# Investigation of Negative Pressure Test Protocols for Wood- and Pellet-Burning Appliances

Prepared for:
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## *Executive Summary*

The spillage resistance of wood burning equipment under negative pressure conditions is generally considered to be on the order of 5 Pascals, based on previous laboratory testing and field studies of wood burning stoves and fireplaces. Where this depressurization limit is referenced in building codes, the option of using a limit provided by the appliance manufacturer is offered. However, a reliable test procedure for negative pressure testing of any vented fuel burning equipment does not currently exist. This project was undertaken to investigate a new test protocol proposed in draft standard ULC S658 for pellet stoves, and to devise a suitable protocol for the testing of batch fed wood stoves. Once the protocols were evaluated, refined and confirmed as suitable, the responsible technical committees could consider their adoption into the appropriate standards. It was also hoped that the basic protocol could be adapted for use in the testing of vented oil and gas appliances.

Two pellet stoves were tested using the draft protocol, one of top feed design and one of side feed design, to determine whether substantial differences in combustion system design affect performance in negative pressure environments. Two natural-draft wood stoves were also tested, one catalytic and one non-catalytic, again, to determine if combustion design is a significant factor in spillage susceptibility. Both wood stoves were of current design and both met the emission limits established by the US Environmental Protection Agency.

The test stand configuration used in this project is the mobile home appliance test specified in ULC standards S610 for wood burning fireplaces, S627 for wood burning space heaters, and draft S658 for pellet stoves. The venting configuration for wood stoves was based on that specified in S627. The venting configuration for the pellet stoves was based on the requirements of draft S658.

As the protocol was being investigated, difficulties were experienced in the measurement of the test enclosure pressure because of the influence of the air conditioner used to maintain the enclosure temperature within the limits required by the standards. Ultimately, reliable pressure readings were achievable only by installing a perforated false ceiling in the enclosure and discharging the conditioned air into the plenum thus created. It was also necessary to operate the air conditioner continuously and control the room temperature by modulating the output of an electric resistance heater installed in the A/C discharge duct. The problems of enclosure pressure management and measurement dominated the activities of the project team throughout the test program. As a result of these problems, the objective of devising a test that would be reasonably economical to set up and conduct was not achieved.

Both pellet stoves functioned successfully under normal operating conditions when the room was depressurized by 15 Pa. With combustion air taken from within the test room, the stoves spilled during power failure testing with carbon monoxide concentrations in the test room air peaking at less than 150 parts per million before receding. According to the emission rate and room air concentration calculations done for this project, the emissions from these pellet stoves would not exceed the Health Canada one hour

exposure limit of 25 ppm if the spillage occurred in a space with a volume of 200 $m^3$ (7060 $ft^3$), which is roughly half that of a small house. No significant differences were noted in the spillage susceptibility of the pellet stoves, despite differences in combustion system design. One of the pellet stoves, selected for its especially tight construction, was tested with its combustion air taken from outside the test enclosure. The timing and duration of spillage under power failure conditions was similar to the other tests, but the volume of spillage was lower, peaking at 28 ppm. This series of tests suggest that pellet stoves should be placed in a different category of spillage susceptibility than wood stoves since both pellet stoves were capable of operating normally in an environment depressurized by 15 Pa. Note that the power failure tests of pellet stoves is inherently unrealistic because the household fans that would produce such a high level of depressurization would also not function during a power failure.

Both wood stoves spilled during tests at 5 and 10 Pa room depressurization. In the -5 Pa tests the stoves operated for at least two hours before spillage started. The concentration of CO in air extracted from the test enclosure peaked within about an hour at less than 150 ppm before receding. When extrapolated to a space equivalent to that of half a small house, this concentration level and its apparent duration would not exceed a one hour exposure limit of 25 ppm. At 10 Pa room depressurization, spillage started earlier, in one hour or less, and room concentrations of CO went higher, reaching over 200 ppm before the tests were terminated. Although the full spillage profile during tail out was not determined because the -10 Pa tests were terminated before they were complete, it is likely that CO emissions would exceed a one hour exposure limit of 25 ppm. No significant differences were noted in the performance of the two stoves under negative pressure conditions, although only a limited number of test runs were completed.

The findings of this test program cast some doubt on the value of negative pressure testing of pellet and wood stoves, particularly since no differences were detected in the spillage susceptibility between the two pellet stoves or between the two wood stoves, despite significant design differences. In the case of pellet stoves, the measurement of combustion chamber static pressure during normal operation would likely be as effective in revealing spillage susceptibility as would the more elaborate and expensive testing in a depressurized environment. In the case of wood stoves, it is apparent that the configuration of the test stand was the dominant factor in spillage susceptibility. The extremely short system height used in standard safety tests and negative pressure tests of wood stoves for use in mobile homes, and the absence of the equivalent of indoor/outdoor temperature difference in laboratory testing, combine to create unrealistic conditions for negative pressure testing.

More laboratory testing would be required to fully evaluate the spillage profile of wood stoves under negative pressure conditions. The groundwork laid by this project would make a follow-up project significantly more productive in terms of insights into the behaviour of natural draft wood burning equipment. Based on this work, the responsible technical committees for wood burning equipment should review existing negative pressure test protocols to evaluate their effectiveness and relevance.

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# Investigation of Negative Pressure Test Protocols for Wood- and Pellet-Burning Appliances

## 1. Introduction

Building codes and related equipment standards assume that different categories of vented fuel burning equipment have different tolerances to room depressurization. The limited number of relevant studies have shown that appliances vented by natural draft through chimneys have a low tolerance to room depressurization and that direct vent gas appliances have a higher tolerance. This difference in performance is reflected in building codes through limitations on the installation of natural draft equipment that do not apply to direct vent equipment.

Two recognized standards contain default pressure limits for vented combustion equipment. CSA standard F326, Residential Mechanical Ventilation, contains a default depressurization limit of -5 Pa for any chimney vented combustion appliance. CGSB standard 51.71, The Spillage Test, provides default intermittent pressure limits for various categories of vented equipment, as follows:

- Sealed gas and oil appliances that take all combustion air from outdoors: -20 Pa
- Closed gas and oil appliances without draft hoods or barometric controls or those using induced draft: -10 Pa
- Wood heating appliances with controlled combustion: -7 Pa
- Open appliances, includes all other equipment -5 Pa

Both CSA F326 and CGSB 51.71, which have been referenced in some building codes, contain clauses noting that certified depressurization limits provided by the equipment manufacturer may be used instead of these default values. ***However, no credible test is available that can be used to demonstrate the limit for a specific appliance.***

The UL Canada technical committee on Factory-Built Fireplaces, Chimneys and Vents is developing a new standard S658 for pellet stoves. The general structure of standard S658 is patterned on ULC S627 for solid fuel space heaters, which in Part B for appliances for use in mobile homes, includes a negative pressure test. However, the test is flawed in ways that make it inappropriate as a means of determining appliance tolerance to negative pressure. See Appendix A for an explanation of these flaws.

The sub-committee for draft standard S658 has developed a revised negative pressure test protocol in an attempt to address the flaws in the S627 approach.  However, reservations have been expressed about adopting the revised negative pressure test protocol because it has not been investigated. This research project was initiated to investigate the proposed test protocol and produce a report for the technical committee and the funding partners.

The funding partners for the project are the Hearth, Patio and Barbecue Association, the Hearth, Patio and Barbecue Association of Canada and Canada Mortgage and Housing Corporation, an agency of the Canadian government that has supported and published the majority of independent combustion venting research conducted in North America. The research was conducted at the Montreal laboratory of Intertek Testing Services.

## 2. Research Method

**Appliances tested** Two pellet stoves were tested using the experimental protocol, one of top feed design and one of side feed design, to determine whether substantial differences in combustion system design affect performance in negative pressure environments. Two natural-draft wood stoves were also tested, one catalytic and one non-catalytic, again, to determine if combustion design is a significant factor. In this report, the four appliances are given the following designations:

PT – pellet stove, top feed
PS – pellet stove, side feed
WN – wood stove, non-catalytic
WC – wood stove, catalytic

**Test stand configuration** The size and configuration of the test enclosure was the same as that described in ULC S627 Part B (appliances for use in mobile homes). That is, a room 2.4 m wide by 2.4 m long by 2.1 m high.

**Venting system configuration, wood stoves** Single wall flue pipe connects between the stove flue collar and the base of the factory-built insulated metal chimney mounted in the enclosure ceiling. The top of the chimney was 4.6 m (15 ft) above the enclosure floor, as stipulated in ULC S627, Part B. The exhaust was discharged from the top of the chimney into a capture hood within the lab.

**Venting system configuration, pellet stoves** A horizontal pellet vent installation was used. This configuration is considered to provide worst-case conditions for power failure tests since it provides no rise and therefore no residual draft.

**Enclosure depressurization** After the test fuel was loaded in a stove firebox and the air control set, the enclosure was tightly sealed and the air extraction system was activated. The system was capable of producing pressures inside the test structure in the range of 5 Pa to 10 Pa below atmospheric pressure at an air extraction rate of not more than 10 L/s, and 11 Pa to 50 Pa below atmospheric pressure at an air extraction rate of not more than 25 L/s. The room termination of the air extraction system was located in a wall within 0.5 metres of the enclosure ceiling.

**Spillage detection** A continuous sample of the air extracted from the room was monitored for carbon monoxide concentration. No CO concentration limit was established for the test program. Instead, test runs were only terminated if concentrations exceeded recognized allowable safety levels in order to protect laboratory staff.

**Pressure control** A barometric draft control was tested as a pressure-sensitive air inlet to the enclosure so that, as stove exhaust flow declined during tail-out, the target room pressure would be automatically maintained. This approach did not prove fully successful for three reasons: first, the required setting of the control at the start of a test run led to an extraction flow higher than the 10 L/s permitted by the protocol; second, oscillations of the control damper blade prevented pressure stability in the enclosure, the correction of which made the assembly too complicated; and third, the limited sensitivity of the device. After several attempts with a damper to control oscillations and various settings to reduce excessive flow rates, automatic control was abandoned and enclosure pressure was controlled manually by a technician for most of the recorded test runs. Electronic pressure control was not considered because of the cost implications for production certification testing. Since a technician was present throughout the test runs to record various parameters, the manual adjustment of room pressure presented no difficulty.

**Air conditioning** A 50,000 Btuh air conditioner was installed within the enclosure to maintain the maximum air temperature to within 11°C of the temperature at the start of a test, as required in the negative pressure test in ULC draft Standard S658, Cl 7.2.3. Water was used as the transfer medium to remove excess heat from the enclosure. The influence of the air conditioner proved to be a major obstacle in managing stable enclosure pressures. Turbulence from the A/C air discharge made pressure readings erratic. This problem was partly solved by discharging the A/C outlet into a false ceiling perforated with 150 holes 25 mm in size (see Fig. 1). It was also necessary to wire the fan to operate continuously, with only the A/C compressor cycling as necessary to maintain the target temperature. But even after these steps were taken the cycling of the A/C compressor caused fluctuations in the pressure readings. The exact mechanism that created these pressure fluctuations was never fully identified. Finally, stable pressure measurement was achieved by operating the A/C compressor and fan continuously and controlling room temperature by modulating the output of an electric duct heater installed in the discharge duct.

**Figure 1.** The air conditioner was arranged to discharge into a perforated false ceiling to reduce air turbulence in the test enclosure. The white box is the air conditioner and the plywood box above it is the discharge duct leading to the plenum above the perforated ceiling.

**Fuelling – pellet stoves** The test fuel for the pellet stoves was standard wood pellets conforming to the requirements of ULC S658, subsection 7.5.

