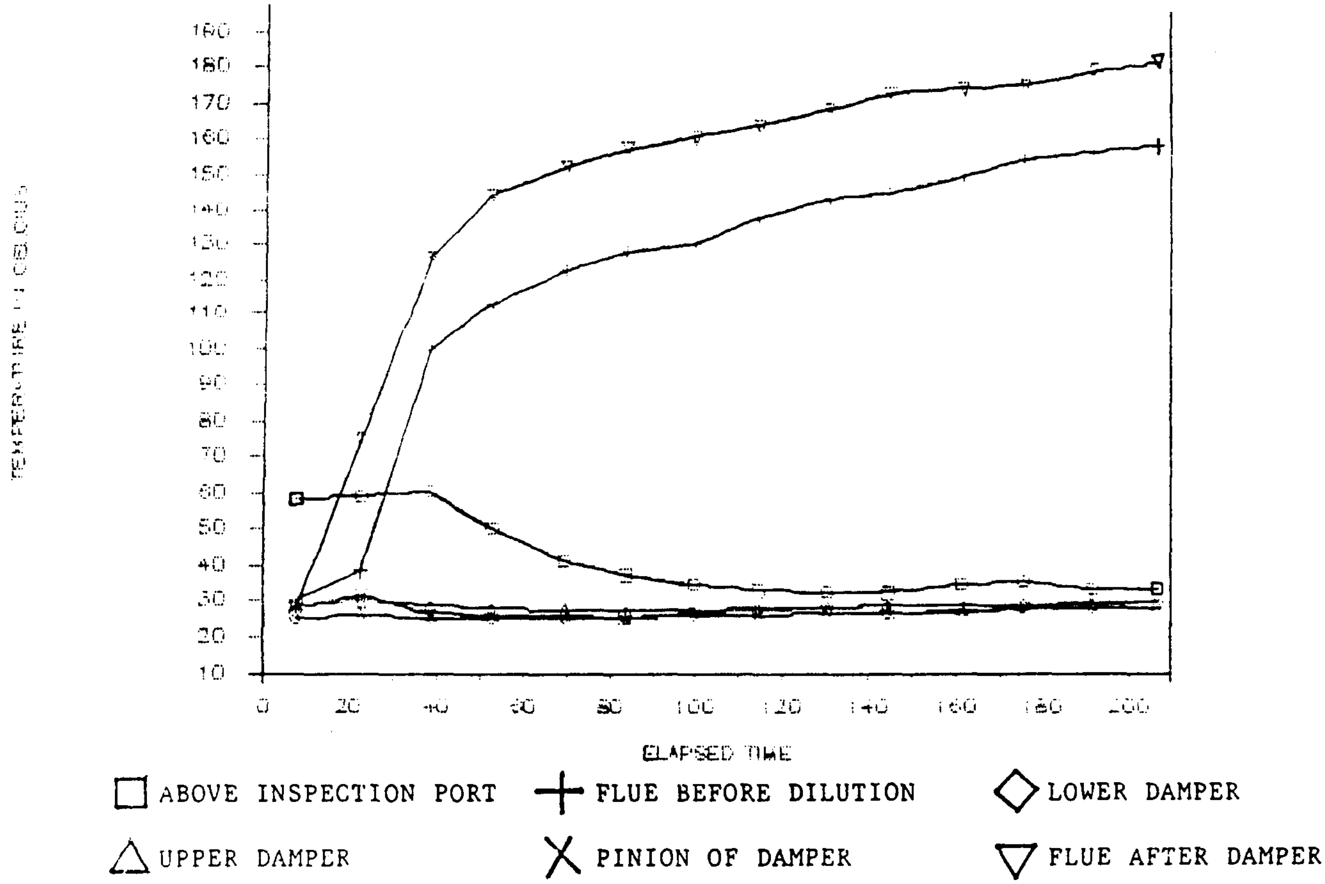


FIGURE 25: Oil furnace Temperatures During Normal Operations
LEGEND FOR FIGURES 25 to 29: Location of Sensors During Temperature Mapping of Oil Furnaces



As Above With Alternate Locations

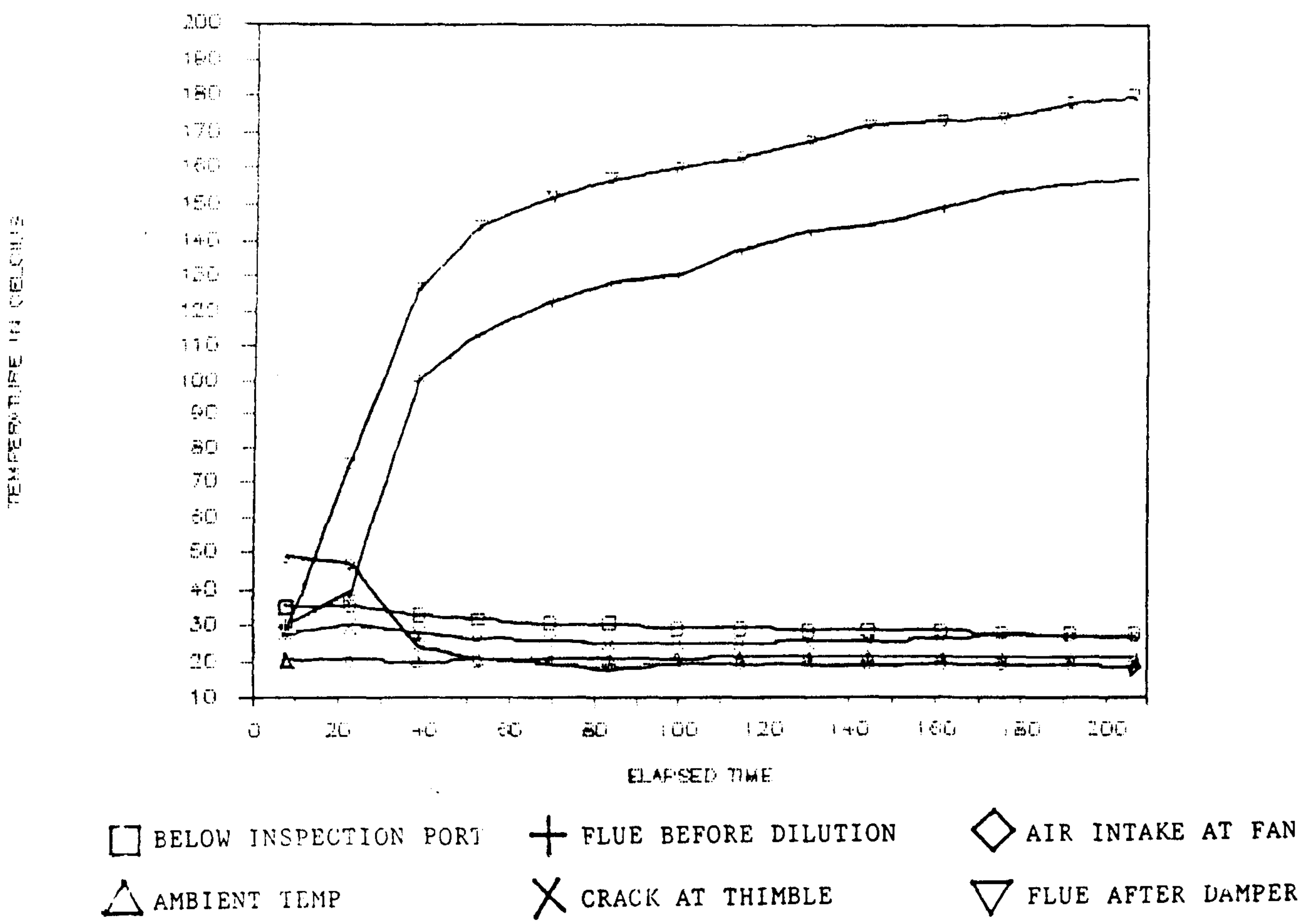
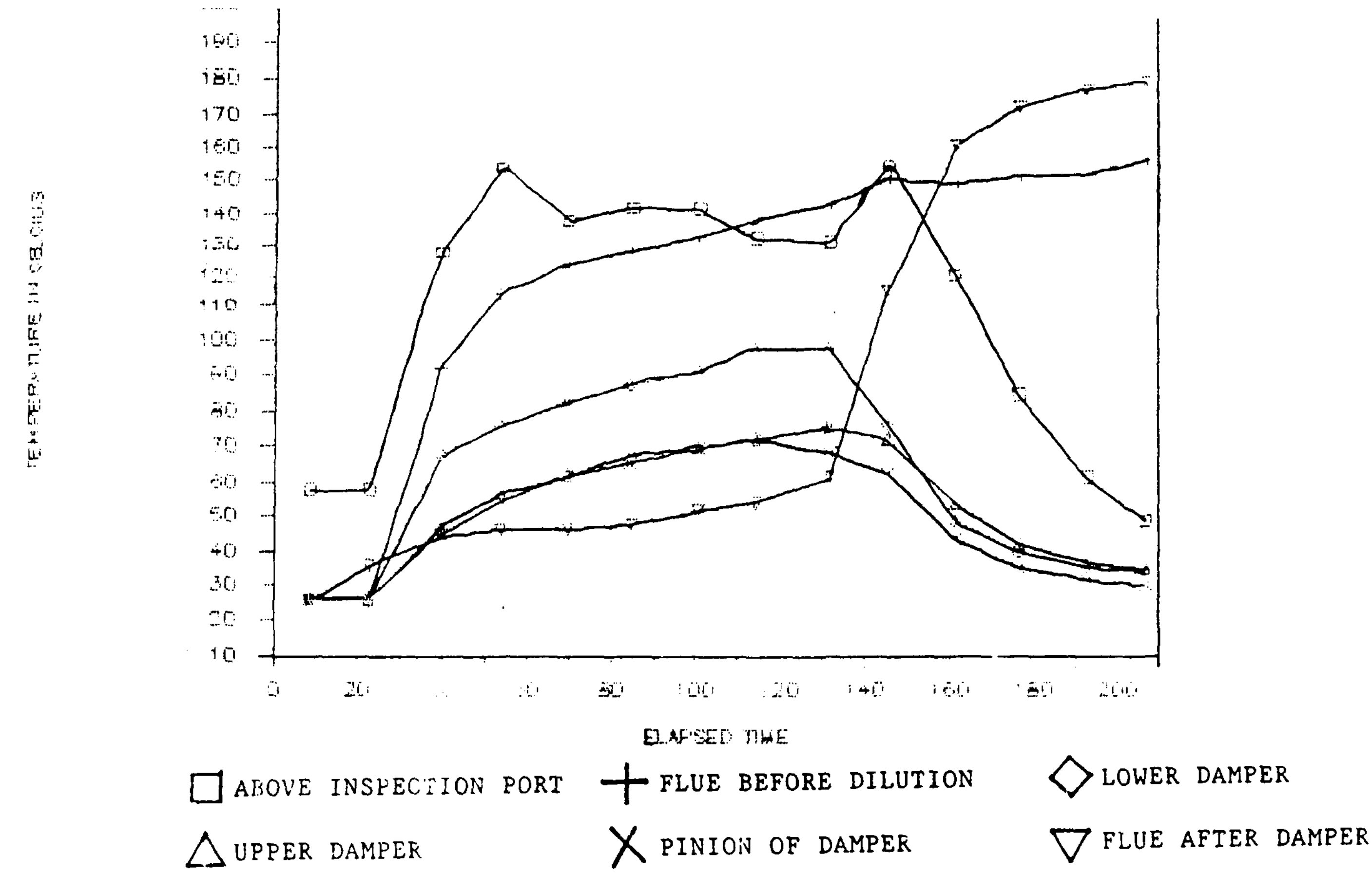


