Development and Evaluation of a new Depressurization Spillage Test for Residential Gas-Fired Combustion Appliances

Final Report

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DISCLAIMER

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Abstract

NRCan, in partnership with CMHC, carried out a project to evaluate the performance of a small sample of residential combustion appliances using a new depressurization spillage test procedure. The tests were done at a Canadian commercial testing laboratory. The new combustion spillage test was relatively easy to perform. Seven gas-fired appliances were tested at 50 Pa depressurization: three had no detectable spillage; three had minor, but measurable spillage; one had significant spillage.

The new depressurization spillage test can be easily performed in-house by manufacturers and certification agencies. It can help them to differentiate products in terms of spillage resistance and assist manufacturers to improve and market more spillage-resistant combustion appliances.

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Summary & Introduction

A new combustion depressurization spillage test for residential combustion appliances has been developed. The test has been designed to accurately measure the amount of combustion spillage from residential combustion appliances and their venting systems when they operate at selected levels of depressurization. The new test uses carbon dioxide (CO_2) that is produced in the fuel combustion process as a tracer gas. The test method has been designed so that it will not require the use of precision space conditioning facilities during the test.

During this project seven (7) gas-fired appliances were purchased and installed to evaluate both the new combustion spillage test and the appliances. The appliances were chosen to cover a cross-section of the types of gas-fired equipment that are commonly installed in Canadian homes.

The sample set comprised:

- Two power-vented storage-tank water heaters
- One code-compliant “mid-efficiency” furnace (with the approved supplemental side wall venting kit that would be required for most if not all “Category 1” negative-vent pressure appliances)
- Two high efficiency “condensing” furnaces
- Two “direct-vent” gas fireplaces

The products and their venting systems were purchased from regular HVAC distributors and they were shipped directly to the testing laboratory by the distributors. Each product was installed in a test room that had been equipped with an exhaust fan that allowed the room to be depressurized to selected levels. Each of the products was installed, following the manufacturer’s certified installation instructions and using the maximum equivalent length and type of venting materials specified by the manufacturer. The condensing furnaces are approved for installation as either direct-vent or as “single-pipe” systems. They were installed as “single-pipe” units, drawing their combustion air from inside the depressurized test room.

For each unit, tests were initially performed with the test room depressurized by 50 Pa (0.2 inches H_2O) compared with the pressure outside the room. If the combustion spillage exceeded 2%, the test was repeated with the room depressurized by 20 Pa (0.08 inches H_2O). Finally, if the measured spillage exceeded 2% at 20 Pa, a test was performed with the room depressurized by 5 Pa (0.02 inches H_2O).

Each appliance was operated for a five minute period of burner operation with the room depressurization level controlled at the selected value. The burner fuel consumption, the concentration of CO_2 in the test room, and the exhaust fan flow rate were monitored throughout the five minute combustion period. Measurements were continued for two minutes immediately following burner shutoff to ensure that any transient spillage of

combustion products into the test room that occurred after the burner shut off would be included in the test. Similarly, the exhaust fan was operated to produce the required depressurization level prior to activating the appliance to ensure that any ignition-related transient spillage that occurred at the start of the test cycle would also be included.

For each test, the amount of CO_2 that was released into the test room from the appliance and its combustion venting system during the test cycle was determined from the measurements. This was compared with the amount of CO_2 that would be produced by combustion of the fuel that was consumed during the test. The ratio of the two provides a direct measure of the combustion spillage of the appliance and its venting system during each test.

The 50 Pa depressurization tests results were quite interesting:

- Three products had essentially undetectable levels of combustion spillage
- Three products had low, but measurable combustion spillage (between 0.7% and 1.5%)
- One product had significant combustion spillage (approximately 13%)

Looked at from a different perspective, if one assumes a performance benchmark for a combustion appliance to have less than 2% combustion spillage at its rated depressurization level, six of the seven appliances that were evaluated with the new spillage test would have "passed" at 50 Pa. The seventh product would not "pass" at either 50 Pa (13% spillage) or at 20 Pa (4% spillage). It would "pass" the test at 5 Pa, at which pressure there was no detectable combustion spillage.

The detailed test results are published in a separate laboratory test report[1]. The results are summarized in Table 1.

This report is intended to provide some of the background for this project and to discuss the test concept and assumptions. It also includes a detailed description of the test procedure that incorporates what was learned during the laboratory testing project. The updated test procedure now includes SI units in the calculations.

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[1] *Laboratory Evaluation to Assess a proposed Test Method to Determine Transient Combustion Spillage, Bodycote Materials Testing Report 04-06-M278b for NRCan, July 2005*

Résumé

Introduction

Un nouveau test de vérification des émanations d'appareils à combustion résidentiels a été mis au point. Il vise à mesurer avec justesse la quantité d'émanations de produits de combustion que rejettent les appareils résidentiels et leur système d'évacuation lorsqu'ils fonctionnent à certains s degrés de dépressurisation. Le nouveau test fait appel au dioxyde de carbone (CO_2), à titre de gaz traceur, produit lors du processus de combustion. Le mode opératoire a été conçu de façon à ne pas requérir l'emploi d'installations de conditionnement de précision.

Au cours de la recherche, les sept appareils à gaz acquis ont été installés dans le but d'éprouver aussi bien le nouvel essai d'émanations de combustion que les appareils. Les appareils à gaz ont été choisis de manière à constituer un échantillon représentatif de ce qui s'installe couramment dans les maisons.