**Fuelling – wood stoves** The project team devised a test fuelling protocol based on the 17 mm x 38 mm spruce strapping used to produce the standard cribs used as fuel for the temperature tests in S627 (see Fig. 2). The fire was prepared by loading one crib every 7 1/2 minutes until the maximum flue gas temperature was reached. This conditioning process produced a large bed of actively burning charcoal. Then a 'log' formed from 10 pieces of strapping 2/3rds the length of the longest firebox dimension was placed on the fire (see Fig. 3). The test enclosure was then sealed and the negative pressure imposed. The test 'log' approach appeared to work well in that it would burn with bright flames until it was reduced to charcoal. During tests with the enclosure depressurized to 10 Pa, which would extinguish active flaming combustion before the log was reduced to charcoal, flaming combustion resumed when the room pressure was returned to neutral.

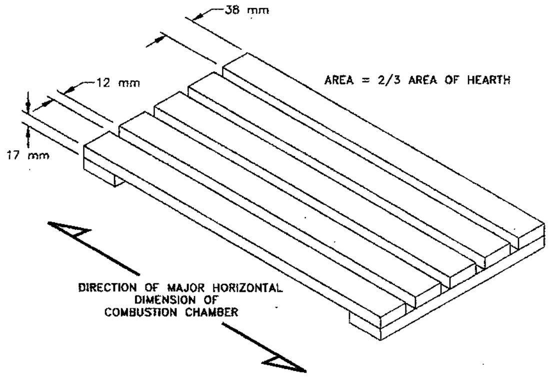

**Figure 2. Fuel crib**

Standard cribs specified in ULC S627 were used condition the stove in preparation for each test run.

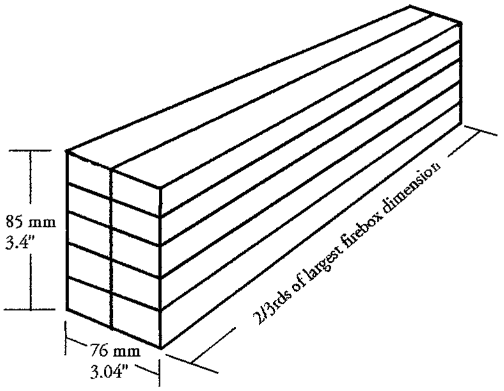

**Figure 3. Test 'log'**

A test 'log' was formed from 10 pieces of 17 mm x 38 mm spruce strapping. A single log formed the fuel load for each test.

**Appliance operation – pellet stoves** The pellet stoves were tested in four modes: a) maximum firing rate, b) minimum firing rate, c) normal shut down using the appliance control panel, and d) power failure conditions. Room depressurization levels tested were 10 Pa and 15 Pa.

**Appliance operation – wood stoves** The wood stoves were tested at 1/2 of maximum combustion air supply as established by setting the air control lever to half of its fully open setting. The objective was to produce charcoal bed tail-out conditions that reflected, to the extent possible, real-world conditions. Note that all current safety tests, including the ULC S627 negative pressure test, are conducted with air controls in the fully open position, or the position that produces the most intense fire. Initial tests with the air controls set to 1/4 of fully open resulted in smouldering and spillage almost immediately. Tests were conducted at – 5 Pa and – 10 Pa room pressure.

## *3. Pellet Stove Test Results*

### Pellet stove, side feed

The side-feed pellet stove operated successfully without spillage when the test room was depressurized by 15 Pa while the stove was operated at minimum and maximum firing rate and when the unit was turned off at its control panel. The control system caused the flue gas exhaust fan to continue to operate for a timed period after the fuel auger stopped. This control strategy, common to all pellet stoves, maintains combustion chamber and heat exchanger negative pressure until combustion has ceased, preventing spillage into the room.

Under power failure conditions, the unit spilled immediately. The room air CO concentration rose to a peak of 93 ppm before beginning to decline. See Figure 4.

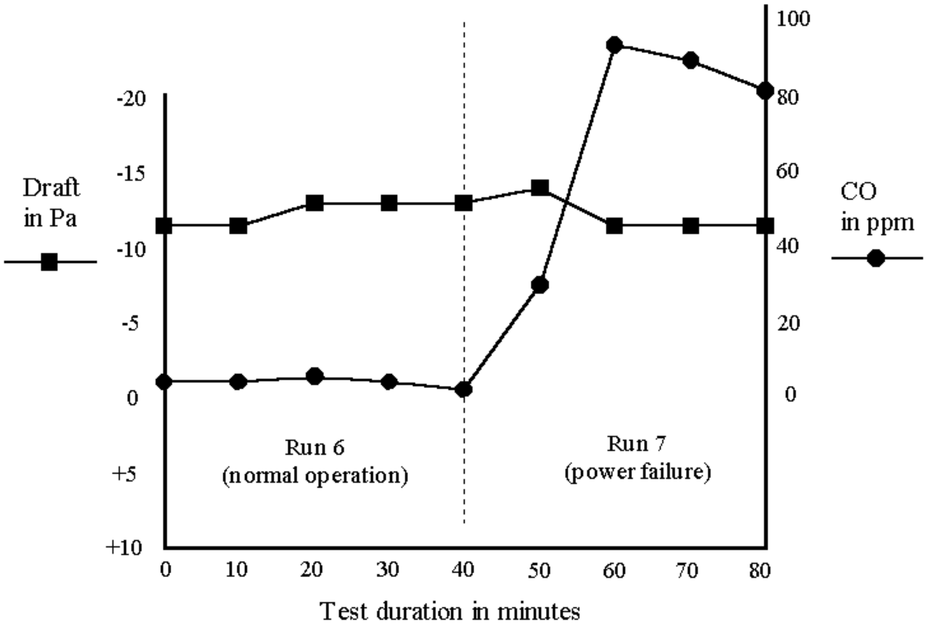

**Figure 4.**
**Stove: PS, Run 6 and 7**

Conditions: Run 6: feeder at minimum; room pressure –15 Pa
Run 7: feeder at maximum; room pressure –15 Pa; power failure
(run 7 was a continuation of run 6)

The side-feed pellet stove had provision for connection of an outdoor combustion air supply, and, unlike the other appliances, this and other areas of the stove appeared to be well-sealed. It was therefore decided to conduct a test with air supplied from outside the test enclosure to evaluate the effectiveness of the outdoor air supply in preventing or reducing spillage. The results of this test are shown in Figure 5. Details of all pellet stove tests are presented in tabular form in Appendix E.

Although spillage began immediately at the start of the power failure test (Run 4), the peak CO level of 25 ppm was lower than during the power failure test with air taken from inside the enclosure (Run 7). This result confirms earlier findings from CMHC research that outdoor air does not appear to prevent spillage or the time at which it occurs, but, in tightly sealed systems, does influence the volume of exhaust spilled.

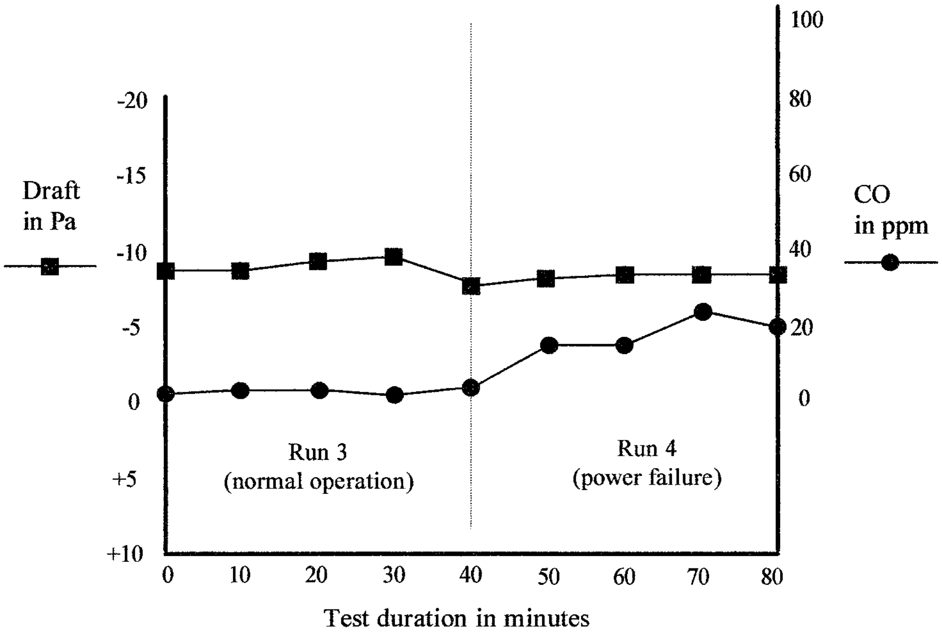

**Figure 5.**
**Stove: PS, Run 3 and 4**

Conditions: Run 3: feeder at maximum; room pressure –15 Pa
Run 4: feeder at maximum; room pressure –15 Pa; power failure
(run 4 was a continuation of run 3)
Note: This was the only run of all tests in which combustion air was taken from outside the test enclosure.

## Pellet stove, top feed

The top-feed pellet stove also operated successfully at 15 Pa room depressurization while operating at maximum and minimum firing rates and when shut down with its control system. Spillage occurred immediately under power failure conditions. The concentration of CO in the test enclosure rose within 10 minutes to a peak of about 140 ppm before receding.

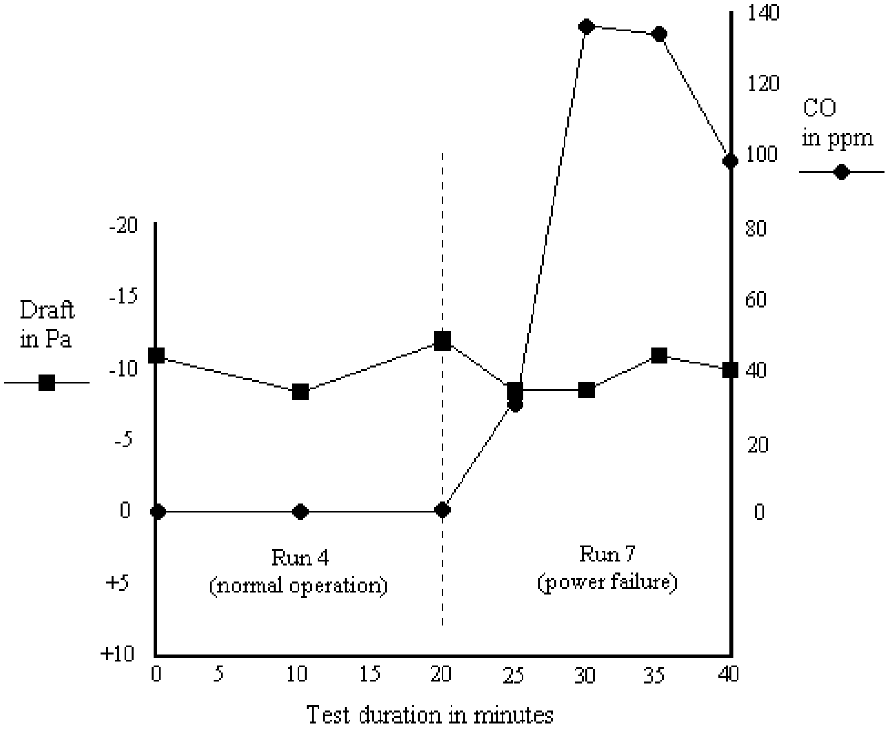

**Figure 6.**
**Stove: PT, Run 4 and 7**

Conditions: Run 4: feeder at maximum; room pressure –10 Pa
Run 7: feeder at maximum; room pressure –10 Pa; power failure
(run 7 was NOT a continuation of run 4)

## *4. Observations on the pellet stove tests*

It is apparent that these two pellet stoves, with substantial differences in design, can operate normally without spillage in environments depressurized to at least 15 Pa. This finding provides a sound rationale for placing pellet stoves in a different category of spillage susceptibility than batch-fed wood stoves operating on natural draft.