FIGURE 26 OIL FURNACE WITH BACKDRAFT OCCURING AT START-UP ONLY
Test House No. 3



As Above With Alternate Locations

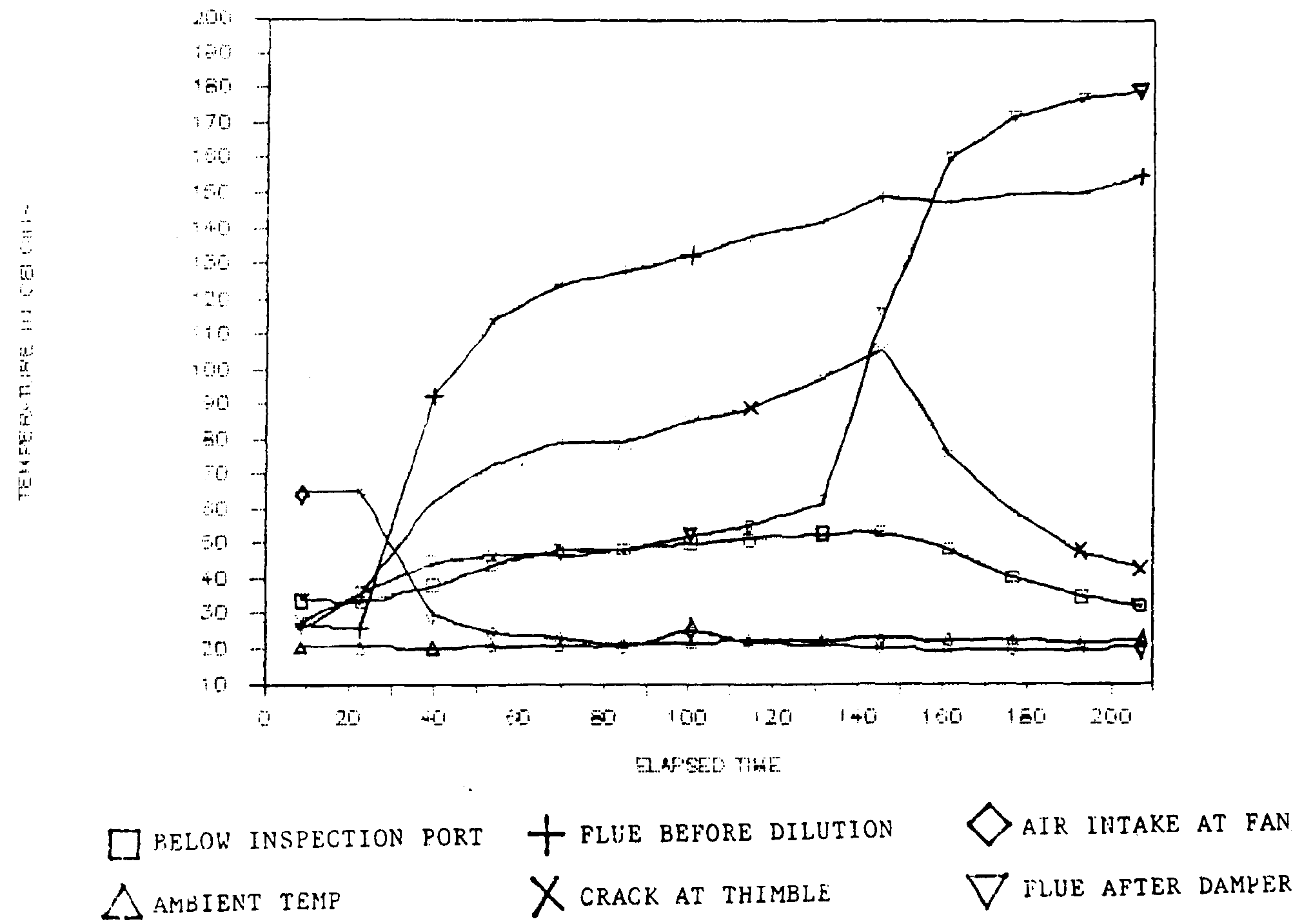
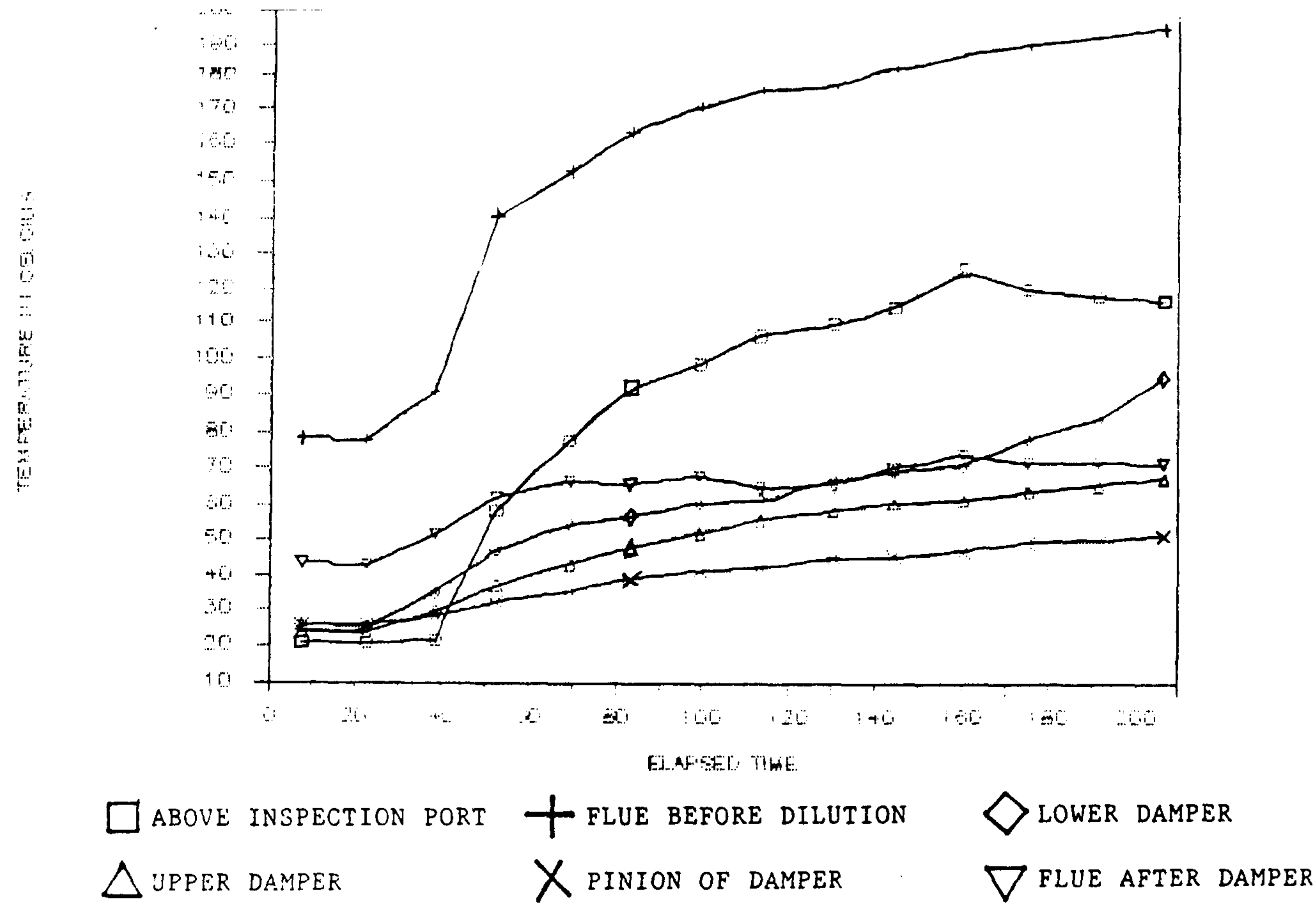