L'échantillon était constitué des appareils suivants :

- deux chauffe-eau munis d'un évent à tirage mécanique;
- un générateur de chaleur d'efficacité moyenne, conforme au code (avec kit d'évacuation murale approuvé, requis pour la plupart sinon pour l'ensemble des appareils à conduit d'évent à pression négative de catégorie 1);
- deux générateurs de chaleur à condensation d'efficacité élevée;
- deux foyers à gaz reliés à un conduit d'évacuation direct.

Les produits et leur système d'évent ont été acquis de distributeurs courants de produits de chauffage, de ventilation et de conditionnement d'air, qui les ont expédiés directement au laboratoire d'essai. Chacun des produits a été installé dans une chambre d'essai équipée d'un ventilateur d'extraction permettant de la dépressuriser aux degrés voulus. Tous les produits ont été installés conformément aux instructions du fabricant, moyennant le type et la longueur équivalente maximale de l'évent spécifiés par le fabricant. Les générateurs à condensation sont approuvés pour être raccordés à un conduit d'évacuation direct ou à un seul conduit. Ils ont été raccordés à un seul conduit et ainsi tiraient leur air comburant de l'intérieur de chambre d'essai dépressurisée.

Pour chaque appareil, les essais ont, au départ, été effectués alors que la chambre d'essai avait subi une dépressurisation de 50 Pa (0,2 po de H_2O) par rapport à la pression à l'extérieur de la chambre. Si les émanations de produits de combustion dépassaient 2 %, l'essai était répété à une dépressurisation de 20 Pa (0,08 po H_2O). Enfin, si les émanations mesurées dépassaient 2 % à une dépressurisation de 20 Pa, l'essai était effectué la chambre dépressurisée de 5 Pa (0,02 po de H_2O).

Le brûleur de chaque appareil a fonctionné pendant une période de cinq minutes, le niveau de dépressurisation de la chambre étant maintenu à la valeur choisie. La

consommation du brûleur en combustible, la concentration de CO_2 dans la chambre d'essai, et le débit du ventilateur d'extraction ont été contrôlés pendant la période complète de cinq minutes. Les prélèvements ont été poursuivis pendant deux minutes après l'arrêt du brûleur pour que toutes les émanations de combustion rejetées dans la chambre d'essai après l'arrêt du brûleur soient incluses dans les résultats d'essais. De même, le fonctionnement du ventilateur d'extraction visait à assurer le niveau de dépressurisation requis avant de faire fonctionner l'appareil pour que toutes les émanations transitoires lors de l'allumage au début du cycle d'essai soient également incluses.

Pour chacun des essais, la quantité de CO_2 rejetée dans la chambre d'essai par l'appareil et son évent au cours du cycle d'essais a été déterminée par des prélèvements. Ils ont par la suite été comparés à la quantité de CO_2 dégagée par la consommation de combustible lors de l'essai. Le rapport des deux fournit une mesure directe des émanations de produits de combustion de l'appareil et de son évent au cours de chacun des essais.

Les résultats des essais de dépressurisation à 50 Pa se sont révélés plutôt intéressants :

- trois produits ont enregistré des niveaux d'émanations essentiellement indétectables;
- trois produits ont rejeté de faibles, mais tout de même mesurables, émanations de combustion (fluctuant entre 0,7 % et 1,5 %);
- un produit a rejeté d'importantes émanations de combustion (environ 13 %).

Selon une perspective différente, si l'on présume que le repère en matière de performance pour un appareil à combustion établit le rejet d'émanations inférieures à 2 % au niveau de dépressurisation coté, six des sept appareils éprouvés selon le nouveau test l'ont « passé » à une dépressurisation de 50 Pa. Le septième produit n'a pas « réussi » ni à 50 Pa (émanations de 13 %) ni à 20 Pa (émanations de 4 %). Il a réussi l'essai à une dépressurisation de 5 %, n'enregistrant aucune émanation de combustion détectable.

Les résultats détaillés des essais en laboratoire ont fait l'objet d'un rapport distinct intitulé *Laboratory Evaluation to Assess a proposed Test Method to Determine Transient Combustion Spillage*, *Bodycote Materials Testing Report 04-06-M278b for NRCan, July 2005*. Par ailleurs, le tableau 1 résume les résultats.

Le rapport est destiné à offrir un contexte pour la recherche et à traiter de la notion des essais et des hypothèses. Il comprend aussi une description détaillée de la méthode d'essai qui intègre les connaissances acquises au cours des essais en laboratoire. La méthode d'essai actualisée comporte maintenant des unités SI dans les calculs.

Project Background

Historically, combustion appliances used in low-rise residential installations have used chimney venting to remove their products of combustion from the living space. This type of venting system relies on the buoyancy of the warm flue products to remove them from the home. This combustion and venting process is sometimes referred to as "natural draft". To avoid excessive draft when the combustion products attain high temperature during periods with prolonged operation of the burner, and to partially decouple the appliance from the chimney, a draft control device was generally installed, either at the appliance or in the vent section between the appliance and the chimney. The draft control device is often called a draft dilution device. It is designed to allow cooler conditioned air from the house to be drawn into the combustion venting system when needed to reduce the temperature of the combustion gases through dilution, thereby reducing the negative pressure (or draft) at the appliance when the burner has been operating for an extended period.