Although spillage did occur during power failure conditions, the level and duration of spillage was such that it could be defined as a nuisance, rather than a hazard. Householders who are intolerant of such spillage in the event of a power failure could add a battery back-up unit to the system to provide exhaust fan operation until the fuel in the combustion chamber is consumed. These back-up systems are readily available from some stove manufacturers or from computer stores in the form of uninterruptible power supplies.

# 5. Wood Stove Test Results

## Wood stove – Non-catalytic

This was the first of the wood stoves tested and was used during the set up of the test stand. For that reason a number of the first test runs were not completely instrumented or were terminated prematurely.

In run 3 at 5 Pa room depressurization, spillage started 2 hours and 15 minutes after the start of the test. Over the next hour the room air CO concentration rose to 150 ppm at which point the test was terminated. The test is shown in graphic form in Figure 7. Details of the test are presented in tabular form in Appendix F.

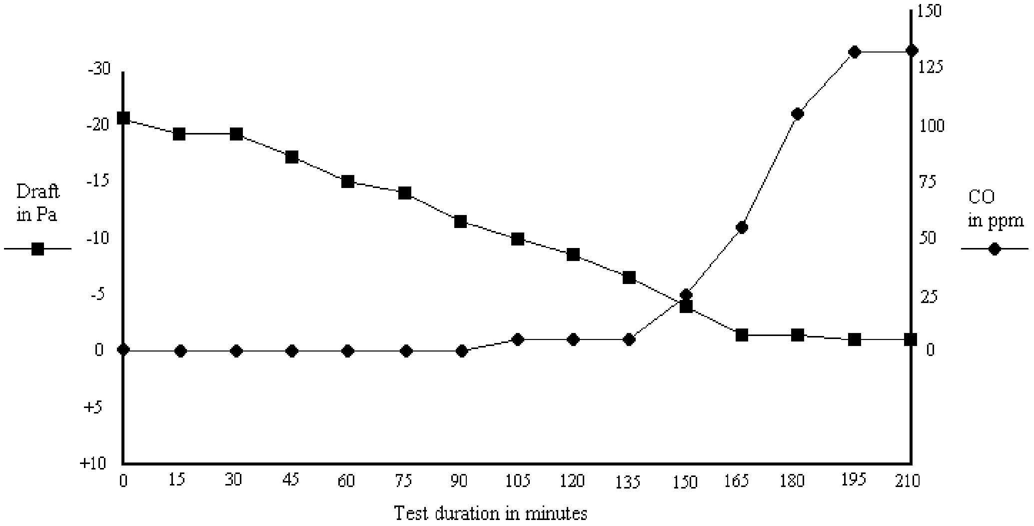

**Figure 7.**
**Stove: WN, run 3**
Conditions: air intake 50%; room pressure –5 Pa

In Run 4 at 10 Pa room depressurization spillage started after about one hour and produced a CO concentration in the test enclosure of 330 ppm at which point the test was terminated. Because the test was terminated the peak concentration and the shape and duration of the tail-out curve are not known. The time, chimney draft and CO concentration is shown in Figure 8.

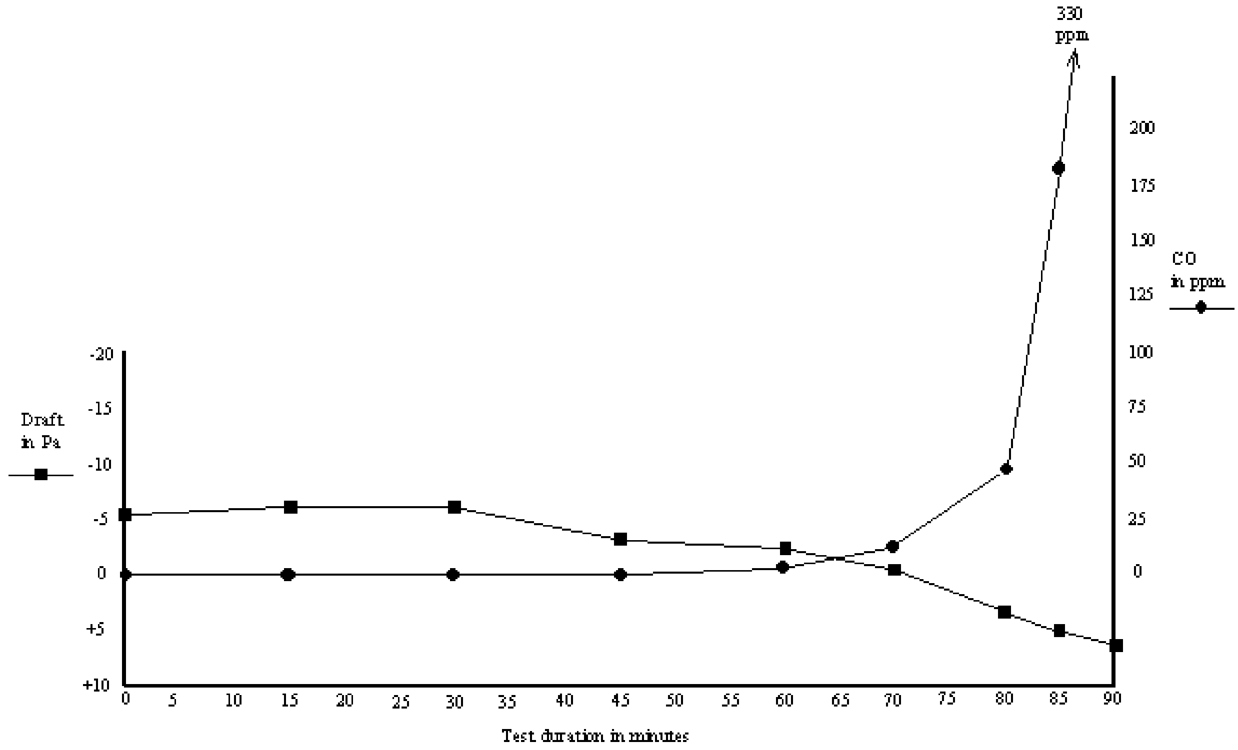

**Figure 8.**
**Stove: WN, run 4**
Conditions: air intake 50%; room pressure –10 Pa

In Run 5 at 5 Pa test room depressurization, the non-catalytic stove operated for two hours and twenty minutes before spillage began. The peak CO concentration produced in the test room was 72 ppm. This concentration was reached 30 minutes after spillage began and was sustained for ten minutes, after which the concentration began to decline.

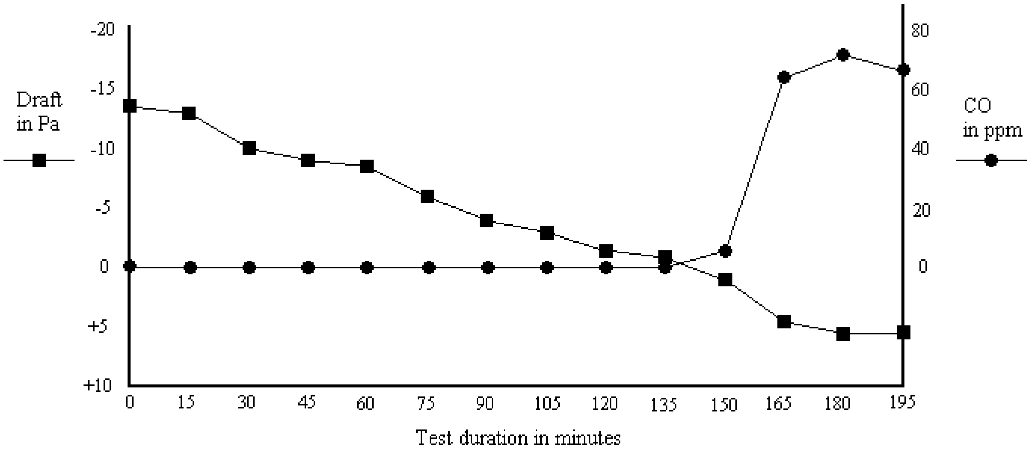

**Figure 9.**
**Stove: WN, run 5**
Conditions: air intake 50%; room pressure –5 Pa

## Wood stove – Catalytic

Run 1 of the catalytic stove at 5 Pa room depressurization produced results similar to those of the non-catalytic stove in run 5. The stove operated for two hours before spillage began. The CO concentration peaked at 91 ppm and the peak was sustained for about 20 minutes before beginning its decline. See Figure 10.

At 10 Pa room depressurization, spillage began immediately because the stove and chimney were apparently not hot enough for draft to overcome the competing negative pressure, even for a short period at the beginning of the test. This result was likely due more to operator error rather than to a characteristic of the stove.

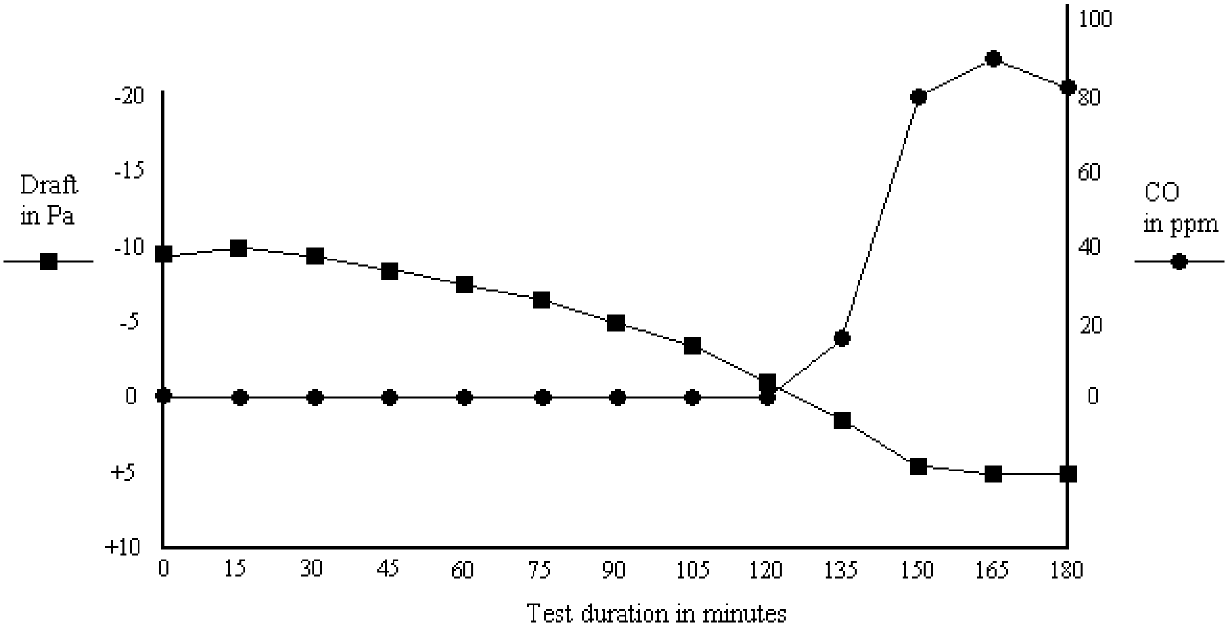

**Figure 10.**
**Stove: WC, Run 1**
Conditions: air intake 50%; room pressure –5 Pa

## 6. Observations on the wood stove tests

**Net draft** At the start of the test runs, after firing with cribs to flue gas temperature equilibrium and the placement of the test log, flue gas temperatures were in the range of 200°C to 250°C, except for test WC2, a test at – 10 Pa room depressurization in which spillage began as soon as the room was sealed because the fire was not prepared in the same way as the other tests.