FIGURE 27 OIL FURNACE WITH CONTINUOUS SPILLAGE
Test House No. 3 DUE TO BACKDRAFT FROM 14 PASCAL HOUSE DEPRESSURIZATION



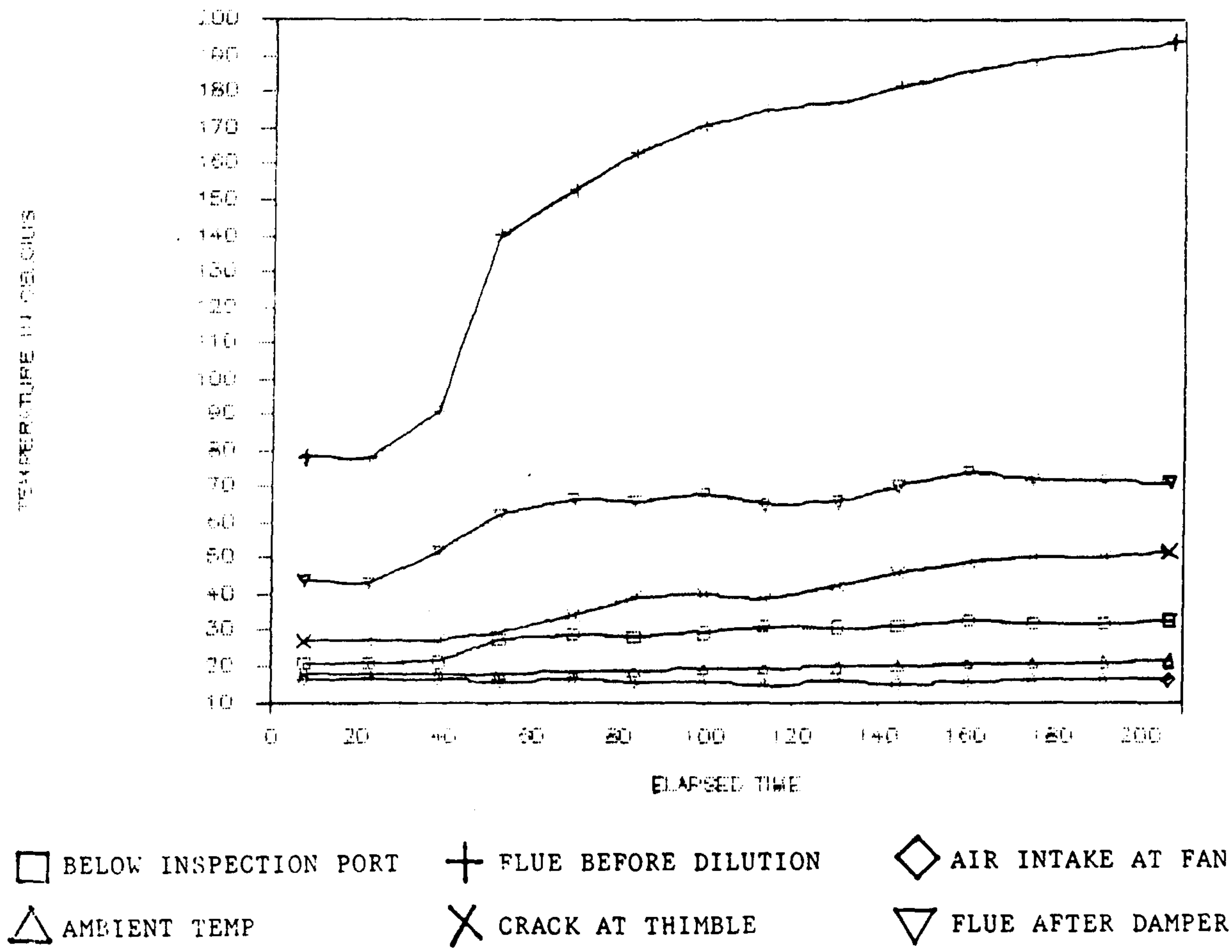
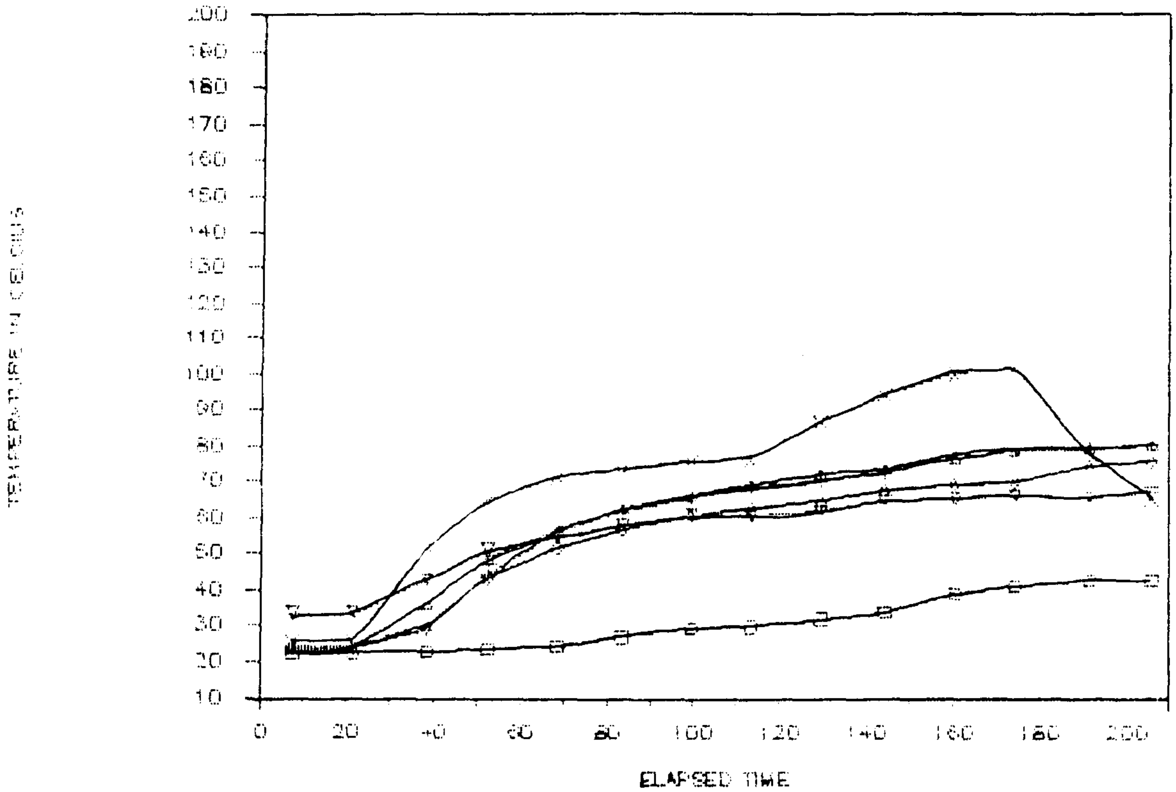
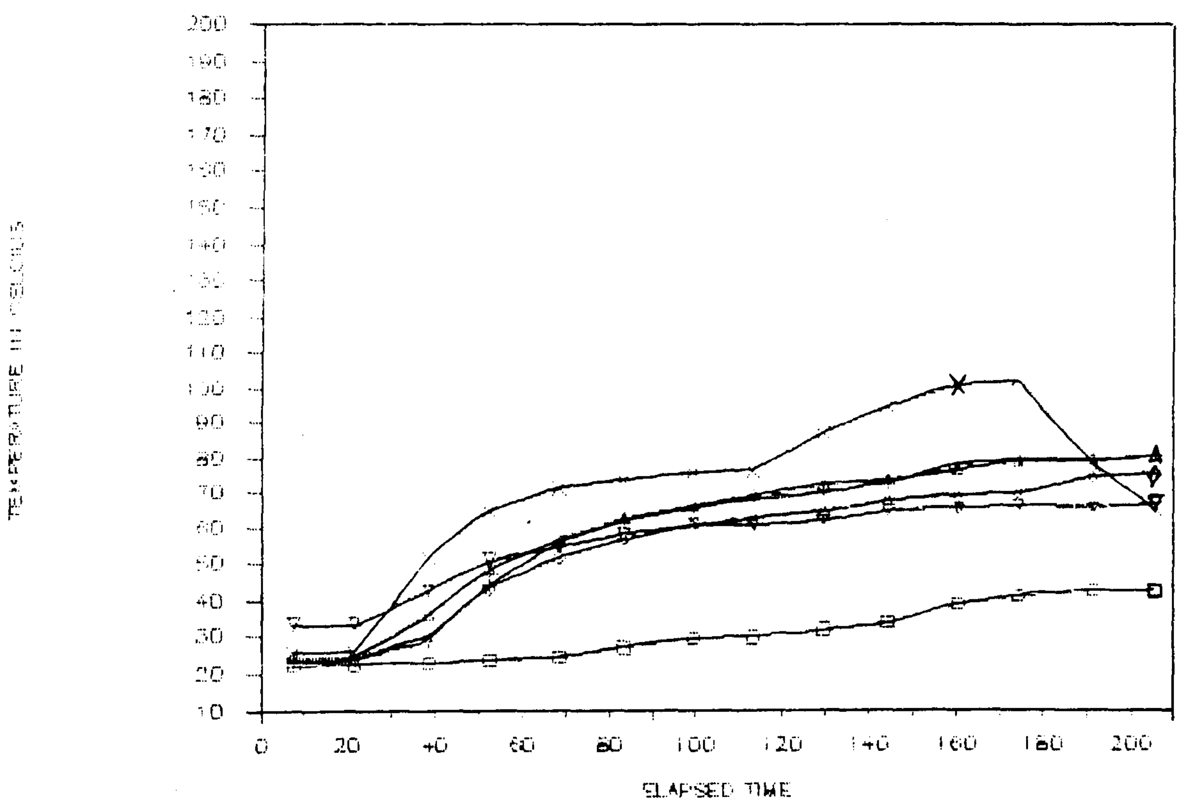


FIGURE 28 OIL FURNACE TEMPERATURES DUE TO 90% BLOCKAGE OF CHIMNEY
Test House No. 3



□ 3" ABOVE DAMPER
+ 3 O'CLOCK
◇ 10 O'CLOCK
△ 2 O'CLOCK
X 9 O'CLOCK
▽ TEMP. IN CHIMNEY



□ TOP OF DAMPER
+ 3 O'CLOCK
◇ 7 O'CLOCK
△ 5 O'CLOCK
X BOTTOM OF DAMPER
▽ TEMP. IN CHIMNEY

FIGURE 29 TEMPERATURE AROUND EXTERIOR OF BAROMETRIC DAMPER DURING SPILLAGE DUE TO BLOCKAGE OF CHIMNEY
Test House No. 3

Figures 26 and 27 illustrate temperatures during start-up backdraft as might be encountered by a furnace under conditions of high house depressurization.

Figure 28 illustrates the temperatures around the furnace during spillage due to 90% blockage of the chimney. Although excess temperatures were experienced in many locations around the furnace, the only possible location for a spillage detector was around the barometric damper. The inspection port is ruled out as a location because the off-cycle backdrafts through a warm furnace cause extremely high heat spillage through the inspection port, and through the burner fan inlet (this would cause erroneous readings). Cracks at the thimble (i.e. the junction of the flue connector with the vertical masonry chimney) are excellent locations for detecting spillage but, because of the variation in flue connector installation, there is no guarantee that crackage exist.

Locations around the barometric damper on the oil furnace indicated that spillage temperatures under all conditions were surprisingly low temperature, and without any consistent pattern. A more detailed mapping of temperatures around the damper was undertaken to better locate a plastic detector, that could be mounted at some location on top of, or beside, the damper so as to detect minor or short-term spillage events

The two graphs in Figure 29, illustrate temperatures around the exterior of the barometric damper during spillage due to blockage of the chimney. The temperatures around the damper appear to vary significantly as a result of the minor changes in crack between the junction of the damper and its housing. Although much of the spillage gas quickly rose up the face of the barometric damper, it was also quickly mixed with indoor air and cooled, so that temperatures above the damper were below any reasonable detection limit.

The design of a barometric damper causes the damper to be shut firmly when backpressures occur in the flue connector. Spillage gases are forced through the crackage around the edge of the damper at fairly high velocities. To capture these gases, as they rose from the damper, an attempt was made to develop a plastic detector that would overhang the top rim of the barometric damper. It would scoop the gases towards heat sensitive dots, located on the lower portion of the hot side of the detector. The plastic detector was strapped to the barometric damper using a metal spring with hooks. After considerable experimentation, this design was rejected because of inconsistent results during field testing. Even major failures with oil furnaces produced spillage quantities at the damper that were inconsistent. Spillage temperatures in this location would typically rise to 50°C or 60°C after 60 seconds of major spill. Use of heat sensitive dots above the damper was felt unlikely to provide a reliable indication of partial or short term spillage.

The optimum location for the heat sensitive dots on an oil furnace was found to be directly on the surface of the vertical face of the barometric damper as illustrated in Figure 24. Four stick-on labels with heat sensitive dots are mounted on a piece of double-sided tape and attached to the uppermost portion of the damper face.

At this location, the dots are easy to apply and extremely easy to read. The high conductivity of the metal damper ensures that the surface temperature of the dots reach the temperature of gas on the opposite side of the face within seconds. The precise time delay was not measured under controlled conditions.

Under normal operating conditions, this portion of the damper is unconnected with the rest of the flue connector eliminating any significant conductive heat gain. The chimney updraft draws room air through the damper, and thus the damper is bather in draft air at ambient temperatures. Field evaluations confirmed that the face of the damper remains relatively cool compared to other parts of the flue connector. Despite warming of the damper duct, and the flue connector, the damper face was found to remain at or just above room temperatures even during extended periods of furnace operation. Radiant heat gain from the hot flue connector would appear to be insignificant as long as the draft air is entering the damper. Even a poorly balanced damper that remains closed during high draft conditions, will still be bathed in cool, draft air around the perimeter of the swing plate.

Under conditions leading to chimney gas spillage, the chimney draft is low, or the flue pipe is pressurized; and the barometric damper shuts tightly. The hot combustion gases gather first in the uppermost portion of the damper cavity. The vertical face of the damper is rapidly heated by these combustion gases, producing an extremely rapid response for dots located on the damper. Since oil furnaces are expected to be prone to short term backdrafting and spillage; as opposed to prolonged spillage or backdrafting, furnace detectors indicate both short term (10 to 30 second) and longer term spillage events, depending on gas temperatures and configuration of the flue pipe.

Field testing of the prototype spillage detectors was conducted on three randomly selected oil furnaces while accompanying an oil furnaceman on his daily visits in the Vancouver area. In each house, spillage conditions were induced by temporarily blocking the chimney. Colour change of the dots was observed and timed following furnace start-up. The response time of the dots in the trial houses are presented in Table 4. In the first house, the delay of over two minutes was a result of two factors: the chimney was only partially blocked, thus spillage was minor; and the barometric damper was connected directly to the vertical chimney above the thimble, and consequently was a long distance from the furnace itself. It was apparent that the entire flue connector had to first purge itself of household air before spillage temperatures were achieved at the damper. (It should be noted that spillage was occurring throughout the first two minutes at the inspection port.) The extremely rapid response of dots in the second test trial house was partly because the flue was blocked at least 95% in this test.

In the third trial house, the face of the barometric damper was observed to reach high temperatures even under normal cycle operation. Application of the detector without any attempt to block the chimney resulted in all of the dots changing colour within a period of 3-1/2 minutes. Further investigation revealed that the chimney was in fact spilling very slightly under normal operating conditions due to poor design and installation. A wood stove was connected to the flue connector of the oil furnace, and shared the same flue in the masonry chimney. Air drawn through the non-operating wood stove and through numerous cracks in the masonry chimney resulted in a very poor draft in the chimney. Thus, the initial test of the spillage detector on the third trial house helped to confirm the suitability of the design.