Because of the historic differences between gas-fired and oil-fired appliances, the design and operation of their draft control devices was different. For naturally aspirated gas-fired appliances, the draft dilution device is commonly referred to as a "draft hood". This may be an integral part of a gas-fired appliance or a separate component. In a natural draft appliance, the combustion venting system is intended to operate with negative pressure in the vent between the appliance and the chimney or stack. For oil-fired appliances, which have used power burners for many years, the dilution device is called a "barometric damper". It is not an integral part of the appliance, but is installed in the vent section. It is generally designed to close during start-up to prevent spillage when the pressure in the vent between the appliance and the stack may be positive until sufficient chimney draft develops.

Draft hoods allow air to flow in either direction (both into and out from the combustion vent section). As a result they generally allow for some spillage on start-up to allow the naturally aspirated burners that have been historically used with most residential gas-fired equipment to stabilize. Barometric dampers are normally designed to allow flow in only one direction to avoid start-up spillage with the power burners that are prevalent with oil-fired equipment. Double-acting barometric dampers that allow air flow in both directions are available.

Residential combustion appliances worked reasonably well when they were properly installed and connected to correctly sized chimneys in relatively leaky (with respect to air tightness) housing stock. In general, leaky houses could provide sufficient air for combustion and dilution to the location in the home where the combustion appliances were located. However, even when installed in leaky houses, there have been issues associated with poor venting and combustion spillage during certain weather conditions, or when other exhaust equipment was operating in the home. As houses have become tighter (through more energy-efficient designs and improved construction of new homes, building code upgrades intended to ensure better integrity of the building envelope, and through renovation of existing housing stock) combustion spillage problems have become more difficult to avoid. Figure 1 illustrates the historic change in air tightness levels for Canadian houses over time[2]. Based on Figure 1, today's homes are twice as tight as they were in the 1970s and four times tighter than they were prior to 1945.

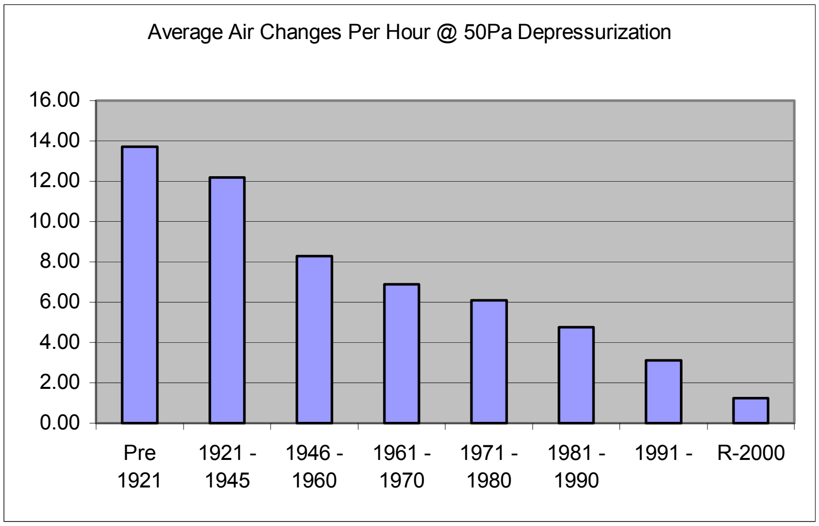

Figure 1: Change in air tightness level of Canadian homes over time

As well as today's houses being tighter than older homes, today's models of traditional exhaust products such as clothes dryers, range hoods and bathroom fans all can have significantly higher capacities than those used twenty years ago. New high powered exhaust equipment is often included in new homes too. Examples include: downdraft cook top exhaust appliances, central vacuums installed in garages, and other power vented combustion appliances. When these exhaust devices operate, they can create increased depressurization levels and increase the potential for combustion spillage in spillage-susceptible appliances as well as reversal of flows in chimneys. This is illustrated in Figure 2.

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[2] Source: NRCan database of Canadian Housing Characteristics

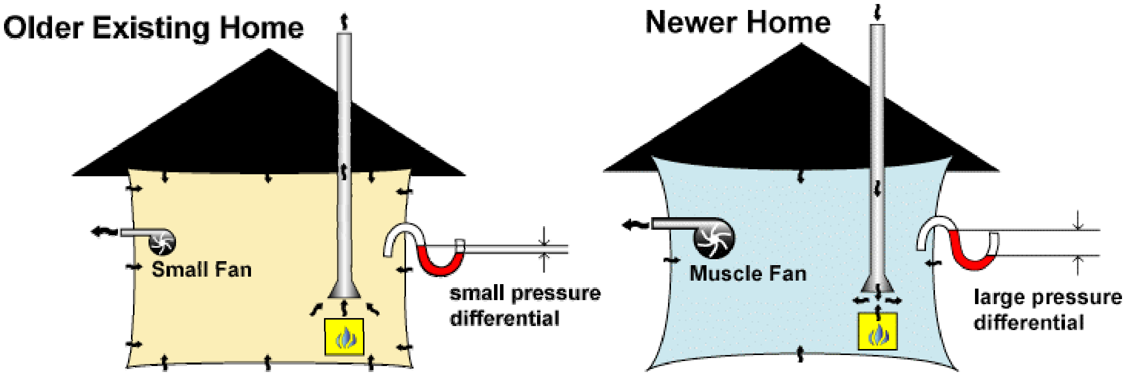

Figure 2: Potential Impact of Tighter Building Envelopes and Increased Exhaust Rates on Depressurization Levels [3]

Dealing with Combustion Spillage

Spillage from combustion appliances is a complex problem to solve. The frequency and severity of combustion spillage is influenced by the design and installation of the equipment, the appliance capacity, the system load factor which in turn is affected by the air tightness level of the building envelope, the thermal integrity of the structure, weather conditions, and system sizing and installation practices. Spillage may also result from the use of other air exhausting equipment installed in the home which can over-power the appliance venting system.