Chimney draft readings throughout the tests were within the range of the calculated draft value less the negative pressure applied to the enclosure. The comparison with calculated draft levels is useful in analyzing the concept of net draft which can be stated as:

Net draft is theoretical draft less room depressurization. Theoretical draft is calculated based on height of the stack and average temperature difference. The formula used to calculate draft is:

D=(3462 x systemheight) x (1/outdoorC+273-1/fluegasC+273)

Below is a table comparing calculated values and actual measured chimney draft figures. The system height used for the calculations was 4 metres and not the 4.6 metre distance from floor to chimney top because the functional systems did not extend to the floor due to legs/pedestal height. Ambient temperature was assumed to be 25°C.

| Test run | **Flue gas temp °C** | **Calculated draft Pa** | **Less enclosure depress. Pa** | **Net calculated draft Pa** | **Measured draft Pa** |
|---|---|---|---|---|---|
| WN2 | 229 | -19 | 10 | -9 | -11 |
| WN3 | 253 | -20 | 5 | -15 | -21 |
| WN4 | 235 | -19 | 10 | -9 | -6 |
| WN5 | 247 | -20 | 5 | -15 | -14 |
| WC1 | 214 | -18 | 5 | -13 | -9 |
| WC2 | 112 | -11 | 10 | -1 | +1 |

**Table 1. Comparison of calculated and measured draft levels**

The calculated and measured draft figures are in relatively close agreement, considering the potential for distortion caused by the single point temperature measurement (rather than an average) and the fact that pressures were measured using inclined tube manometers which can introduce reading distortions.

**Time from start of tests to time that spillage begins** With one exception (WC2), at both 5 and 10 Pa enclosure depressurization the wood stoves exhibited a steady decline in flue draft and temperature until draft was approximately equal to zero, or ambient pressure. At that point spillage began. At 10 Pa room depressurization the time from the start of the test until the point of spillage ranged from zero (WC2) to 60 minutes (WN4).

At a negative pressure of 5 Pa the decline of flue temperature and pressure was more gradual, and the time to spillage was two hours or more for all tests. See Table 2.

| Test run | Enclosure pressure Pa | Time to spillage min. | Peak CO ppm |
|---|---|---|---|
| WN2 | -10 | 10 | >68 |
| WN3 | -5 | 120 | >150 |
| WN4 | -10 | 60 | >330 |
| WN5 | -5 | 150 | 72 |
| WC1 | -5 | 135 | 91 |
| WC2 | -10 | 0 | >205 |

**Table 2. Time to spillage and peak CO levels for wood stoves.**

## Does the protocol reflect real-world spillage potential?

**Standby draft** The amount of draft produced in a venting system depends primarily on two factors and secondarily on a third: The first is the height of the stack; the second is the average temperature difference between the air and/or exhaust gases in the venting system and the outdoor air; and the third is negative pressure induced at the top of the chimney by wind effects. At standby, with no fire burning in a stove, and in summer weather when there is little or no indoor/outdoor temperature difference, no standby draft would be produced unless air movement outdoors induced a negative pressure at the top of the chimney. It has been shown in previous CMHC research that spillage from atmospherically vented natural gas and propane water heaters is a particular problem in the summer months, likely because no standby draft is available to assist the establishment of upward flow in the venting system when the appliance fires.

The laboratory tests conducted for this project to determine spillage resistance occur under conditions similar to summer season operating conditions in that there is no inherent draft in the system at standby because there is no temperature difference to produce a pressure difference. Note that the chimney discharges within the laboratory into a capture hood.

**System height** The standard 4.6 m (15 ft) system height used for all wood stove safety and emission tests in North America represents the minimum system height that would meet code requirements and is considerably shorter than the average for Canadian and US housing stock. The negative pressure tests in ULC standards S627 and S610 were developed specifically for appliances for use in mobile homes, which do have shallow pitch roofs and very short venting systems.

Figure 11 shows the minimum system height specified for the test stand in relation to a standard 2.4 m (8 ft) ceiling height and a shallow 4:12 pitch roof. Note that such a short system can only meet the building code rule requiring chimneys to project at least 0.6 m

(2 ft) higher than any roofline or obstacle within a horizontal distance of 3 m (10 ft) if it is installed near the eave of a 4:12 pitch roof.

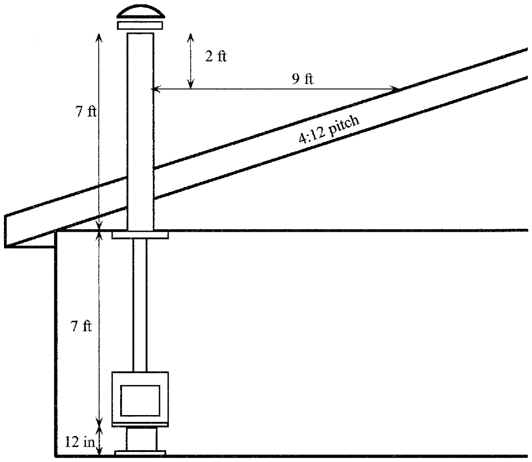

**Figure 11. Test stand system height, room height and roof pitch**

The analysis done for a previous wood stove test program is relevant to the question of representative system height. In developing the specifications for a 2001 test program to investigate toxic emissions from wood stoves, Environment Canada and the hearth industry agreed that a total system height of 7.3 m (24 ft) would be more representative of systems installed in Canadian housing than the 4.6 m (15 ft) standard for emissions testing.

Since system height is one of the key factors in establishing the amount of draft available at the appliance, the 4.6 metre system height, which is essentially the minimum possible under building code provisions, provides the minimum resistance to spillage when the appliance is exposed to negative pressures.

**Implications of test stand configuration** The combined effect of a short system height and the absence of standby draft means that the conditions for negative pressure tests created by the standard configuration for safety testing can be considered extreme worst-case. These conditions are analogous to the spillage resistance of a wood stove served by an extremely short chimney in mid-summer. They are not representative of typical Canadian systems during the heating season. In fact, it could be argued that the test stand configuration is likely to have a greater influence on the spillage resistance (or lack thereof) than the design of the appliance.

For a comparison of standby draft levels for various system heights at different times of the year see Table 3 below.

| | Summer 0° temp. diff. | Fall 11°C temp. diff. | Winter 28°C temp. diff. |
|---|---|---|---|
| Mobile home or cottage – 4.6 m (15 ft) | 0 | 2 | 5 |
| Normal 1 1/2 story – 6.2 m (20 ft) | 0 | 3 | 7 |
| Tall 2 story – 9.2 m (30 ft) | 0 | 5 | 11 |

**Table 3. Calculated standby draft levels for various systems in different seasons, Pa**

(using Table 4 as a reference for temperatures and system heights)

The extent to which these tests reflect real-world conditions is particularly significant in the case of negative pressure testing because of the apparent absence of correlation between predicted spillage and reported cases. Housing research in Canada has shown that a significant proportion of new houses are tight enough and have sufficiently large exhaust devices to be depressurized more than 5 Pa. And all of the existing laboratory research data, including the data produced in this study, show that wood burning appliances are vulnerable to spillage in environments depressurized in excess of 5 Pa. Yet there are relatively few reported cases of smoke spillage from wood burning equipment that can be traced exclusively to room depressurization. Part of the reason for this lack of correlation could be the unrealistic test conditions under which the spillage susceptibility of wood burning appliances has been evaluated.

Using calculated draft values and the concept of net draft, it is possible to evaluate the spillage resistance of natural draft wood burning systems under different conditions. Below is a table of calculated pressure differences based on temperature difference and stack height.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Average temperature difference °F (°C)** Note: This is the average temperature between the gas in the stack (top to bottom) and the outside air | 1000 | (555) | 26 | 39 | 52 | 65 | 78 | 92 | 105 |
| | 800 | (444) | 24 | 36 | 48 | 60 | 73 | 85 | 97 |
| | 600 | (333) | 21 | 32 | 43 | 54 | 64 | 75 | 86 |
| | 400 | (222) | 18 | 26 | 35 | 44 | 52 | 61 | 70 |
| | 200 | (111) | 11 | 17 | 23 | 28 | 34 | 39 | 45 |
| | 100 | (56) | 7 | 10 | 13 | 16 | 20 | 23 | 26 |
| | 50 | (28) | 4 | 5 | 7 | 9 | 11 | 13 | 14 |
| | 20 | (11) | 2 | 2 | 3 | 4 | 5 | 5 | 6 |
| | | | 10<br>(3) | 15<br>(4.6) | 20<br>(6.2) | 25<br>(7.7) | 30<br>(9.2) | 35<br>(10.8) | 40<br>(12.3) |
| | | | Height of stack in feet (metres) | | | | | | |

**Table 4. Pressure differences resulting from various temperature differences and various stack heights, Pa**

Notes:

1. The figures in the body of the table is the pressure difference in pascals that results from the intersecting temperature difference and stack heights. One Pa is equal to 0.004"wc.
2. A single point flue gas temperature measurement, usually at the flue pipe, will give a higher temperature than the average for the total system because of heat loss through the chimney, and therefore will inflate actual draft levels unless a correction is applied.
3. Combustion and venting system height measurements should be taken from the base of the firebox; i.e. from where it gets hot.

Table adapted from The Fireplace in the House as a System, Gulland Associates Inc. 1997

From Table 4, a wood burning system with a system height of 4.6 m (15 ft) would produce a draft of 17 Pa at a temperature difference of 111°C, while a 6.2 m (20 ft) system at the same temperature would produce 23 Pa of draft. Although testing would be required to confirm the hypothesis, it is reasonable to expect that the higher draft produced by the taller system would provide greater spillage resistance for the connected appliance operating in a depressurized environment.

From the test data produced in this project it can be inferred that spillage began when the flue gas temperature rise above ambient fell to about 50°C during the –5 Pa tests and about 150°C during the –10 pa tests. At these temperatures and depressurization conditions, the test stand appliance and vent configuration would produce about – 3 Pa and – 9 Pa net draft respectively. However, two factors could combine make this deduction unreliable. First, the data recording was done at 5, 10, or 15 minute intervals, so the exact point at which spillage occurred and the temperatures and pressures at which it occurred is not precisely known. Second, these calculated values don't account for friction in the system, specifically in the stove which would contain small air supply and flue gas passages with sharp changes in flow direction. It is therefore likely that the pressure at some sites within the appliance would be equal to or greater than the pressure outside the appliance, which would produce spillage. Once spillage begins, some of the heat in the system is bled off, which accelerates the decline in system temperature and draft, resulting in a full backdraft within a few minutes. The speed with which changes occur at the time of spillage make the data recording intervals significant in the interpretation of results.

## *7. Criteria for establishing a carbon monoxide limit*

**Reference CO exposure limit** An appropriate objective is to use a CO concentration limit that relates to an established standard. A good starting point for a reference limit is the Health Canada residential CO guideline of 25 ppm for one hour exposure. No serious health effects are likely to occur at 25 ppm over one hour. Assuming that the CO concentration increases linearly, a one hour exposure of 25 ppm begins from a starting point of zero and rises to a concentration at the end of one hour of 50 ppm.

**Assumed living space volume** The worst case would be a small closed room with a sleeping occupant. However, this is an unlikely scenario because even a small wood stove would quickly overheat the small space, so a larger assumed volume would be more reasonable for the calculations. A practical approach would be to use a volume that represents half the size of a small house. That is, a volume of 200 $m^3$ (7060 $ft^3$) or a floor area of about 83 $m^2$ (890 $ft^2$) an assumption that could be interpreted as liberal.

**Air change rate** A simulated house air change rate of 0.2 air changes per hour (ACPH) is on the low side of normal and would be conservative.

**Maximum CO source rate** The calculated maximum CO source rate from the appliance, based on the above assumptions of the one hour exposure limit, living space volume and air exchange rate, is 12,680 mg/hr* of CO in the spilled gases.