The selection of an appropriate temperature range for dots on the oil spillage detector is complicated by the extremely varied features of existing oil furnace flues and dampers. There was no need for a hot side dot as with the gas appliances since the damper is highly conductive. A 38°C was chosen as a means of detecting even minor short term spillage occurrences, although without further testing, it is unclear whether such a highly sensitive dot is likely to change colour under normal operating conditions on an extremely hot furnace. As with gas appliances, the 54°C and 71°C dots are useful indicators since they bracket the temperature range which is likely to be experienced after approximately one minute of minor spillage. In addition, a hot dot of 121°C was selected as an indicator of definite major spillage problems. The rapid temperature response of the swing plate does not provide a reliable time delay for dot changes, as with the gas appliance dot detectors.

3.6 Design of the Fireplace Spillage Detector

Three different strategies were examined for detecting spillage from fireplaces: carbon monoxide, temperature, and particle density (i.e. smoke).

Carbon Monoxide Detectors:

The use of carbon monoxide as an indicator of fireplace spillage was initially rejected on the basis of cost. Both a literature review, and a field experiment conducted for this project, indicated that carbon monoxide levels from wood fireplaces are sufficiently high to be used as an indicator of spillage. The fireplace in Test House No. 2 was monitored using an Interscan Digital CO Meter. Figure 30 presents the carbon monoxide concentration at the mantle above the fireplace during slight spillage and marginal backdrafting. A low heat would ember fire was maintained during spillage and backdrafting. CO levels were monitored on a millivolt strip chart recorder. Figure 30 is actually a portion of the strip chart recorded during these events, and indicates that even during slight spillage and backdraft at a low house depressurization of 4 Pa, the concentrations of carbon monoxide are consistently above 50 ppm.

Two CO alarms were tested for use as a CO detector: the Co-Sensor produced by CO-Sensor International, and the Gas Sniffer produced by Revco Products. The Co-Sensor alarm is rated to be much more sensitive to CO than the Gas Sniffer. The Co-Sensor alarm is normally set at the factory to detect CO limits of 50 ppm. The alarm has a built-in 2-1/2 minute time delay which causes problems in detecting spillage since fireplaces often spill irregularly or briefly. Also the cost of the alarm (approximately $100.00 in bulk) mitigated against widespread application during the Canada-wide survey. Finally, the CO alarm using a

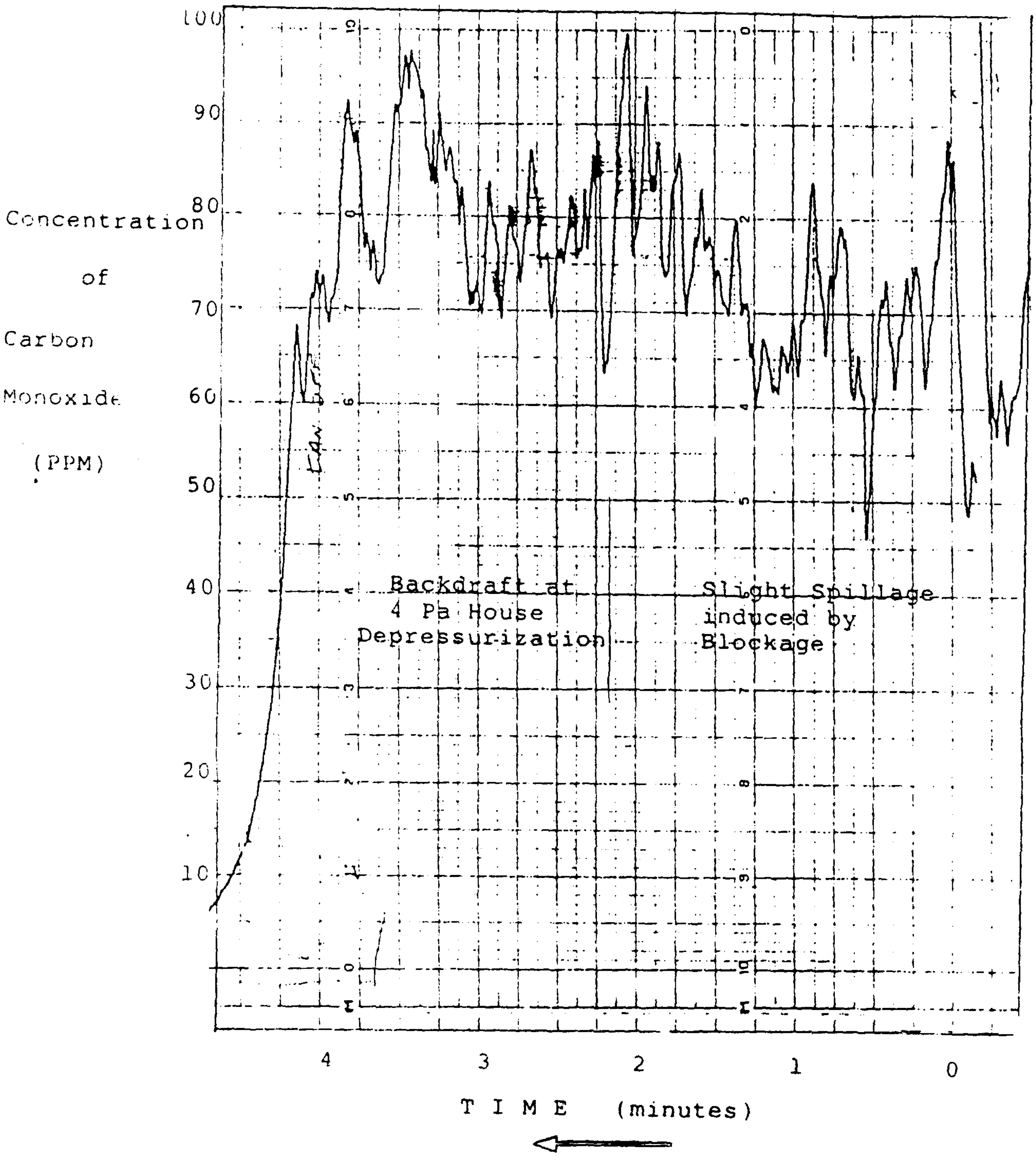


FIGURE 30: Carbon Monoxide Concentrations at Mantle Above Fireplace with a Low Heat Wood/Ember Fire During Slight Spillage and Marginal Backdrafting

solid state CO sensor requires a constant AC power and therefore is not easy to mount at the mantle, since wiring must be stretched to the closest AC plug.

Temperature Detectors:

A strategy based on detecting excess temperatures around the fireplace opening was evaluated in a similar manner to gas and oil fired appliances. The Sciemetrics Data Acquisition system was used to develop time/temperature profiles for various locations around the front of the fireplace opening during various failure modes. Ten thermocouple sensors were used for this purpose (Nos. 2 to 11) and the location of each of these sensor numbers is noted in the Figure 31. A full day of testing on the fireplace in Test House No. 2 as the fireplace was caused to spill under all possible failure modes using both simulated fire (propane stove), and a real wood fire at varying intensities of burn.

Figures 32, 33 and 34 contain graphs that illustrate time/temperatures profiles for some of the most important types of fireplace spillage incidents. Figure 32 illustrates temperatures during partial spillage from a wood fire, as might occur under stall or backdraft conditions. Figure 33 illustrates temperatures of minimal spillage from a low heat wood fire. Figure 34 shows the same fire and spillage only 600 seconds later. Throughout the entire spillage occurring in Figures 33 and 34, the house was maintained at a depressurization level of 4 Pa. At approximately 670 seconds, the heat from the fire was insufficient to maintain an updraft and flow reversal occurred. (This scenario may be typical for many wood fireplaces in houses where slight depressurization causes backdrafting as the fire is burning low.)

A number of observations were made from analyzing the data on fireplace time/temperature profiles.

SENSOR NO.	LOCATION	ABBREVIATION
2	60mm above hearth, centre, flush with face	H + 6
3	300mm inside fireplace opening at top of smoke chamber	chimney
4	60mm above lip at masonry face	6 AB
5	60mm in front of lip	6
6	120mm in front of lip	12
7	inside lip 75mm at opening of chamber	@OP
8	under mantle (455mm above lip)	MAN
9	60mm below lip	6 BEL
10	150mm above hearth	H + 15
11	at the lip	LIP

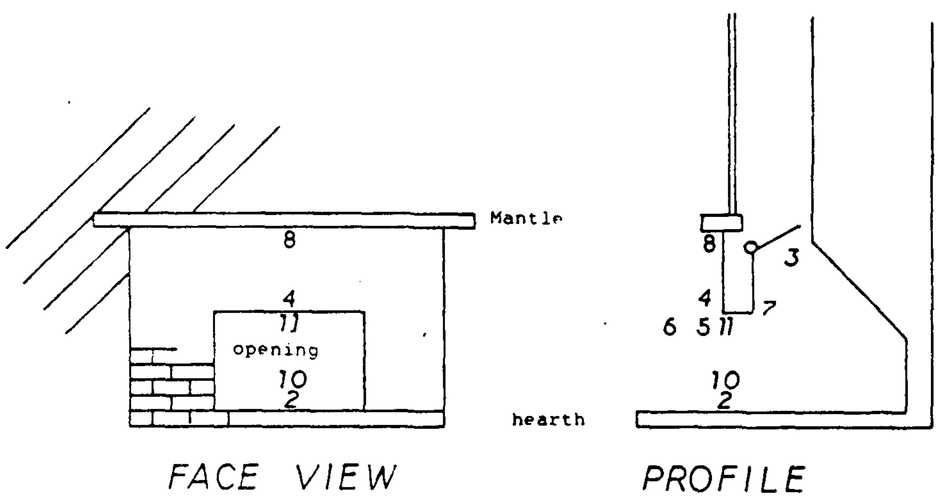
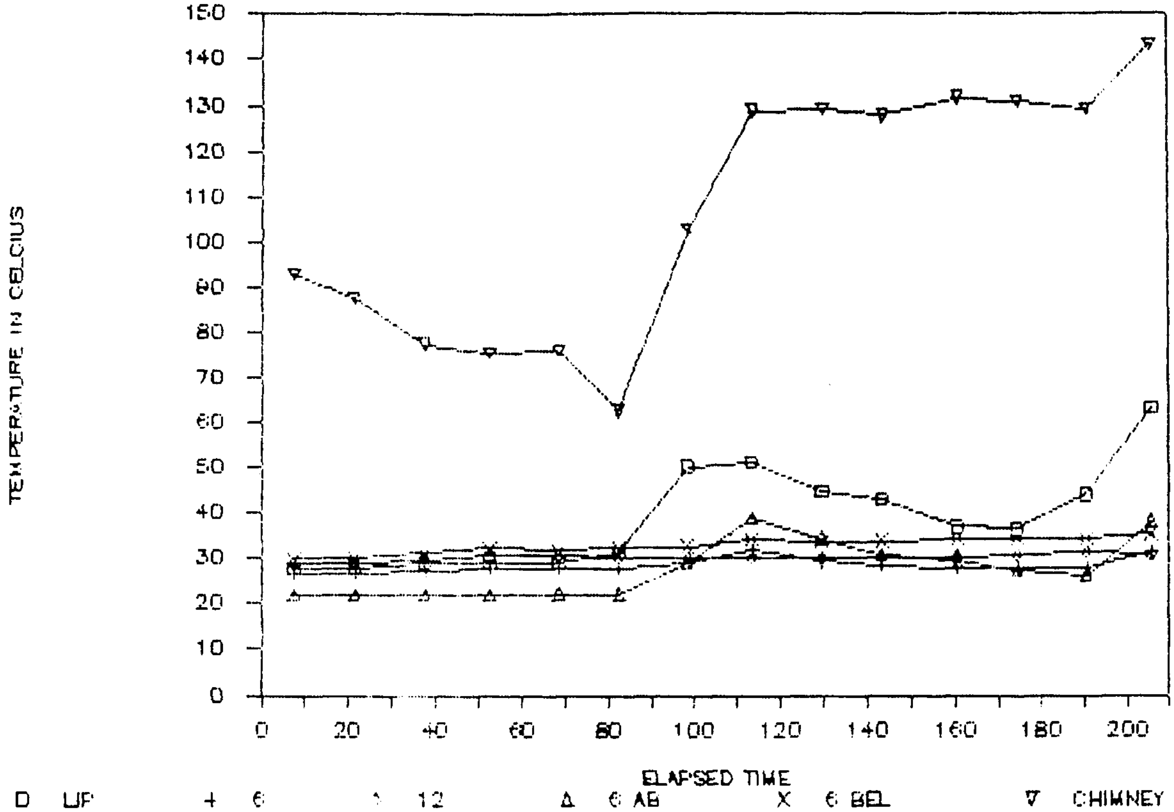