Existing Canadian Codes and Standards have attempted to deal with combustion spillage by such strategies as requiring make-up air supplies for installations that may not have sufficient air leakage to support the proper operation of the combustion appliances.

Manufacturers have manufactured appliances that are designed to be more spillage-resistant. Generally, they have either been designed in such a way that their combustion and venting components should not be exposed to the pressure regime inside the house, or they have been equipped with strong power venting systems that should be able to operate even when depressurized conditions exist. The first type of product are often referred to as direct-vent or isolated combustion appliances. They are often, but not always, vented using side-wall mounted terminals rather than through a chimney. Power vented water heater tanks are one of the more familiar examples of the second type of appliance designed for improved resistance to combustion spillage.

Despite the widespread availability of appliances that have been designed to have greater resistance to depressurization spillage, no mechanism exists that would allow a

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[3] Figure 2 and Figure 3 were supplied by Tony Euser, NRCan. NRCan's consent for their use in this report is gratefully acknowledged.

manufacturer to directly test and rate their products for combustion spillage resistance. This means that manufacturers have no accepted way to notify consumers, builders or other stakeholders of the rated spillage resistance of their appliances, or to indicate which of their products perform better under reduced pressure conditions that might cause spillage in other products.

The new depressurization spillage test has been developed as a key instrument towards addressing this gap. The spillage test will allow manufacturers to include depressurization spillage resistance ratings in their literature alongside their other product performance data. It is anticipated that the spillage test will be immediately useful to manufacturers and other stakeholders in making product differentiating and purchasing decisions.

Overview of Test Method

Definition of “Combustion Spillage”:
Throughout this project, the term “Combustion Spillage” during the depressurization spillage test is defined as:

> *Any products that are formed by combustion of a fuel that are released from the appliance or its venting system into the test room.*

The spillage test actually uses the carbon dioxide (CO_2) that is produced by the combustion process as a tracer gas to determine the portion of the combustion products that are released into the test room. For any fuel, the amount of CO_2 associated with consumption of a unit of fuel can be obtained from the fuel supplier, or it can be calculated from chemical analysis of the fuel. This can be considered as the fuel CO_2 production factor. For simplicity, all of the products evaluated in this project were fuelled by natural gas, so a single value for the CO_2 production factor could be used in all of the calculations.

Example calculations of fuel CO_2 production factors for natural gas, in SI and IP units, are provided in attachment 1. Both unit volume and unit energy CO_2 production factors are calculated.

The combustion depressurization spillage test is described below.

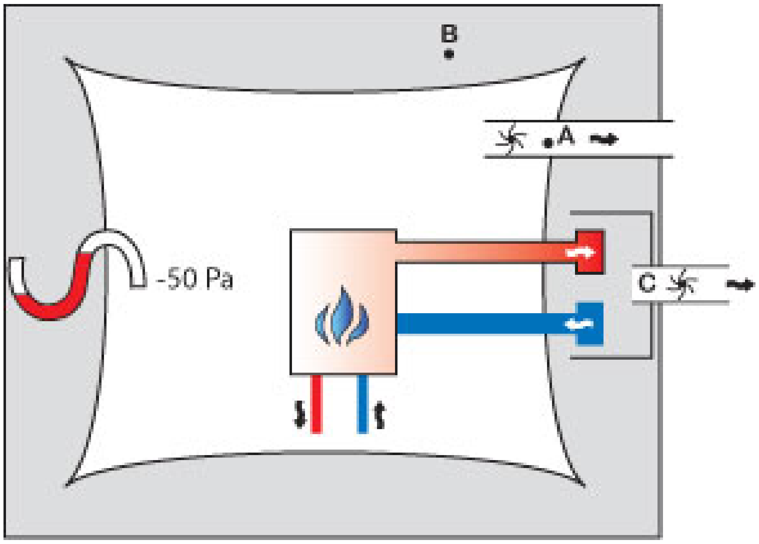

Figure 3: Simplified Concept of Depressurization Spillage Test

In Figure 3, the box with a flame represents a combustion appliance that is installed inside the depressurized test room. The horizontal ducts (with white arrows) attached to the appliance represent the combustion air inlet and the combustion vent. The combustion appliance is shown drawing its combustion air from outside the test room and exhausting its combustion products outside the test room. Some, but not all, appliances draw their combustion air from inside the test room. The vertical lines represent the thermal load and output from the appliance that may either be released inside the test room or rejected outside the room (rejection is simpler for products that heat water such as water heaters and boilers).