*For a rough conversion from mg/cu. m. CO to ppm, multiply by 0.87; from ppm CO to mg/cu. m., multiply by 1.15

**Maximum allowable CO concentrations in test room air** The maximum emission rate is then applied to the test room size and air change rate to determine the maximum measurable CO rate in the test room exhaust air stream. The test room has a volume of 12.1 $m^3$ (427 $ft^3$), and its air change rate was required to be 10 L/s at a 5 Pa depressurization. The calculated result is a maximum allowable test room concentration of 306 ppm CO.

**Caution regarding these assumptions and calculations** As simple as the determination of allowable CO concentrations may seem, the above is based on many hours of discussion of the assumptions and calculations. Still more discussion, recalculation and verification is needed to produce the necessary confidence for adoption by the responsible committees. Therefore, these should be considered preliminary estimates for discussion purposes only.

## *8. Calculation procedure for carbon monoxide concentrations*

The key equations* are:

$$C_i = C_{ss} \times (1 - e^{-t_i/t^*})$$

Where:
$C_i$ = the concentration at time $t_i$
$C_{ss}$= steady state concentration
$t^*$ = the characteristic time constant

and

$$S = C_{ss} \times q^*$$

Where
S is the source rate
q* is the characteristic flow rate

For our purposes, q* is the infiltration rate or volume air change rate. We are assuming perfect mixing and no deposition or filtration within the volume.

Also:
$$t^* = V/q^*$$
Where:
V is the volume in question (e.g room or house)
Note that the time constant t* is the inverse of the effective air change rate, so that an infiltration rate of 0.2 air changes per hour would have a time constant of 5 hours.

It is assumed for these calculations that the mixing volume is half a small house or 200 $m^3$. The infiltration rate of this space is assumed to be low, 0.2 air changes per hour (or 40 $m^3$/hr), which provides a time constant of 5 hours (i.e. the total room volume is changed every five hours).

In the following scenarios, the Health Canada residential CO guideline of 25 ppm for one hour exposure is used as the referenced limit. It is also assumed that CO concentration increases linearly so that a one hour exposure of 25 ppm is produced from a starting point of 0 ppm and a concentration at the end of one hour of 50 ppm.

### Scenario 1: Maximum of 50 ppm in the house after one hour

(based on the Health Canada one hour exposure limit of 25 ppm)

Using the equation $C_i = C_{ss} (1 - e^{-ti/t^*})$,

$50 \text{ ppm} = C_{ss} (1- e^{-1/5})$ therefore, $C_{ss} = 276$ ppm

Therefore, at a constant emission rate producing a concentration of 50 ppm at the end of the first hour, the simulated steady state concentration in the house several hours later would be 276 ppm, if all conditions are unchanged. But it is apparent that a wood stove does not produce a constant spillage rate, but one that rises as spillage begins, peaks, then declines as the charcoal fire tails-out. In two of the tests at 5 Pa room depressurization (WN5 and WC1), the test room concentrations peaked in 30 to 45 minutes, and the peak lasted for about 10 minutes before beginning to decline. One test run appeared to have a longer tail-out, but it and all other runs were terminated at or before the peak concentration was reached, so a complete record of the peak and tail-out profile was not produced.

Using this calculated steady state concentration ($C_{ss}$), the source rate would be:

$S = (317 \text{ mg/m}^3)(40 \text{ m}^3\text{/hr}) = 12{,}680 \text{ mg/hr}$
Note: $276 \text{ ppm} = 317 \text{ mg/m}^3$

12,680 mg/hr is the permissible emission rate for this scenario. Applying this emission rate to the size of the test enclosure:

$2.4 \text{ m} \times 2.4 \text{ m} \times 2.1 \text{ m} = 12.1 \text{ m}^3$

The test enclosure exhaust flow rate used for these tests was 10 L/s. This is 36,000 L/hr or 36 $\text{m}^3$/hr, or an air change rate of close to 3 air changes per hour. The time constant of the test room is the inverse, or 0.33 hour. Using the equation $C_{ss} = S/q^*$, the maximum allowable observed concentration in the test room would be:

$C_{ss} = (12{,}680 \text{ mg/hr})/(36 \text{ m}^3\text{/hr}) = 352 \text{ mg/m}^3$ or 306 ppm.

## Scenario 2: Concentration of 25 ppm in the house after one hour

(reflecting a one hour average concentration of 13 ppm)

This is simply half of the previous calculation or 153 ppm allowable in the test room. Assuming a linear increase in CO concentration this scenario represents an average exposure over one hour of half of the Health Canada guideline of 25 ppm.

## Scenario 3: Concentration of 25 ppm in the house (steady state)

(reflecting the result of long-term spillage)

In this case, $C_{ss} = 25$ ppm in the house and the maximum test room observable concentration would be:
$C_{ss} = (25/276)(306 \text{ ppm}) = 28$ ppm

This scenario is presented to clarify the implications of using steady state versus timed average concentrations as limits. Since wood stoves do not produce continuous long-term spillage because of fuel depletion over time, a 25 ppm steady state concentration limit is not realistic or necessary for safety.

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* Equations are taken from the text Indoor Air Pollution by Wadden and Scheff. These are common pollutant concentration calculations for a one-cell model with a constant pollutant emission rate.

## *9. Summary and discussion of findings*

### Pellet stove tests

- The two pellet stoves operated under normal conditions without spillage when the room was depressurized by 15 Pa.
- Both pellet stoves spilled immediately at the beginning of the power failure tests.
- In tests with the pellet stoves taking their combustion air from within the test room, CO concentrations in the air extracted from the test room peaked within 20 minutes of the start of the test, reaching a high of about 140 ppm for the top feed model and 93 ppm for the side feed model.
- When the tightly sealed side feed model was tested with its combustion air being taken from outside the test room, spillage occurred as soon as the test started, but the CO concentrations were lower, peaking at 25 ppm.
- Based on Health Canada's one hour exposure limit of 25 ppm, the spillage from the pellet stoves under power failure conditions would not constitute a health hazard, although it would certainly be considered a nuisance.
- The test results suggest that the time and expense of negative pressure testing may not be justified considering that these two representative pellet stoves performed successfully (and similarly) under normal operating conditions at room depressurizations of up to 15 Pa. Approximately the same insights into their performance under negative pressure conditions could be achieved by measuring the static pressure developed within the appliance by its exhaust fan when it is connected to a typical venting system. The static pressure reading would roughly indicate its spillage resistance under normal operating conditions. For pellet stoves vented horizontally, spillage is a virtual certainty under power failure conditions unless the appliance has a battery back up system. Again, negative pressure testing would not necessarily shed more light on appliance performance.

### Wood stove tests

- Both wood stoves spilled during tests at both 5 Pa and 10 Pa room depressurization.
- The design differences between the appliances did not have a significant effect on their spillage susceptibility.
- Although the full spillage profile during tail out was not determined in all cases because some tests were terminated before they were complete, it appears that the stoves would not exceed the Health Canada one hour exposure limit of 25 ppm during tests at 5 Pa room depressurization.
- The stoves and their venting systems were incapable of sustaining sufficient chimney draft to resist spillage. In all cases chimney draft gradually declined to the point of spillage, which occurred when chimney draft was approximately equal to room

pressure. At 5 Pa room depressurization, the stoves operated for at least two hours before spillage began. At 10 Pa depressurization, the results were more variable: in one case spillage started after one hour, in a second case it started after 10 minutes, and in one case it started immediately, apparently because the stove was not heated sufficiently before starting the test.

- During tests at 10 Pa room depressurization, spillage occurred sooner and CO concentrations were higher, reaching 330 ppm in one case and 205 ppm in another test run before the tests were terminated. Peak concentrations and the tail out profiles were not determined. It would appear that, had the full tail out been permitted to take its course, the one hour exposure limit of 25 ppm would have been exceeded.
- More work is required to explore the tail out profile of wood stoves under negative pressure conditions. If CO limits such as Health Canada's one hour limit of 25 ppm are used as a reference, then the full tail out profile is relevant in the evaluation of the health impacts of wood stove spillage under various conditions of negative pressure. If such work is contemplated, it would be advisable to discharge the air exhausted from the room into the chimney exhaust capture hood to prevent CO build up in the lab and the need to terminate tests before they are complete. Another challenging aspect of any future testing would be an assessment of the tail out characteristics of the 'log' used for this program compared to normal loads of wood used by householders.
- The 4.6 m (15 ft) standard system height for safety testing and mobile home negative pressure testing, combined with the absence of standby temperature difference, make these tests representative of extreme worst case conditions under even slight room depressurization. The short chimney and warm ambient temperature mean there is no draft at standby and minimal draft even when a fire burns. As a result, the principal factor in the spillage susceptibility of these appliances is not their design but the configuration of the test stand.
- Using calculated net draft as a guide, it may be possible to predict the spillage susceptibility of systems without conducting certification tests under negative pressure conditions. The responsible technical committees need to consider the relevance of negative pressure testing in light of the results of this project.
- If negative pressure testing is felt to be desirable, the committees then need to determine what system configuration is representative, considering the primary role of test stand configuration in determining the spillage susceptibility of natural draft wood burning equipment.

## General

- Although it was a principal objective of this project, it was not possible to devise a negative pressure test protocol suitable for use in evaluating the spillage resistance of wood stoves that would produce consistent, reliable and representative results. Conflicts between temperature control and pressure control and measurement dominated the activities of the project team throughout the testing, leading to cost overruns and limits on the time that could be invested in actual testing. More work will be required to evaluate other options for temperature control within the test enclosure with a view to reducing the associated cost and complexity of maintaining enclosure temperatures within reasonable bounds.

## *Appendix A Why the negative pressure test in ULC S627 is unsuitable.*

The test in Part B of S627 (and S610 for fireplaces) imposes a negative pressure of 17.5 Pa. Many appliances have been certified as meeting this standard. However, the only published research studies reported that the wood-fired, chimney-vented fireplaces tested (a total of six) could tolerate 5 Pa depressurization, but none could tolerate -10 Pa without significant spillage of combustion products. (Both are CMHC sponsored studies: Fireplace Air Requirements, 1989; and The Effects of Glass Doors on Masonry Fireplace Spillage and Surface Temperatures, 1994.)

Although the exact mechanisms by which the S627 negative pressure test fails to reflect performance patterns that have been demonstrated in fully-instrumented laboratory tests has not been investigated, some flaws in the procedure are apparent:

- In the current test a 150 mm deep charcoal fire is started in a basket grate and allowed to burn at maximum intensity, then the room is sealed and the test is begun. There are two fuel-related problems with this approach. First, a charcoal fire may not be representative of the tail-out phase of a wood fire, and second, the charcoal is burned on a grate with combustion air reaching the fuel from underneath, a design which is uncommon in wood stoves and non-existent in stoves meeting the EPA particulate emission limits.