FIGURE 31: Legend for Fireplace Mapping



As Above With Alternate Locations

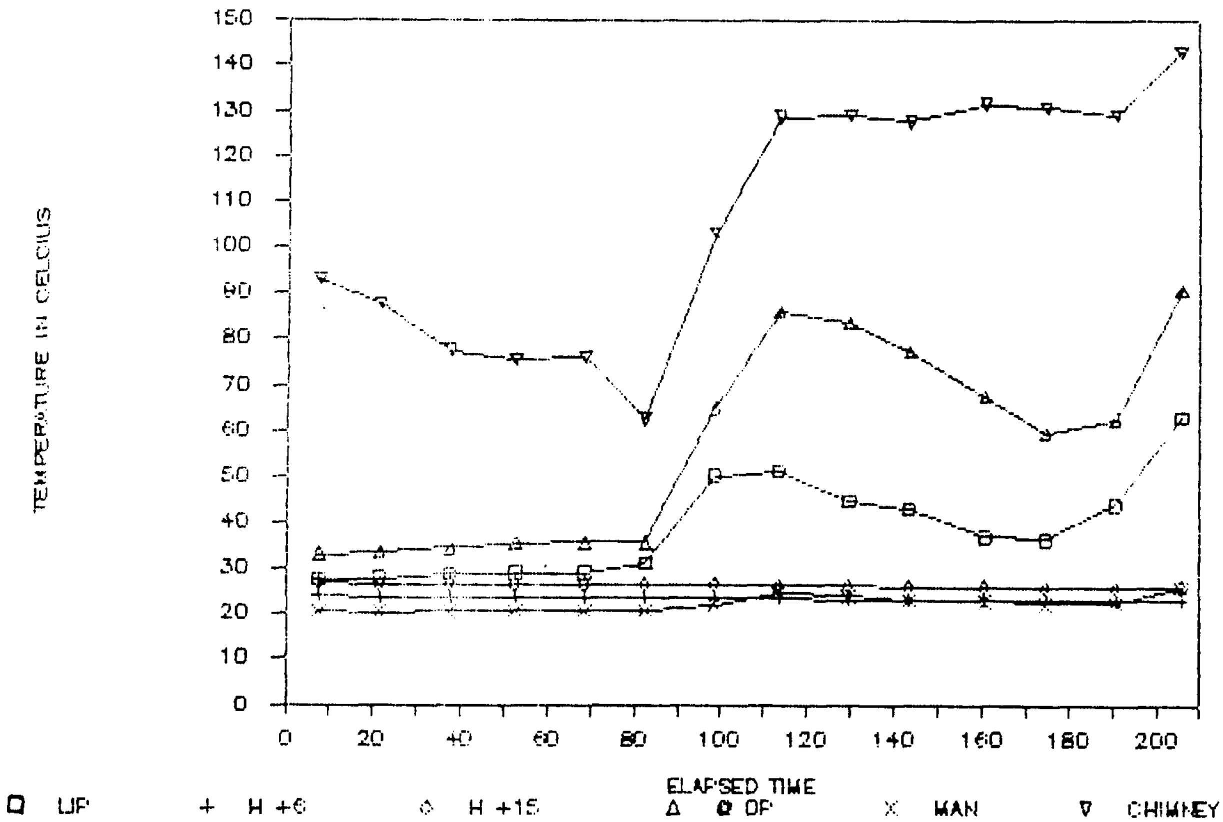
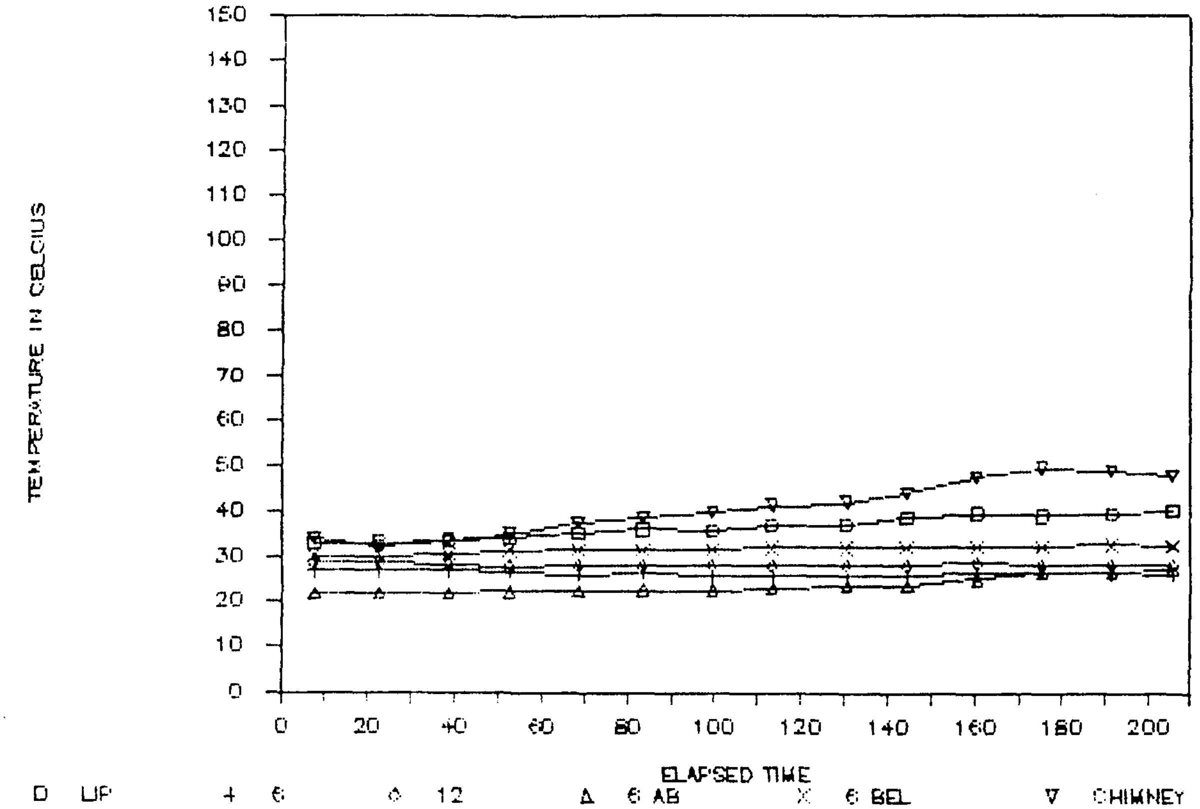


FIGURE 32: Wood Fire with Partial Spillage



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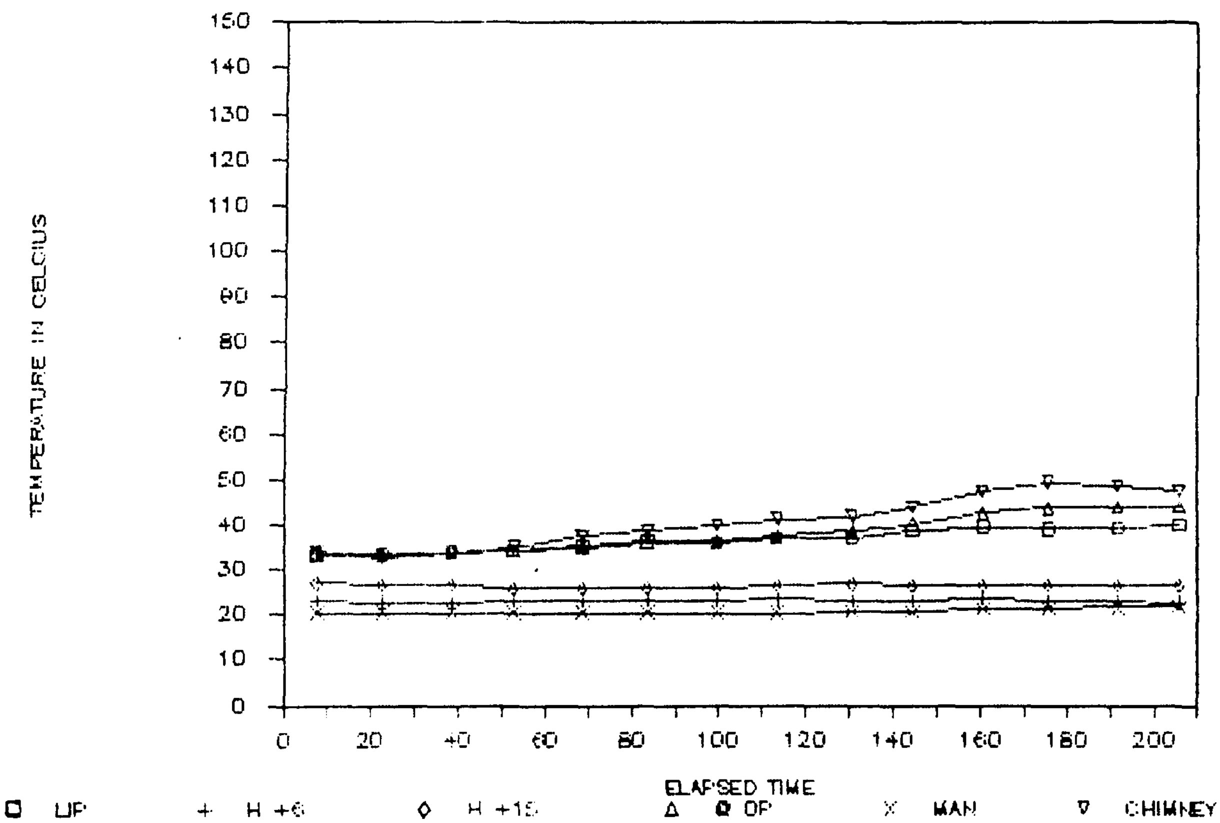
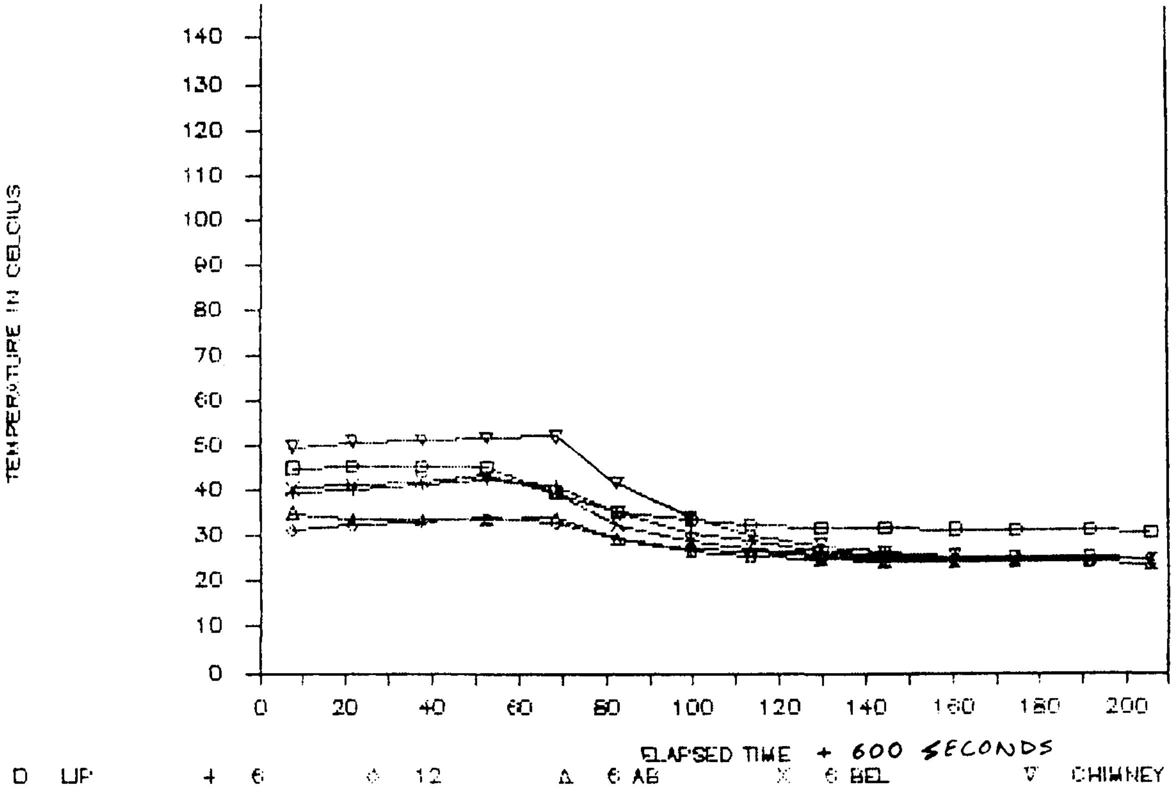