In the Figure, the test room is depressurized to 50 Pa with respect to its surroundings using a fan installed in duct “A”. A supplemental exhaust system “C” captures and removes the combustion products to avoid contaminating the area “B” adjacent to the test room. For the same reason, the depressurization fan in duct “A” is discharged outside the building.

To briefly summarize the depressurization spillage test:

- The combustion appliance is installed in a well-sealed room.
- A fan is used to draw air from the test room so that the appliance can be tested against different levels of depressurization.
- The appliance is operated
- Measurements of the following parameters are taken
    - room pressure,
    - fuel consumption rate

  - airflow drawn from the room by the depressurization fan and
  - the CO_2 concentration (A) in the air being removed from the room
  - the CO_2 concentration (B) in the surrounding area

Prior to this project, a spillage test procedure had been validated and used to evaluate the depressurization spillage resistance of a few prototype water heating products. In the previous testing, the water heating appliances had been tested to equilibrium or "steady-state" spillage conditions in the depressurized test room while their thermal outputs were rejected outside the test room.

In this project CMHC and NRCan wanted to simplify the previous test procedure and incorporate a test cycle that could be more readily used with other types of combustion appliances. Using a test cycle also allowed start-up and shut down combustion spillage transients to be included in the test method.

The new cyclic test setup is essentially the same as the "steady-state" test concept that had been used earlier. In the new version of the depressurization spillage test:

- The appliance is installed inside the test room, following the manufacturer's instructions and using approved venting materials and maximum vent lengths
- The test room is depressurized before the appliance burner is activated
- The test is based on operating the appliance burner for five minutes and collecting data for seven minutes. This ensures that start-up and shut-down combustion spillage will be included in the test. The temperature in the test room is allowed to "float" during the test.
- The CO_2 spilled into the test room by the appliance during the test cycle is calculated. Calculations include the following:
  - CO_2 that is removed from the test room by the depressurization fan
  - CO_2 included in any combustion and dilution air that is drawn from the test room by the combustion venting system of the appliance being tested (This is only applicable if the appliance draws combustion air from the test room)
  - CO_2 that accumulates in the test room during the test

The amount of CO_2 removed from the test room by the depressurization fan is determined from measurements of the air flow drawn from the test room and the CO_2 level that is recorded during the test.

The flow of combustion and dilution air from the test-room (if applicable) is calculated from the fuel consumption rate and the excess-air level in the flue, determined from flue gas analysis.

For this project, the amount of CO_2 drawn from the test room has been calculated for each 30 second time interval and the intervals have been summed over the seven minute test time.

The CO_2 that accumulates in the test room during the test is determined from the measured volume of the room and the change in the CO_2 concentration in the room at the start and at the end of each test.

A more detailed description of the test procedure and a worked example of the calculations are provided in Attachments 2 & 3.

Test Results

Tests were performed on three furnaces (two condensing models and one non-condensing model), two power-vented water heaters and two gas fireplaces.

When tested at 50 Pa depressurization,

- Three products had essentially undetectable levels of combustion spillage
- Three products had low, but measurable combustion spillage (between 0.7% and 1.5%)
- One product had significant combustion spillage (approximately 13%)

The products that were tested and the test results are shown in Table 1

Table 1: Product Identification & Results of Depressurization Spillage Tests

	Power Vented Water Heater Tank	**Power Vented Water Heater Tank**	**Non Condensing Furnace**	**Condensing Furnace**	**Condensing Furnace**	**Direct Vent Fireplace Insert**	**Direct Vent Zero Clearance Fireplace**
Manufacturer	Rheem	GSW	Keeprite	Nordyne	Payne	Withheld	Kingsman
Model Number	PVS50	6G50NVH-04	C8MPN075B12-A1	KG6RC080C-12B	PG9MAA036080	-	ZDV3622N
Maximum Rated Input Btu/h*1000 (kW)	36 (10.5)	34 (10)	75 (22)	80 (23.4)	80 (23.4)	24 (7)	21 (6.2)
Maximum Rated Combustion Vent Length - ft (m)	60 (18)	50 (15)	35 (11)	60 (18)	55 (17)	35 (11)	12 (4) [1]
Maximum Rated Intake-Air Length - ft (m)	N/A	N/A	N/A	60 (18) [2]	55 (17) [2]	35 (11)	12 (4) [1]
Burner Pre-Purge Time (s)	15	15	15	60	45	0	0
Burner Post-Purge Time (s)	30	30	15	30	15	0	0
Depressurization Spillage at 50 Pa (%)	1.1	1.55	0.2 [3]	0.04	0.14	13.3 12.8 [4]	0.7
Depressurization Spillage at 20 Pa (%)	-	-	-	-	-	3.5	-
Depressurization Spillage at 5 Pa (%)	-	-	-	-	-	0.0	-

Notes to Table 1

1. Installed and tested with 4 ft. (1.2 m) vertical, 8 ft. (2.4 m) horizontal venting in test room.
2. Installed and tested as single pipe installations – optional sidewall two-pipe configuration with outdoor combustion air intake was not tested.
3. Installed and tested with a manufacturer-approved supplemental sidewall vent kit.
4. Repeat test with additional air circulation in test room

Discussion

Products Sampled

Seven appliances (two water heaters, three furnaces and two gas-fireplaces) were chosen to cover a cross-section of the types of gas-fired equipment that are commonly installed in Canadian homes. The products and their venting systems were purchased from regular HVAC distributors and they were shipped directly to the testing laboratory by the distributors for the tests. Each of the products was installed, following the manufacturer's certified installation instructions and using the maximum equivalent length and type of venting materials specified by the manufacturer.