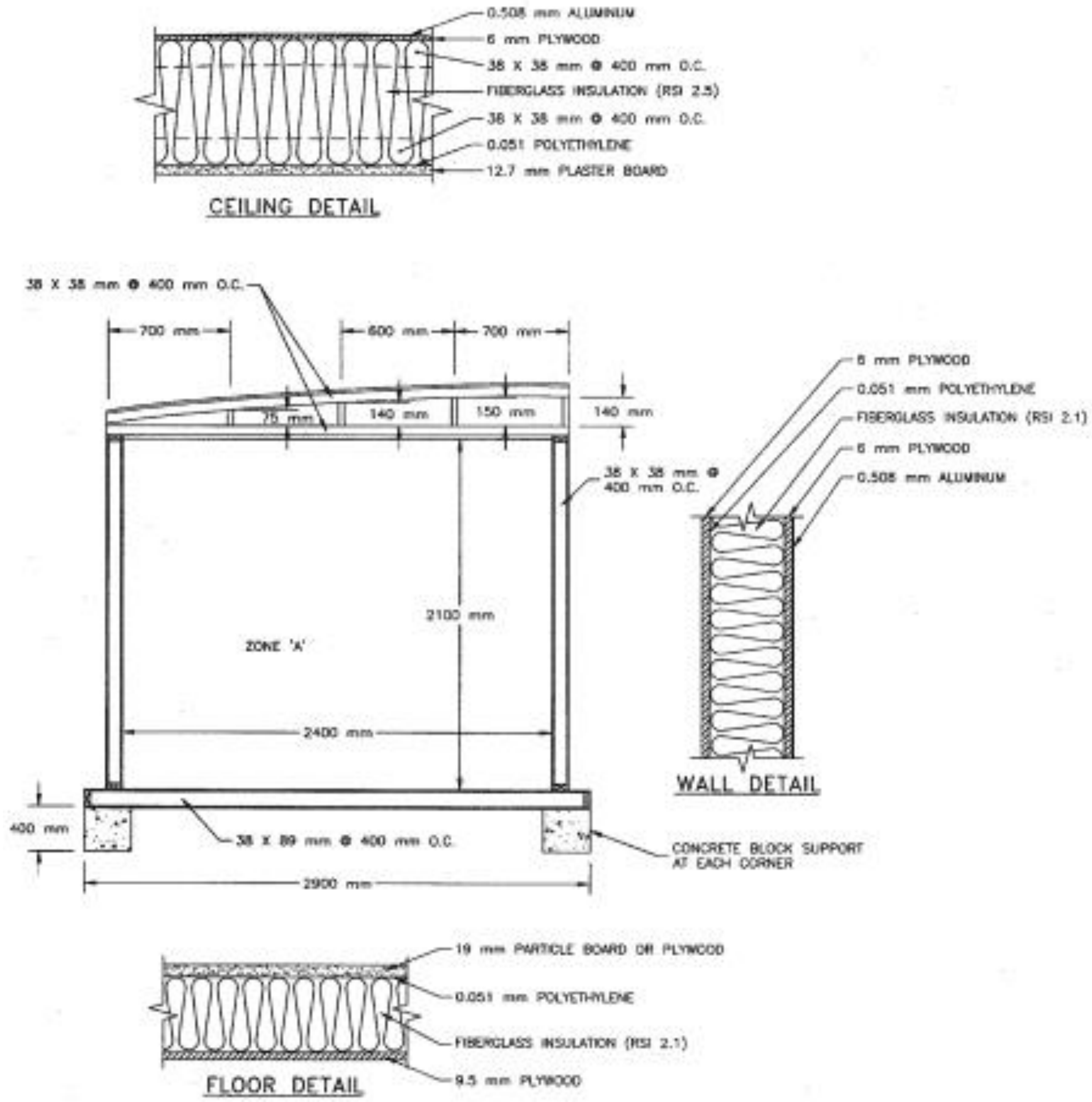
- The appliance is operated throughout the test at its maximum firing rate, a setting which is not representative of real-world fire tail-out conditions.

- After the room is sealed a negative pressure of 17.5 Pa is induced with a fan exhausting around 35 L/s (70 cfm). But a large stove running at maximum output could consume more than half of the required fan flow. Therefore, at the start of the test the total air being exhausted by the combined effects of the exhaust fan and flow up the chimney could exceed 100 cfm to produce the required negative pressure of –17.5 Pa. After the fire peaks and begins to tail out, stack temperature, draft and flue gas flow start to decline, which would reduce exhaust flow from the room and therefore the negative pressure the appliance is exposed to. A rough calculation shows that a room with an equivalent leakage area of 25 square inches will be depressurized to 17.5 Pa by a 112 cfm exhaust flow. The same room would be depressurized by only 7 Pa by a 70 cfm exhaust flow (just the fan at the end of tail out). Therefore, the necessary leakiness of the test enclosure to achieve the target pressure at the start of the test means that the final room pressure could be only slightly negative, despite the fact that the fan continues to operate.

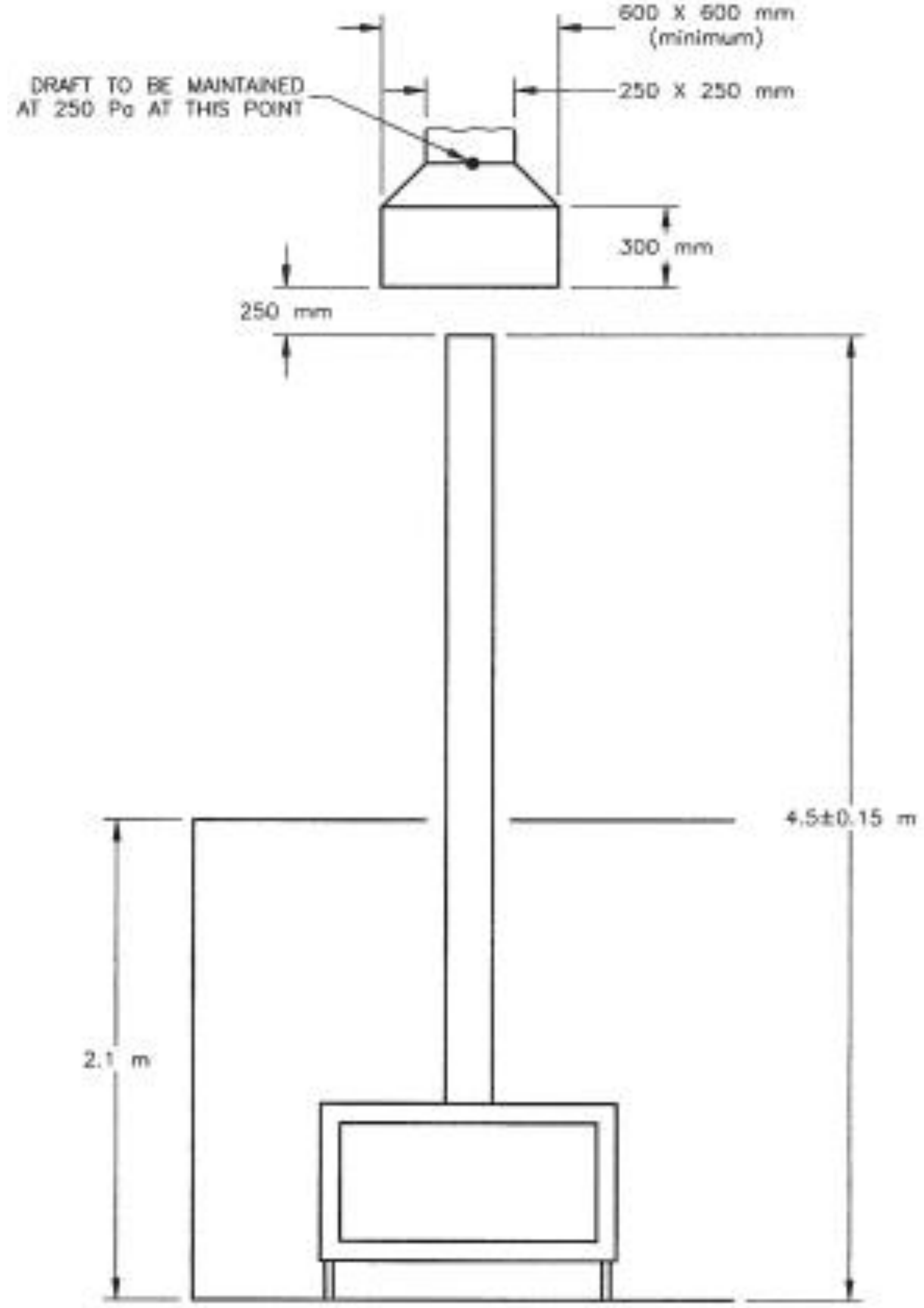
- The CO limit is 100 ppm as detected in samples of the atmosphere taken within the test enclosure at a point 1.2 m above the floor and 0.6 m directly in front of the space heater. The effectiveness of this CO detection procedure depends largely on the location from which air is extracted from the enclosure and on the leakage patterns of the enclosure. With this test configuration, it is possible for a plume of spilled products of combustion to bypass the sampling location.

For these reasons the protocol in ULC S627 and ULC S610 should not be considered a reliable means to evaluate the tolerance of wood burning appliances to depressurized environments. The equivalent standards used in the United States, UL 1482 for room heaters and UL 127 for factory-built fireplaces, do not contain tests suitable for determining negative pressure tolerance.

## *Appendix B Mobile home test enclosure from ULC S627, S610 and draft S658*



## Appendix C Venting configuration from ULC standard S627



## *Appendix D Summary of mobile home test protocols in Canadian and US standards*

| | **ULC S658-00draft** | **ULC S627/S610** | **UL 1482/127** |
|---|---|---|---|
| **Normal test stand** | h: 2.1m (6' 10")<br>wall length: 2.4m<br>chimney: 4.5m | h: 2.1m (6' 10")<br>wall length: 2.4m<br>chimney: 4.5m | h: 2.4m (8')<br>chimney: 1482 4.5 m |
| **Mobile test stand** | h: 2.1m (6' 10")<br>wall length: 2.4m<br>floor, walls and ceiling all insulated with fibreglass | h: 2.1m (6' 10")<br>wall length: 2.4m<br>floor, walls and ceiling all insulated with fibreglass | h: 2.13m (7')<br>w&d: 2.44 (8')<br>no insulation |
| **Normal fuel**<br>**Crib fire**<br>**Brand fire** | pellet fuel meeting ASTM standards | S627: 17 mm by 38 mm spruce strapping cribs with 12 mm spacing<br>S610: brands as in UL127 | 3/4 x 3/4 (19.1mm sq) Douglas Fir brands spaced 1" apart on centres |
| **Flash fire fuel**<br>**Radiant fire fuel** | N/A | 17 mm by 38 mm spruce strapping cribs with 12 mm spacing | 3/4 x 3/4 (19.1mm sq) Douglas Fir brands spaced 1" apart on centres |
| **Mobile home fuel** | pellet fuel meeting ASTM standards | charcoal briquettes (Kingsford) on grate | charcoal briquettes (Kingsford) on grate |
| **Mobile home test method** | fire the unit then depressurize enclosure to –5Pa or as spec'd at < 25 L/s room flow | fire unit then depressurize enclosure to –17.5Pa at 0.033 $m^3/s$ (70 cfm) ± 10% air flow | continuation of radiant fire test, seal enclosure, **no despressurization** |
| **CO limit/standard** | < 10 ppm above ambient for normal operation; < 20 ppm for abnormal tests and units for use in mobile homes | < 100 ppm above ambient | < 50 ppm |