FIGURE 33: Wood Fire with Minimal Spillage



AS ABOVE WITH ALTERNATE LOCATION

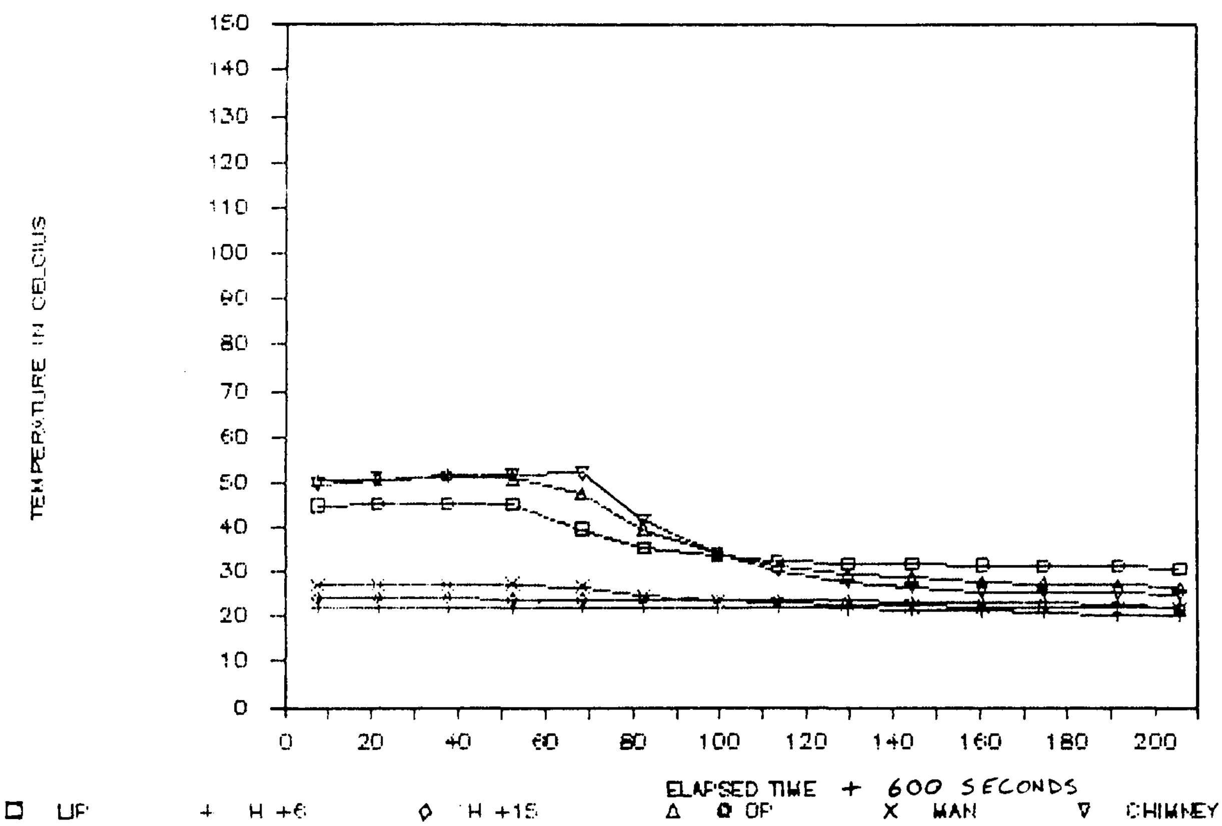


FIGURE 34: Wood Ember Fire with Minimal Spillage Continued until Full Backdraft Occurs

Extreme high temperatures were recorded at all locations around the face of the fireplace during a roaring fire. Although spillage was not occurring under these conditions, the radiation from the fire would be sufficient to cause dots to change colour at all temperature ranges. Therefore, any detection strategy based on temperatures would need to use a location or a shielding mechanism that avoided radiative heat gain from hot fires.

Both backdraft and blockage caused fireplaces to spill along the uppermost portion of the opening. Often the velocity of spillage caused gases to overshoot the area immediately above the upper lip of the fireplace.

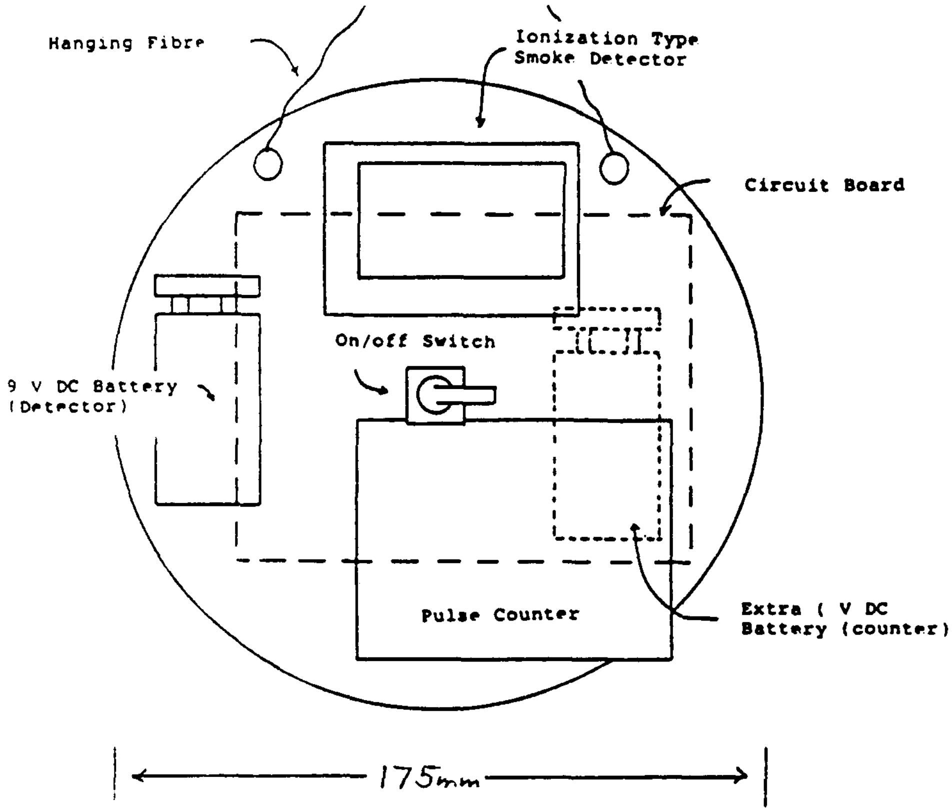
The temperatures experienced above and outside the fireplace opening are extremely low during conditions of partial spillage, below the range that can be easily detected using the heat sensitive materials.

Smoke Detectors:

A third strategy for detecting spillage from fireplaces was the use of conventional smoke alarms connected to counters and/or time totalizers.

Extensive testing of smoke alarms located above fireplace openings during conditions of partial spillage from low heat wood fires demonstrated that in almost all cases a smoke alarm is sufficiently sensitive to identify a spillage event.

The method employed for converting a smoke alarm to a fireplace spillage detector is shown in Figure 35. The detector consists of an ionization type smoke detector (Dicon Model 300B1) with a snap-in sonic alarm removed and replaced by a Tecon non-zeroing pulse counter. The pulse counter is powered directly from a 9 Volt battery. The test button of



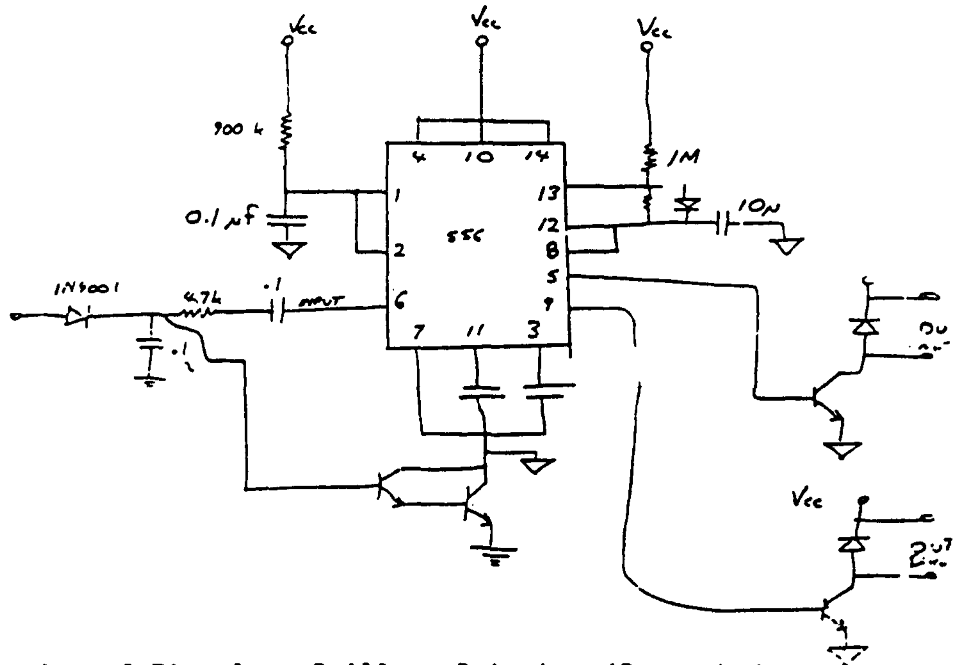


FIGURE 35: Proposed Design of Fireplace Spillage Detector (Converted Ionization Smoke Alarm)

FIGURE 36: Wiring Schematic for Circuit Board of Spillage Detector

the smoke alarm has been replaced with an on/off switch so that the smoke detector can be temporarily de-activated by the homeowner during starting and loading of fireplaces.

An additional circuit board is installed inside the detector to permit the detector to operate the pulse counter. The wiring schematic for this customized circuit board is presented in Figure 36. The power supply from the extra battery to the counter is reduced by a resistor to minimize battery drain. Power supply is controlled by a transistor connected to the smoke detector. A diode and capacitor are used to convert the high frequency oscillating current from the detector to a current sufficient to operate the transistor.