Although the test results were generally good, it must be stressed that only one sample of each appliance was actually tested in this project. Sample to sample production changes and differences in the installation methods or materials may produce different results.

Accuracy and Repeatability

The use of CO_2 to measure combustion spillage inherently introduces some uncertainties to the test method and result because CO_2 is a naturally-occurring gas that is produced by human respiration and many other processes. Ambient air contains on the order of 425 PPM CO_2 but the actual level in any facility will change from day to day, from test to test, and perhaps during a test. The background level of ambient CO_2 will be affected by changes in the activity level in and around the facility, the way that the building HVAC systems are operated and weather conditions. To minimize the effect of changes in the background CO_2 on the test results, the spillage calculations include an adjustment for changes to the CO_2 "background level" measured in the air-space that surrounds the test room during each spillage test. As well, the combustion gases that are produced during each test are removed away from the test area to avoid contamination from that source.

To investigate the accuracy and repeatability of the test method, some additional tests were performed.

After one of the water heater tests had been completed, the combustion vent was disconnected from the appliance and the exhaust vent was sealed at the wall terminal. A depressurization spillage test was undertaken with the water heater discharging its combustion products directly into the test room. The test indicated combustion spillage of 85 percent, rather than the expected result of 100 percent. Extending the data analysis test time from seven minutes to ten minutes for the calculations had no effect on the result. The calculated additional amount of CO_2 that was removed from the chamber during the extra three minutes was almost exactly offset by the reduction in the calculated amount of CO_2 remaining inside the test room at the end of the test. Venting all of the combustion products into the test room raised the room CO_2 level to over 1400 PPM during the test, substantially higher than for any of the real depressurization spillage tests.

The CO_2 analyser was checked at 900 PPM using span gas for these tests. However, any error or non-linearity in the analyser could have a greater impact in the calculated result at high contamination levels. If the spillage test were focussed on extreme spillage, additional calibrations at higher CO_2 concentrations would be required.

While the root cause for the 85 % result from the simulated spillage test was not identified, it should be understood that the depressurization spillage test has been designed to detect and quantify relatively low levels of combustion spillage in appliances, not the 100 % spillage that was simulated during that test. Notwithstanding the imperfect CO_2 balance, the result of the test is clear. It is evident that any vented appliance with either 85 % spillage or 100 % spillage (or indeed, 10 % spillage) would be considered unacceptable by all stakeholders, especially the manufacturer.

A further test simulation was performed following the depressurization test on one of the condensing furnaces. It was thought that if the 85 % spillage result from the water heater test were caused by inadequate air mixing in the test room (resulting in not obtaining a representative CO_2 sample), operation of the furnace blower during the test might improve air mixing inside the test room, and thereby improve the CO_2 balance. However, because of the much higher firing rate of the furnace compared with the water heater, the test room CO_2 concentration almost immediately exceeded the 2500 PPM range of the CO_2 analyser during the simulated spillage test, and the results could not be used.

During some of the spillage tests, oscillations were apparent in the readings recorded from an analyser that was being used to monitor CO_2 concentrations in the space adjacent to the test room. When the problem occurred, the magnitude of the oscillations was on the order of ±15 PPM. Combustion spillage for these tests was analysed using both the recorded values for each time interval and the average value from the same analyser over the full seven minute test period. The results using either calculation approach were essentially the same. The spillage results in Table 1 were determined using the average CO_2 measurements in the air space surrounding the test room.

The 50 Pa spillage test on the direct vent fireplace insert indicated combustion spillage of 13.3 %. The same product was re-tested after an additional air circulation fan was installed in the test room in an attempt to promote better mixing of the air inside the test room environment. The repeat test produced a calculated spillage result of 12.8 %, a spillage difference of 0.5 %, which is approximately 4 % of the original spillage result. This is considered to be a reasonable agreement, and it suggests that additional air mixing was not needed.

This 4 % change in the measured spillage result may be associated with the difference in mixing of the test room environment or, it may simply reflect the level of repeatability of the test method, test instrumentation, test conditions and/or the repeatability of the spillage performance of the appliance itself. For this reason, the test may have difficulty in conclusively differentiating between a close “pass” and a marginal “fail”. If such a spillage result were obtained, further investigations and repeat tests would likely be warranted before reaching a conclusion. In this project, the closest result to the spillage threshold was 1.55 % for one product. While higher than ideal, that test result is more than 20 % below the threshold limit of 2% spillage. The result is considered to be a “pass”.

The proposed 2% limit to pass the spillage test is further discussed in the next section.

The 2% Spillage Limit

The new test incorporates a “pass” threshold of 2% spillage. This figure has been proposed for this test to provide for some flexibility in the choice of test instrumentation and to allow for some margin for error associated with cumulative uncertainties in the testing procedure and the required measurements. The proposed tolerance of 2% is the same as that allowed in the static vent leakage tests for the combustion vent section of sealed combustion appliances that operate with positive vent pressures. Such appliances already require vent leakage tests according to some existing Standards (for example CSA 4.3 CSA 4.9, CSA B140.0). However, it must be understood that static leakage tests are performed at different pressures and they are undertaken with the appliances and their vent systems at ambient temperature. It should also be noted that acceptance of a 2% “pass” tolerance in the new depressurization spillage test should not be construed as a general finding that 2% combustion spillage constitutes acceptable performance for all combustion appliances. Indeed, 2% spillage from certain types of combustion appliances may not be acceptable for all installations.