# *Appendix E Pellet stove test results*

## Pellet Stove Top Feed, runs 1 through 7

Tests conducted June 14 and 20, 2002

Conditions: Combustion air supplied from inside test enclosure
1- Feeder at minimum (10 Pa)
2- Feeder at minimum (15 Pa)
3- Feeder at maximum (15 Pa)
4- Feeder at maximum (10 Pa)
5- Shut down at control panel (10 Pa)
6- Shut down at control panel (15 Pa)
7- Power failure (10 Pa) 147 ppm CO obtained at 13:50 pm

| Cond. | Time | Exh Fan Flow (L/sec) | Exh Air Temp. (°C) | Exh Air CO ppm | Encl. Pressure (Pa) | Flue Draft (Pa) | Hopper Temp (°C) |
|---|---|---|---|---|---|---|---|
| 1 | 2:00 PM | 8.3 | 26 | 0 | 10 | 13 | 39 |
| 1 | 2:10 PM | 6.5 | 27 | 0 | 11 | 14 | 39 |
| 1 | 2:32 PM | 6.5 | 27 | 0 | 11 | 13 | 40 |
| 2 | 2:42 PM | 9.3 | 26 | 0 | 15 | 19 | 40 |
| 2 | 2:52 PM | 9.3 | 25 | 0 | 15 | 19 | 40 |
| 2 | 3:02 PM | 9.3 | 25 | 0 | 15 | 19 | 40 |
| 3 | 3:44 PM | 8.3 | 21 | 0 | 15 | 19 | 37 |
| 3 | 3:54 PM | 8.3 | 22 | 0 | 15 | 19 | 37 |
| 3 | 4:04 PM | 7.4 | 21 | 0 | 15 | 19 | 37 |
| 4 | 8:51 AM | 5.6 | 26 | 0 | 11 | 12 | 37 |
| 4 | 9:01 AM | 4.6 | 26 | 0 | 9 | 13 | 37 |
| 4 | 9:11 AM | 5.6 | 26 | 0 | 12 | 13 | 37 |
| 5 | 9:17 AM | 4.6 | 26 | 0 | 12 | 13 | 37 |
| 5 | 9:28 AM | 0.0 | 25 | 0 | 10 | 11 | 34 |
| 5 | 9:38 AM | 0.0 | 25 | 0 | 11 | 12 | 32 |
| 6 | 11:38 AM | 13.0 | 25 | 0 | 17 | 19 | 36 |
| 6 | 11:48 AM | 7.4 | 25 | 0 | 15 | 18 | 34 |
| 6 | 11:58 AM | 6.5 | 25 | 0 | 16 | 19 | 32 |
| 7 | 1:43 PM | 17.6 | 23 | 30 | 9 | 7 | 36 |
| 7 | 1:48 PM | 17.6 | 23 | 137 | 9 | 6 | 39 |
| 7 | 1:53 PM | 18.5 | 24 | 135 | 11 | 7 | 41 |
| 7 | 1:58 PM | 17.6 | 24 | 99 | 10 | 9 | 42 |

## Pellet Stove Side Feed Runs 1 through 5

Test date:

Conditions 1 & 2: June 26 '02
Conditions 3 through 5: July 11 '02

Conditions: Combustion air supplied from outside test enclosure
1- Feeder at minimum (10 Pa)
2- Feeder at minimum (15 Pa)
3- Feeder at maximum (15 Pa)
4- Power failure (15 Pa)
5- Normal shut down (15 Pa)

| Cond. | Time | Exh Fan Flow (L/sec) | Exh Air Temp. (°C) | Exh Air CO ppm | Encl. Pressure (Pa) | Flue Draft (Pa) | Hopper Temp (°C) |
|---|---|---|---|---|---|---|---|
| 1 | 2:07 PM | 15.8 | 23 | 0 | 12 | 13 | 27 |
| 1 | 2:17 PM | 15.8 | 23 | 0 | 10 | 12 | 27 |
| 1 | 2:27 PM | 15.8 | 24 | 0 | 11 | 12 | 27 |
| 2 | 2:35 PM | 25.9 | 24 | 0 | 15 | 18 | 27 |
| 2 | 2:45 PM | 26.9 | 24 | 0 | 16 | 19 | 27 |
| 2 | 2:55 PM | 26.9 | 23 | 0 | 16 | 19 | 27 |
| 3 | 11:38 AM | 18.5 | 26 | 2 | 14 | 8 | 29 |
| 3 | 11:43 AM | 17.6 | 27 | 3 | 14 | 8 | 29 |
| 3 | 11:48 AM | 16.7 | 27 | 4 | 14 | 8 | 30 |
| 3 | 11:53 AM | 17.6 | 27 | 4 | 14 | 8 | 29 |
| 3 | 11:58 AM | 16.7 | 26 | 3 | 14 | 8 | 30 |
| 3 | 12:03 PM | 17.6 | 26 | 5 | 14 | 8 | 30 |
| 3 | 12:08 PM | 17.6 | 26 | 4 | 14 | 8 | 30 |
| 3 | 12:13 PM | 17.6 | 26 | 5 | 14 | 8 | 30 |
| 3 | 12:18 PM | 17.6 | 27 | 5 | 14 | 8 | 30 |
| 3 | 12:23 PM | 17.6 | 27 | 6 | 14 | 8 | 30 |
| 3 | 12:28 PM | 17.6 | 26 | 5 | 14 | 8 | 30 |
| 3 | 12:33 PM | 17.6 | 27 | 4 | 14 | 8 | 30 |
| 4 | 12:38 PM | 19.5 | 25 | 4 | 11 | 9 | 30 |
| 4 | 12:43 PM | 15.8 | 26 | 4 | 14 | 5 | 32 |
| 4 | 12:48 PM | 16.7 | 27 | 6 | 12 | 7 | 35 |
| 4 | 12:53 PM | 18.5 | 27 | 8 | 12 | 8 | 40 |
| 4 | 12:58 PM | 18.5 | 27 | 16 | 12 | 8 | 41 |
| 4 | 1:03 PM | 16.7 | 26 | 20 | 12 | 8 | 43 |
| 4 | 1:08 PM | 17.6 | 27 | 16 | 12 | 8 | 43 |
| 4 | 1:13 PM | 16.7 | 28 | 28 | 12 | 8 | 44 |
| 4 | 1:18 PM | 17.6 | 29 | 25 | 12 | 7 | 44 |
| 4 | 1:23 PM | 17.6 | 26 | 10 | 12 | 8 | 43 |
| 4 | 1:28 PM | 18.5 | 27 | 20 | 12 | 7 | 43 |
| 5 | 2:37 PM | 25.0 | 27 | 1 | 15 | 10 | 30 |
| 5 | 2:42 PM | 33.4 | 26 | 0 | 17 | 12 | 31 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5 | 2:47 PM | 27.8 | 27 | 0 | 14 | 11 | 31 |
| 5 | 2:52 PM | 32.4 | 26 | 1 | 17 | 12 | 31 |
| 5 | 2:57 PM | 30.6 | 26 | 3 | 15 | 12 | 32 |
| 5 | 3:02 PM | 30.6 | 26 | 5 | 15 | 12 | 32 |
| 5 | 3:07 PM | 32.4 | 26 | 4 | 14 | 12 | 31 |
| 5 | 3:12 PM | 32.4 | 27 | 2 | 14 | 11 | 31 |
| 5 | 3:17 PM | 30.6 | 27 | 1 | 15 | 12 | 31 |
| 5 | 3:22 PM | 33.4 | 27 | 0 | 15 | 11 | 31 |

## Pellet Stove Side Feed, runs 6 through 8

Tests conducted July 12, 2002
Conditions: Combustion air supplied from inside test enclosure
6- Feeder at minimum (15Pa)
7- Feeder at maximum (15 Pa)
8- Feeder at maximum (10 Pa)

| Cond. | Time | Exh Fan Flow (L/sec) | Exh Air Temp. (°C) | Exh Air CO ppm | Encl. Pressure (Pa) | Flue Draft (Pa) | Hopper Temp (°C) |
|---|---|---|---|---|---|---|---|
| 6 | 9:30 AM | 24.1 | 21 | 5 | 15 | 12 | 25 |
| 6 | 9:40 AM | 24.1 | 21 | 5 | 15 | 12 | 25 |
| 6 | 9:50 AM | 24.1 | 23 | 6 | 16 | 13 | 25 |
| 6 | 10:00 AM | 24.1 | 23 | 5 | 15 | 13 | 25 |
| 7 | 10:10 AM | 21.3 | 22 | 3 | 15 | 13 | 24 |
| 7 | 10:20 AM | 21.3 | 23 | 31 | 16 | 14 | 25 |
| 7 | 10:30 AM | 23.2 | 24 | 93 | 16 | 12 | 25 |
| 7 | 10:40 AM | 23.2 | 25 | 87 | 16 | 12 | 26 |
| 7 | 10:45 AM | 23.2 | 25 | 83 | 16 | 12 | 26 |
| 8 | 1:30 PM | 0.0 | 23 | 82 | 11 | 7 | 24 |
| 8 | 1:40 PM | 0.0 | 24 | 128 | 11 | 7 | 25 |
| 8 | 1:50 PM | 0.0 | 24 | 118 | 11 | 7 | 26 |

## *Appendix F Wood stove test results*

### Non-catalytic wood stove run 1 & 2

Tests conducted on July 16, 2002

Conditions: Combustion air supplied from inside test enclosure

1. a) air intake 25% open
   b) room negative pressure 10 Pa
   Elapsed time: 29 min.
   Test terminated due to excessive CO emission of 94 ppm
2. a) air intake 50% open
   b) room negative pressure 10 Pa
   Elapsed time
   Elapsed time: 27 min.
   Test terminated due to excessive CO emission of 68 ppm

| Cond. | Time | Exh Fan Flow | Exh Air Temp. | Exh Air CO | Encl. Pressure | Flue Draft | Flue Gas Temp |
|---|---|---|---|---|---|---|---|
| 0 | 0 | (L/sec) | (°C) | ppm | (Pa) | (Pa) | (°C) |
| 1 | 11:04 AM | 22.2 | 24 | 3 | 10 | 11 | --- |
| 1 | 11:09 AM | 23.2 | 23 | 2 | 11 | 11 | --- |
| 1 | 11:14 AM | 22.2 | 21 | 3 | 11 | 10 | --- |
| 1 | 11:19 AM | 23.2 | 22 | 7 | 11 | 8 | --- |
| 1 | 11:24 AM | 22.2 | 22 | 16 | 11 | 7 | --- |
| 1 | 11:29 AM | 24.1 | 21 | 36 | 10 | 7 | --- |
| 1 | 11:33 AM | --- | --- | 94 | --- | --- | --- |
| | | | | | | | |
| 2 | 1:32 PM | 20.4 | 20 | 0 | 10 | 17 | 229 |
| 2 | 1:37 PM | 22.2 | 20 | 0 | 11 | 15 | 203 |
| 2 | 1:42 PM | 24.1 | 21 | 2 | 10 | 14 | 181 |
| 2 | 1:47 PM | 23.2 | 23 | 7 | 10 | 13 | 171 |
| 2 | 1:52 PM | 23.2 | 22 | 15 | 11 | 11 | 139 |
| 2 | 1:57 PM | 24.1 | 21 | 51 | 10 | 9 | 88 |
| 2 | 1:59 PM | --- | --- | 68 | --- | --- | --- |

## Non-catalytic wood stove run 3

Test conducted on July 17, 2002
Conditions:
1. a) air intake 50% open
   b) room negative pressure 5 Pa