The Dicon Model 300BI is a Canadian made ionization smoke alarm, with a 112 mm diameter housing that is approximately 37 mm thick. An ionization alarm was chosen in preference to photoelectric because of its greater sensitivity to small smoke particles. There is no direct relationship between particle density and the detector sensitivity. The ULC Standard for smoke alarm sensitivity is based on the percentage of light obscuration per foot. The alarms are normally factory set to be sensitive to a nominal value of 1% light attenuation per foot. The calibration procedures involve generating smoke (using a cotton wick) with a small particle size of 0.1 to 10 micron particles. The smoke is blown through a 5 ft long optical beam, and the light obscuration is measured. It is probable that light obscuration will vary for a given density of smoke, with such factors as emissivity and particle size. The detectors are reported to be capable of sensing smoke that is invisible to the naked eye.

The performance of smoke alarms as spillage detectors was evaluated in the personal home of a Sheltair employee. The test fireplace was masonry construction with a conventional hearth and no doors or combustion air

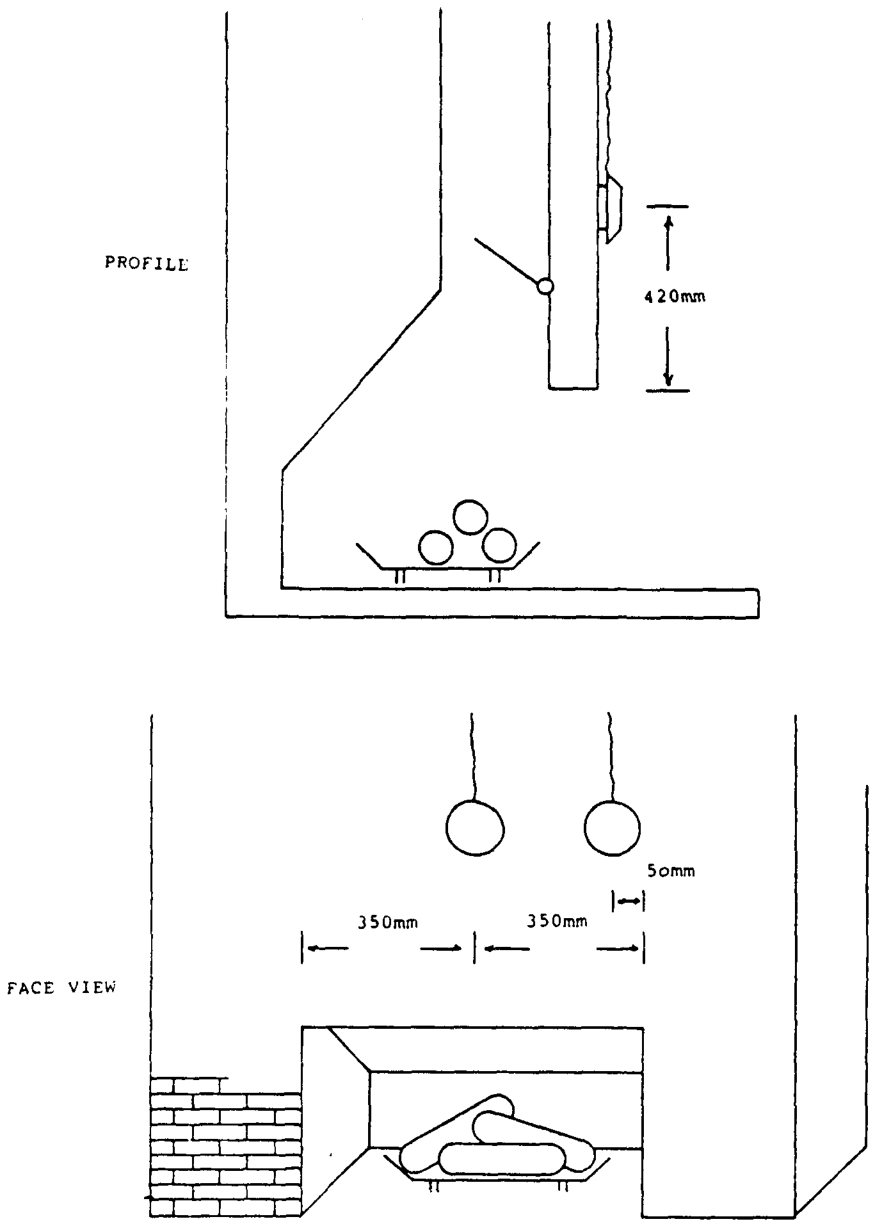


FIGURE 37: Smoke Alarm Testing Above Open Fireplace

supply, and a 150 mm X 275 mm flue. The location of the smoke alarm is illustrated in Figure 37. Observations of the smoke alarm performance during testing are summarized below:

1. In all cases where spillage occurred along the entire length of the fireplace opening, the alarm succeeded in detecting the smoke. This was true for spillage from a hot fire, a newspaper fire, a wet wood fire, and glowing embers.

2. Slight spillage from the fireplace opening would occur first at the corners, although this location would vary depending on which are of the fire was generating the largest amount of smoke. Generally, the hotter and least smokey areas of the fire would generate highest draft, causing the fireplace to spill elsewhere.

3. The smoke alarm was found to be unable to detect slight spillage from the corners of the fireplace even when moved directly above the spillage location. Only when spillage occurred in sufficient quantities to spill all along the upper lip of the fireplace opening, would the smoke alarm activate.

4. The alarm appeared to respond instantly to smoke generation. The only delay that was observed was the delay required for smoke particles derived from the lip of the firebox up to the alarm.

5. Once the alarm was activated, it tended to stay activated until the spillage event had finished. An exception to this was caused by puffing of smoke in response to wind gusts when the fireplace in a marginal spillage condition. However, it appeared unlikely that any single spillage event in a house would activate the alarm more than once. In one case the alarm sounded when logs were being stirred in the fireplace.

6. The plastic components of the smoke alarm appeared to burn easily when exposed to a direct flame. They also tended to melt and malform at temperatures above 80°C to 100°C. Consequently the location of the alarm would have to be kept away from the fireplace opening, preferably below or at the mantle height. A non-combustible string or fibre was found to work well for hanging the smoke alarm against the face of the fireplace chimney.

The smoke alarm was very visible hanging above the fireplace, and it was clear that it would be preferable to hide the pulse counter inside the alarm so that operation of the counter did not affect the behaviour of the house.

A Smoke and CO Detector:

Further testing of wood fire spillage gas composition was conducted as part of research on fireplace remedial measures (Ref. 8). During this testing both a particle counter and a CO analyzer were used to continuously monitor spillage gases from a wood fireplace (in Test

House No. 2). The results indicated that neither a smoke detector nor a CO detector were adequate, by themselves, to detect all spillage events. Roaring fires tended to experience high particle counts, but low CO concentrations (eg. 20 ppm). Ember fires, on the other hand, experienced high CO concentrations, but very low particle counts. Table 5 summarizes some of the data obtained during these tests. (The tests were duplicated on other fireplaces with similar results.)

On the basis of this test data it was concluded that the best approach was to construct a spillage monitoring device for fireplaces that incorporated both a smoke detector and a CO detector. Further investigations into CO detector technology revealed a new type of low-cost CO detector developed by Newtech of Vancouver, B.C. The Newtech detector was still undergoing tests and patent applications, but 10 of these detectors were made available for the Canada-wide survey. The 10 detectors were calibrated by Newtech at 80 ppm of CO, and then were retested by Sheltair for accuracy and response time. The Newtech CO detectors were connected to the smoke detector pulse counter devices that had already been designed and tested for use in the survey. The final design of the spillage monitor device for fireplaces is illustrated in Figure 38. The CO detector and the smoke detector are both wired to pulse counters for recording the frequency and duration of spillage events. The response time of the CO detector is slower than the smoke detector, because the device has a 60 second operating cycle, which delays detection by approximately 60 seconds after CO concentrations exceed the limit.

The fireplace spillage monitoring devices were relatively expensive and could not be employed during the Canada-wide survey. Instead, it was proposed to fabricate 10 devices only, and install them in British Columbia survey houses in which householders were known to regularly use their fireplaces. Without a suitable low-cost spillage detector, this approach was the only alternative.

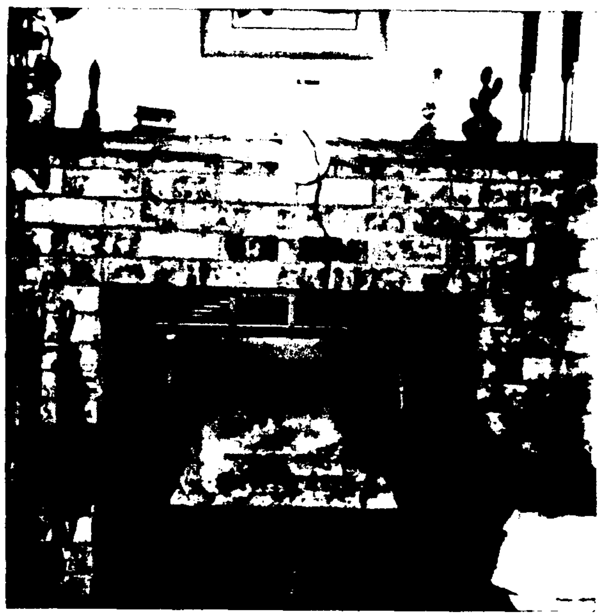


FIGURE 38: Smoke and Carbon Monoxide Detector Mounted Above Fireplace

4.0 CONCLUSIONS

The most appropriate low-cost spillage monitoring device for naturally aspirated gas-fired furnaces and water heaters is a "dot detector," consisting of a piece of heat resistant plastic, on the surface of which are mounted a series of heat sensitive dots. The plastic detector is stuck to the top or bottom of the dilution air opening so as to intercept the flow of spillage gases. When the spillage gases cause the dots to exceed their detection temperature, the dots turn irreversibly from white, to dark black.

A range of detection temperatures can be used for the dots, to allow for an assessment of the quantity and/or duration of spillage. Dots in the 50°C to 70°C range are suitable to indicate unusual and excessive spillage (periods of longer than 60 seconds). The dots can be mounted on the cold side of the plastic, so as to provide a time delay and avoid sensing heat from start-up spillage events (spillage of less than 30 seconds).

Detectors mounted on furnaces with flue dampers must be mounted on the lower edge of the dilution air inlet, so as to avoid sensing heat spillage after the appliance has shut down and the damper closed. Otherwise the last location for the dot detectors is at the upper centre of the dilution air opening, 25 to 50 mm below the upper lip. A detector designed and installed in this fashion is a suitable device for use in monitoring large numbers of houses.

Detectors for gas-fired water heaters should be designed for a slightly higher temperature range, and should be mounted so as to bridge the gap between the top of the water tank and the rim of the drafthood.

At greater cost, detectors for gas-fired furnaces and water heaters could be constructed from thermodiscs or thermistors mounted in a similar location to the dot detectors, and connected to mechanical event counters and time totalizers.

The most appropriate low-cost spillage monitoring device for oil-fired furnaces is a "dot detector," similar to the detectors for gas-fired appliances, but mounted directly on the upper face of the swing plate of the barometric damper. This location is suitable for detecting short-term and longer-term spillage events. A time buffer may be desirable, but at present there is no apparent means of delaying the response time of dots at this location. Consequently oil-furnace detectors may only be capable of detecting spillage in the 10 to 30 second period after start-up.

At greater cost, an appropriate oil furnace spillage detector would consist of a conventional ionization type smoke alarm hung 200 to 300 mm above the upper lip of the barometric damper, so as to intercept spillage gases that are forced around the perimeter of the face plate. By de-activating the alarm, and connecting the smoke detectors to an event counter and time totalizer, a device can be constructed for continuously monitoring spillage frequency and duration.

No low-cost device was found suitable for detecting spillage events from wood fireplaces. Temperature sensitive devices were not appropriate because spillage gas temperatures were too cool, above the fireplace opening, and lower locations were subjected to radiative heating.

At greater cost, an appropriate fireplace spillage monitoring device consists of a carbon monoxide detector and a smoke detector, mounted above the fireplace on the face of the mantle (or equivalent). Both detectors are needed because concentrations of CO and particles vary with the intensity of the burning. By combining the two detectors, it becomes possible to detector all significant spillage events.