However, if the “pass” tolerance for the depressurization spillage test were to be reduced to a significantly lower value, (perhaps to 1%) the instrumentation required to perform the tests would require at least a corresponding level of upgrade. This would apply both to the airflow measurements and to the CO_2 monitoring instruments. More frequent measurements during the test cycle may also be required.

Minimizing Uncertainties

In order to minimize the uncertainties during the tests, the following procedures were implemented during the project:

- CO_2 analysers were calibrated before and after each test using calibration gas.
- All evident openings in the envelope of the test room were sealed.
- Flow in the supplemental exhaust products capture system was increased to improve the capture efficiency and minimize contamination of the space adjacent to the test room. Care was taken to ensure that the supplemental capture system did not affect the CO_2 level in the combustion vent section of the appliance.

- Air circulation fans were operated in the test room to promote proper mixing of the environment inside the room.

Differences with Static Pressure Testing

Vent leakage testing is required in product standards for direct vent appliances and condensing products. It is not required for naturally aspirating products or for non-condensing induced draft products.

When used, vent leakage testing enables manufacturers to find out whether or not their venting systems have any significant leakage. The supply air and the combustion air vents are each removed from their wall terminals and sealed except for an air inlet connection. The air intake section is sealed at the entrance to the combustion chamber to isolate the two sections. Depending upon which appliance standard the vent leakage test is taken from, it may also include the combustion product but not the burner. Each section is then pressurized independently. The air flow required to maintain the static pressure level in the component is measured and used to calculate the leakage for each section of the vent system. The combustion vent section cannot leak by more than two percent and the supply air section cannot leak by more than eight percent for the appliance and vent system to be classified as a sealed combustion system[4].

During this project static leakage tests were performed with the cabinets of the two gas fireplaces pressurized to 25 Pa. Both had less than 2% leakage and therefore passed the leakage tests. However, one of them had significant spillage during the 50 Pa depressurization spillage test while the other passed the spillage test easily. As noted above, when they are performed, static leakage tests are done with the appliances at ambient temperature, without the burner operating. By contrast, the appliances are fully operational for the combustion spillage tests. One may suppose that the new combustion spillage test detected combustion-gas leakage paths that only exist when the appliance operates, with its gaskets and other components at normal temperatures and pressures. If this is so, it reinforces the need for the new test and it directly demonstrates the potential product improvement benefit for manufacturers, installers and end-users of residential combustion appliances.

Conclusions and Recommendations

This project demonstrates that a relatively simple depressurization spillage test can be used to differentiate between products that spill and those that do not.

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[4] For vent leakage tests, the percentages are calculated from the measured airflow required to maintain the static pressure compared with a nominal flow calculated from the fuel input rating, assuming complete combustion of the fuel plus an additional 50% excess air

The facility and instrumentation requirements for the depressurization spillage test are low enough that manufacturers should have little or no difficulty in setting up the test in their own facilities and using it as a product development tool. This will enable them to verify the performance of their products and improve their spillage resistance. It will eventually allow them to provide the information in their product documentation.

Commercial laboratories can offer their services to manufacturers to carry out depressurization-spillage testing. Based on a test cycle time of seven minutes, the cost of such testing should be low, particularly if other work is to be performed at the same time.

Many existing products are capable of performing very well. Some will not. This test will differentiate the good and the bad.

Combustion spillage tests should be included within the applicable appliance safety standards to enable manufacturers to differentiate their products and to enable specifying engineers and other selecting parties to make appropriate product selections for their particular applications.

Natural Gas Trans Canada Pipeline Analysis: March 2005

Component	Volume %
Methane	95.71
Ethane	1.69
Propane	0.14
N-Butane	0.02
Iso-Butane	0.02
N-Pentane	0.01
Iso-Pentane	0.00
Hexanes plus	0.00
Nitrogen	1.77
Carbon dioxide	0.64
Oxygen	0.00
Hydrogen	0.00
Heating Value	1005.8 Btu/cu ft
	37.46 MJ/cu m
Total sulphur	0.15 gr/CCF
	3.56 mg/cu m
Relative Density	0.578

Using this fuel analysis, assuming complete combustion (no CO), combustion of one volume of Natural Gas will produce [0.9571 + (2*.0169) + (3*.0014) + .0064] = 1.0015 volume of CO_2 in the combustion vent products.

Natural Gas CO_2 Production Factors per unit Volume consumed and per unit Energy Input:

1000 btu/h input from gas produces 1.0015 / 1.0058 / 60 = .0165954 = .0166 cfm CO_2

1 ft^3/h gas consumption produces 1.0015 / 60 = 0.01669 cfm CO_2 = .0167 cfm CO_2

1 M^3 Natural Gas produces 1.0015 M^3 CO_2

1 MJ energy input from gas produces 1000 / 37.46 = 26.695 L CO_2

1 kW power input from gas produces 26.695 *3.6 / 3600
= 0.026695 L/s CO_2

(Conversions are based on 1 M^3 = 35.30 ft^3: 1 M^3 = 1000 L; 1 kWh = 3.6 MJ)

Depressurization Spillage Test Procedure

1 Installation & Preconditioning of Combustion Appliance

1.1 Test Setup

The appliance shall be installed in the test room using the manufacturer's installation instructions, and using the venting materials, connectors and vent terminations specified by the manufacturer. Gas supply and potable water connections, if applicable, may use flexible piping or hoses.