Elapsed time: 3 hours, 35 min.
Test terminated due to excessive CO emissions of 150 ppm

| Cond. | Time | Exh Fan | Exh Air | Exh Air | Encl. | Flue | Flue Gas |
|---|---|---|---|---|---|---|---|
| | | Flow | Temp. | CO | Pressure | Draft | Temp |
| 0 | 0 | (L/sec) | (°C) | ppm | (Pa) | (Pa) | (°C) |
| 1 | 8:08 AM | 0.0 | 25 | 0 | -6 | -21 | 253 |
| 1 | 8:13 AM | 0.0 | 24 | 0 | -6 | -20 | 240 |
| 1 | 8:18 AM | 0.0 | 24 | 0 | -6 | -19 | 230 |
| 1 | 8:23 AM | 0.0 | 24 | 0 | -6 | -19 | 225 |
| 1 | 8:28 AM | 0.0 | 24 | 0 | -6 | -19 | 222 |
| 1 | 8:33 AM | 4.6 | 24 | 0 | -4 | -19 | 222 |
| 1 | 8:38 AM | 0.0 | 24 | 0 | -5 | -19 | 216 |
| 1 | 8:43 AM | 0.0 | 24 | 0 | -5 | -19 | 221 |
| 1 | 8:48 AM | 3.7 | 24 | 0 | -4 | -19 | 217 |
| 1 | 8:53 AM | 0.0 | 25 | 0 | -5 | -17 | 197 |
| 1 | 8:58 AM | 0.0 | 24 | 0 | -6 | -16 | 177 |
| 1 | 9:03 AM | 4.6 | 24 | 0 | -4 | -16 | 172 |
| 1 | 9:08 AM | 2.8 | 24 | 0 | -5 | -15 | 165 |
| 1 | 9:13 AM | 5.6 | 24 | 0 | -6 | -15 | 156 |
| 1 | 9:18 AM | 2.8 | 24 | 0 | -5 | -14 | 151 |
| 1 | 9:23 AM | 5.6 | 24 | 0 | -6 | -14 | 143 |
| 1 | 9:28 AM | 0.0 | 24 | 0 | -5 | -13 | 137 |
| 1 | 9:33 AM | 0.0 | 24 | 0 | -4 | -12 | 130 |
| 1 | 9:38 AM | 3.7 | 24 | 0 | -5 | -12 | 125 |
| 1 | 9:43 AM | 0.0 | 25 | 0 | -5 | -12 | 120 |
| 1 | 9:48 AM | 6.5 | 24 | 2 | -6 | -11 | 116 |
| 1 | 9:53 AM | 4.6 | 24 | 6 | -6 | -10 | 93 |
| 1 | 9:58 AM | 1.9 | 24 | 0 | -4 | -11 | 105 |
| 1 | 10:03 AM | --- | --- | --- | --- | ---- | --- |
| 1 | 10:08 AM | 0.0 | 24 | 7 | -5 | -9 | 88 |
| 1 | 10:13 AM | 0.0 | 24 | 8 | -6 | -7 | 83 |
| 1 | 10:18 AM | 6.5 | 25 | 3 | -5 | -7 | 80 |
| 1 | 10:23 AM | 0.9 | 25 | 7 | -5 | -7 | 80 |
| 1 | 10:28 AM | 0.0 | 25 | 9 | -5 | -3 | 62 |
| 1 | 10:33 AM | 5.6 | 25 | 14 | -6 | -2 | 49 |
| 1 | 10:38 AM | 2.8 | 25 | 25 | -5 | -4 | 54 |
| 1 | 10:43 AM | 3.7 | 24 | 25 | -5 | -2 | 46 |
| 1 | 10:48 AM | 3.7 | 24 | 31 | -5 | -2 | 40 |
| 1 | 10:53 AM | 0.0 | 24 | 56 | -5 | -2 | 37 |
| 1 | 10:58 AM | 6.5 | 24 | 80 | -5 | -2 | 36 |
| 1 | 11:03 AM | 3.7 | 24 | 72 | -5 | -2 | 35 |
| 1 | 11:08 AM | 8.3 | 23 | 106 | -5 | -2 | 34 |
| 1 | 11:13 AM | 8.3 | 23 | 108 | -4 | -2 | 33 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 11:18 AM | 10.2 | 23 | 120 | -5 | -1 | 33 |
| 1 | 11:23 AM | 9.3 | 23 | 132 | -5 | -1 | 32 |
| 1 | 11:28 AM | 6.5 | 23 | 137 | -4 | -1 | 32 |
| 1 | 11:33 AM | 10.2 | 23 | 137 | -5 | -1 | 32 |
| 1 | 11:38 AM | 10.2 | 23 | 131 | -5 | -1 | 31 |
| 1 | 11:43 AM | 10.2 | 23 | 138 | -5 | -1 | 31 |

## Non-catalytic wood stove run 4

Test conducted on November 12, 2002
Conditions:

1. a) air intake 50% open
   b) room negative pressure 10 Pa

Elapsed time: 1 hour, 35 min.
Test terminated due to excessive CO emissions of 330 ppm

| Cond. | Time | Exh Fan Flow (L/sec) | Exh Air Temp. (°C) | Exh Air CO ppm | Encl. Pressure (Pa) | Flue Draft (Pa) | Flue Gas Temp (°C) |
|---|---|---|---|---|---|---|---|
| 1 | 11:55 AM | 10.3 | 21.8 | 0 | - 10.6 | - 5.6 | 235.5 |
| 1 | 12:10 PM | 8.3 | 23.7 | 0 | - 10.6 | - 6.2 | 225.1 |
| 1 | 12:25 PM | 7.6 | 23.6 | 0 | - 10.0 | - 6.2 | 232.2 |
| 1 | 12:40 PM | 7.6 | 23.1 | 0 | - 10.0 | - 3.7 | 183.4 |
| 1 | 12:55 PM | 8.8 | 23.2 | 4 | - 10.0 | - 2.5 | 156.7 |
| 1 | 1:10 PM | 9.8 | 23.2 | 11 | - 10.0 | - 0.6 | 134.6 |
| 1 | 1:20 PM | 7.0 | 23.5 | 49 | - 10.0 | + 3.7 | 58.8 |
| 1 | 1:25 PM | 8.6 | 23.4 | 185 | - 10.0 | + 5.0 | 56.6 |
| 1 | 1:30 PM | 23.4 | 23 | 330 | - 10.0 | + 6.2 | 55.8 |

## Non-catalytic wood stove run 5

Test conducted on November 15, 2002

Conditions:

1. a) air intake 50% open
   b) room negative pressure 5 Pa

Elapsed time: 3 hours, 10 min.

Test terminated 15 minutes after CO emissions peaked at 72 ppm

| Cond. | Time | Exh Fan Flow (L/sec) | Exh Air Temp. (°C) | Exh Air CO ppm | Encl. Pressure (Pa) | Flue Draft (Pa) | Flue Gas Temp (°C) |
|---|---|---|---|---|---|---|---|
| 1 | 9:55 AM | 21.5 | 23.2 | 0 | - 5 | - 13.7 | 246.7 |
| 1 | 10:10 AM | 21.5 | 25.1 | 0 | - 5 | - 13.1 | 233.6 |
| 1 | 10:25 AM | 21.9 | 25.2 | 0 | - 5 | - 10.6 | 191.8 |
| 1 | 10:40 AM | 21.6 | 24.2 | 0 | - 5 | - 9.3 | 165.1 |
| 1 | 10:55 AM | 21.5 | 23.9 | 0 | - 5 | - 8.1 | 146.7 |
| 1 | 11:10 AM | 23.4 | 23.7 | 0 | - 5 | - 6.8 | 128 |
| 1 | 11:25 AM | 21.5 | 24.5 | 0 | - 5 | - 4.4 | 112 |
| 1 | 11:40 AM | 21.6 | 24.6 | 0 | - 5 | - 3.1 | 96.8 |
| 1 | 11:55 AM | 21.9 | 24.6 | 0 | - 5 | - 1.9 | 84.1 |
| 1 | 12:10 PM | 21.8 | 24.3 | 0 | - 5 | - 0.6 | 67.2 |
| 1 | 12:20 PM | 21.6 | 23.9 | 5 | - 5 | + 0.6 | 56.4 |
| 1 | 12:26 PM | 21.6 | 23.8 | 7 | - 5 | + 1.9 | 41.6 |
| 1 | 12:31 PM | 21.9 | 23.6 | 35 | - 5 | + 3.7 | 35.5 |
| 1 | 12:35 PM | 21.6 | 23.5 | 55 | - 5 | + 4.4 | 35.2 |
| 1 | 12:40 PM | 21.6 | 23.5 | 65 | - 5 | + 4.4 | 33.1 |
| 1 | 12:45 PM | 21.6 | 23.4 | 69 | - 5 | + 4.4 | 31.4 |
| 1 | 12:50 PM | 21.8 | 23.3 | 72 | - 5 | + 5.0 | 30 |
| 1 | 12:55 PM | 21.8 | 23.3 | 72 | - 5 | + 5.6 | 28.6 |
| 1 | 1:00 PM | 21.6 | 23.5 | 70 | - 5 | + 5.0 | 27.2 |
| 1 | 1:05 PM | 21.5 | 23.8 | 66 | - 5 | + 5.6 | 26.6 |

## Catalytic wood stove run 1

Test conducted on November 26, 2002
Conditions: Combustion air supplied from inside test enclosure
1. a) air intake 50% open
   b) room negative pressure 5 Pa

Elapsed time: 20 min.
Test terminated 20 minutes after CO concentrations peaked at 91 ppm

| Cond. | Time | Exh Fan Flow (L/sec) | Exh Air Temp. (°C) | Exh Air CO ppm | Encl. Pressure (Pa) | Flue Draft (Pa) | Flue Gas Temp (°C) |
|---|---|---|---|---|---|---|---|
| 1 | 9:02 AM | 7.4 | 21.9 | 0 | 5 | 9.4 | 213.7 |
| 1 | 9:17 AM | 7.5 | 23.3 | 0 | 5 | 10 | 212 |
| 1 | 9:32 AM | 7.5 | 37.8 | 0 | 5 | 9.4 | 211.8 |
| 1 | 9:47 AM | 7.3 | 25.7 | 0 | 5 | 8.7 | 199 |
| 1 | 10:02 AM | 7.3 | 24.2 | 0 | 5 | 7.5 | 190 |
| 1 | 10:17 AM | 7.4 | 23.1 | 0 | 5 | 6.2 | 160.4 |
| 1 | 10:32 AM | 7.3 | 22.2 | 0 | 5 | 5 | 134.2 |
| 1 | 10:47 AM | 7.3 | 20.9 | 0 | 5 | 3.1 | 110 |
| 1 | 11:02 AM | 7.4 | 19.9 | 0 | 5 | 0.6 | 83.3 |
| 1 | 11:17 AM | 7.5 | 21.7 | 16 | 5 | -1.9 | 34.7 |
| 1 | 11:22 AM | 7.5 | 21.8 | 35 | 5 | -2.5 | 37.2 |
| 1 | 11:27 AM | 7.5 | 21.7 | 64 | 5 | -3.7 | 39.8 |
| 1 | 11:32 AM | 7.5 | 21.6 | 80 | 5 | -4.4 | 37.3 |
| 1 | 11:37 AM | 7.5 | 21.4 | 90 | 5 | -4.4 | 35.1 |
| 1 | 11:42 AM | 7.5 | 21.3 | 91 | 5 | -5 | 33.2 |
| 1 | 11:47 AM | 7.5 | 21.3 | 89 | 5 | -5 | 31.4 |
| 1 | 11:52 AM | 7.5 | 21.1 | 89 | 5 | -5 | 29.8 |
| 1 | 11:57 AM | 7.4 | 21.1 | 82 | 5 | -5 | 29.2 |

## Catalytic wood stove run 2

Test conducted on November 26, 2002
Conditions: Combustion air supplied from inside test enclosure
1. a) air intake 50% open
   b) room negative pressure 10 Pa

Elapsed time: 20 min.
Test terminated due to high CO concentrations exceeding 200 ppm

| Cond. | Time | Exh Fan Flow (L/sec) | Exh Air Temp. (°C) | Exh Air CO ppm | Encl. Pressure (Pa) | Flue Draft (Pa) | Flue Gas Temp (°C) |
|---|---|---|---|---|---|---|---|
| 1 | 2:09 PM | 11.6 | 21.6 | 15 | 10 | -1.2 | 111.7 |
| 1 | 2:14 PM | 11.7 | 22.9 | 86 | 10 | -3.7 | 53.1 |
| 1 | 2:19 PM | 11.7 | 23.2 | 117 | 10 | -4.4 | 55.1 |
| 1 | 2:24 PM | 11.7 | 23 | 146 | 10 | -5.6 | 66 |
| 1 | 2:29 PM | 11.7 | 23 | 205 | 10 | -7.5 | 65.2 |