5.0 REFERENCES

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RESIDENTIAL COMBUSTION VENTING FAILURES

A SYSTEMS APPROACH

PROJECT 1, PHASE 1

COUNTRY-WIDE SURVEY;

DEVELOPMENT AND TESTING OF SPILLAGE DETECTORS

APPENDIX 1

INSTALLATION GUIDES FOR SPILLAGE MONITORING DEVICES

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

Prepared by:
Scanada Sheltair Consortium

January, 1987

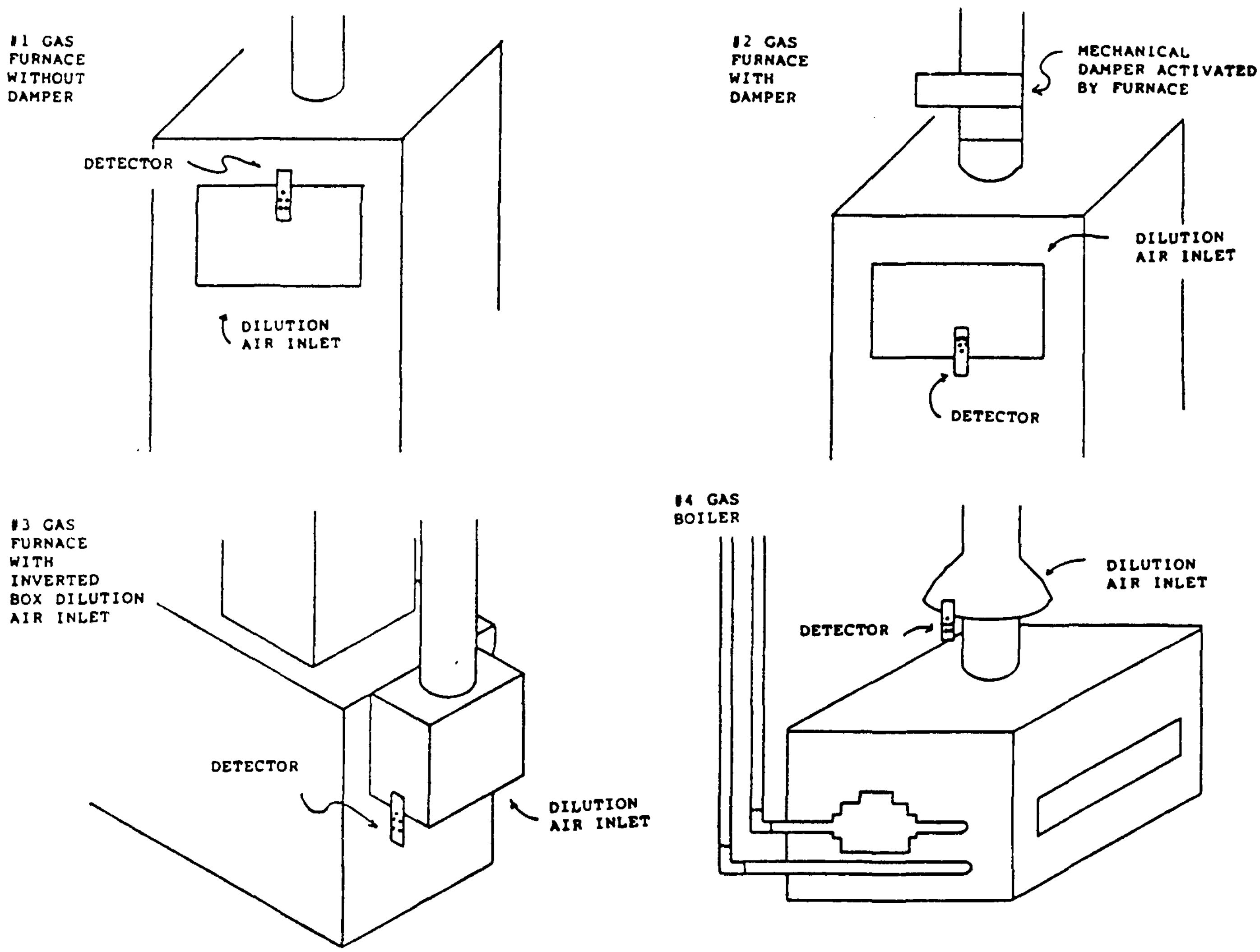
INSTALLATION GUIDE: GAS FURNACE SPILLAGE DETECTOR

1. Observe the drawing below. Determine the most appropriate location for application of the detector on this furnace. Wipe the surface clean at that location.

2. Peel off the paper backing on detector to expose adhesive.

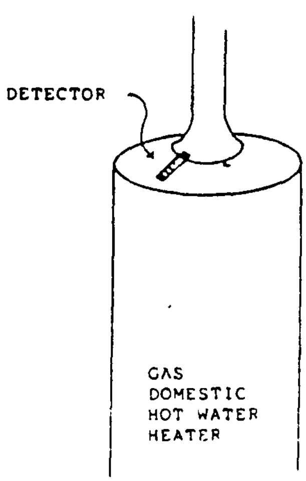
3. Apply the detector as indicated in the drawing and FIRMLY rub the portion glued to the furnace.

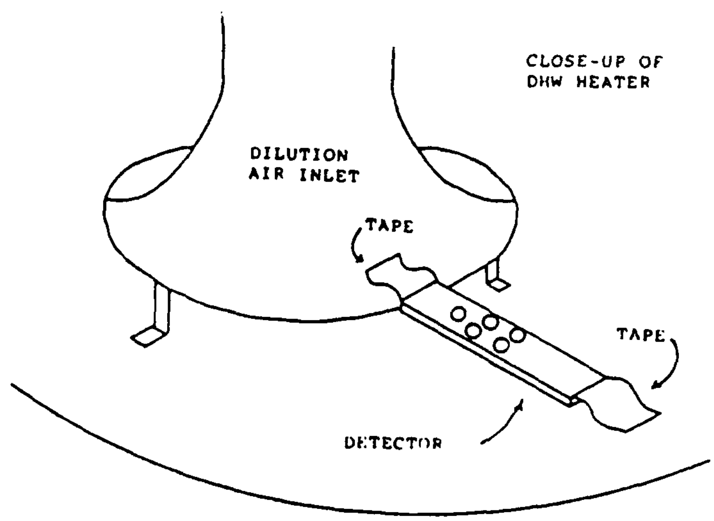
4. Complete and return the Installation Report Form.
   Leave a copy of the Letter to Householder.
   (Information on a commercial product - the Aptech Detector - is included for your reference, but is not essential reading.)



INSTALLATION GUIDE: GAS WATER HEATER SPILLAGE DETECTOR

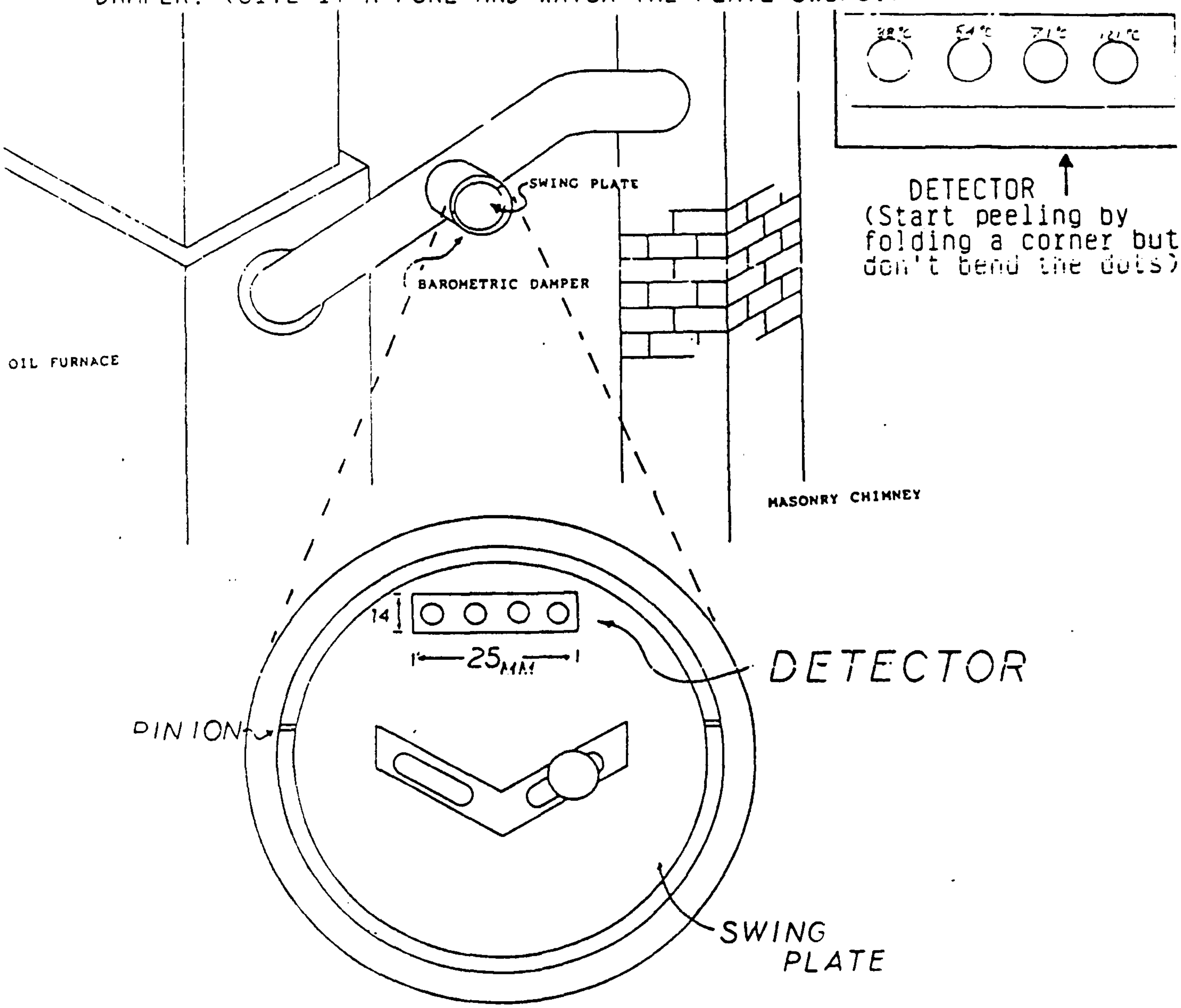
1. Observe the drawing below. Notice how the tape holds one end of the detector to the surface of the tank, and the other end to the rim of the draft hood.
2. Wipe clean the top surface of the tank and the draft hood where tape is to be applied.
3. Peel off the paper backing on the tape.
4. Prop the detector between the tank and the hood, with white dots and temperature labels facing up.
5. Firmly rub tape to surfaces.
6. Complete and return the Installation Report Form.





INSTALLATION GUIDE: OIL FURNACE SPILLAGE DETECTOR

1. OBSERVE THE DRAWING BELOW.
2. LOCATE THE BAROMETRIC DAMPER ON THE FURNACE FLUE CONNECTOR.
3. WIPE CLEAN THE UPPER SURFACE OF THE SWING PLATE.
4. PEEL OFF THE PAPER BACKING ON THE DETECTOR AND RUB TAPE TO THE UPPER SURFACE OF THE SWING PLATE.
5. MAKE SURE DETECTOR DOES NOT RESTRICT FREE MOVEMENT OF DAMPER. (GIVE IT A POKE AND WATCH THE PLATE SWING.)



RESIDENTIAL COMBUSTION VENTING FAILURE

A SYSTEMS APPROACH

PROJECT 1, PHASE 1

COUNTRY-WIDE SURVEY;

DEVELOPMENT AND TESTING OF SPILLAGE DETECTORS

APPENDIX 2

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.