1.2 Preconditioning

Before performing a combustion spillage test, a new appliance shall be operated at its maximum firing rate for a period of at least four (4) hours to allow for the removal of any manufacturing residues within the appliance or its venting system that may affect the test measurements.

1.3 Depressurization

The test room shall be equipped with an exhaust fan and be sufficiently sealed to allow the test room to be evacuated to produce the depressurization level required for the test while the appliance is operating.
Note: In most cases, depressurization of the test room by up to 50 Pa (0.2 in water column) will be sufficient for the test.

1.4 Combustion & Vent Terminals

The combustion air inlet and vent terminals shall be installed at the wall or ceiling of the test room to discharge the vent products from the test room and to bring combustion air into the test room (if applicable). The test shall be performed with the maximum certified equivalent lengths of combustion vent and combustion air intake installed and connected inside the test room in accordance with the manufacturer's instructions. The combustion and vent terminals may connect with an outdoor space or may connect with the adjacent space surrounding the test room.

The adjacent space around the test room shall be adequately ventilated to ensure that the combustion products do not cause contamination of the space. A supplemental gas-capture and exhaust apparatus may be used to remove combustion products from the space adjacent to the test room, provided that the CO_2 content, vent temperature and flows of the combustion products in the appliance venting system are not affected by the operation of the apparatus.

1.5 Sampling Ports

A sampling port shall be installed to monitor the CO2 level within the test room and in the exhaust duct from the test room.
A sampling port shall be installed to monitor the pressure inside the test room. This pressure shall be monitored in a location between 0.5 m and 1 m of the appliance burner.

2 Test Tolerances

Pressure

The test room fan shall be operated and adjusted to produce the required static pressure in the test room (below the pressure in the surrounding area). The specified depressurization level shall be maintained within ± 2 Pa for the duration of the depressurization test by adjusting the flow through the test-room exhaust fan. The airflow through the test-room exhaust fan shall be measured during the test.

Temperature

Before a spillage test is performed the depressurization fan shall be operated until the test room temperature and the combustion vent temperature are within ±3°C of the ambient temperature in the surrounding space.

Note: This ensures that the spillage test will have a reproducible "cold-start" venting condition.

3 Test Procedures

3.1 The pressure inside the test room shall be adjusted to the level at which the appliance is to be tested within the tolerance outlined in Section 2

3.2 The appliance shall be operated at its maximum firing rate or at another firing rate if specified.

3.3 Measurements of the test room CO_2 level, the test room depressurization flow, and the appliance fuel consumption rate shall be recorded at least every 30 seconds during the test. Measurements shall continue for an additional 2 minutes after burner shutdown. The last two minutes of monitoring are conducted to observe the effects of shutdown spillage.

3.4 If the appliance draws combustion air from inside the test room, the CO_2 content and temperature in the combustion venting system at the vent termination shall be monitored during the test to establish the excess-air[5] level in the combustion vent.

3.5 The fuel supply to the appliance shall be shut off after 5 minutes of burner operation.

3.6 The electrical supply (if applicable) to the appliance shall be shut off seven minutes following the time that burner ignition occurred.

3.7 The CO_2 content in the space adjacent to the test room shall be measured at least immediately prior to and immediately following the seven minute test to ensure that the air surrounding the test room has not become contaminated.

4 Calculations

Combustion spillage shall be calculated and reported over the seven minute test period as outlined in attachment 3.

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[5] At the discretion of the testing agency, excess air may be determined using calculations from the Combustion and Fuels chapter of the current edition of ASHRAE Fundamentals. Combustion charts or combustion software are also acceptable methods to determine the excess air. North American Combustion Handbook,: Vol. 1 published by North American Mfg. Co.; is one acceptable source for combustion charts

Example Calculation of Spillage for a Power Vented Water Heater

Test Conditions

Test Room Static Pressure	-50 Pa	
Room Exhaust Fan Flow	123 L/s	(261 scfm)
Combustion Air Flow from Room	10 L/s	(21 scfm)
(Note: Sample water heater draws combustion air from the test room)		
Fuel Input Rate during Test	10.6 kW	36000 Btu/h
Room CO_2 at start of test	433 PPM	
Room CO_2 at end of test	443 PPM	
Volume of test room	44.7 M^3	(1578 ft^3)

Spillage = *(CO_2 accumulated in the test room between start and end of test + CO_2 removed by room depressurization fan and appliance combustion air) / CO_2 produced*

Calculations

CO_2 accumulated in the test room during test
*((Room CO_2 at end of test - Room CO_2 at start of test) * Scaling Factor) * Volume of Test Room*
(The Scaling Factor converts CO_2 concentrations in ppm to a decimal fraction)
$((443 - 433) * 0.000001) * 44.7 = 0.000447\ M^3$
$((443 - 433) * 0.000001) * 1578 = 0.01578\ ft^3$

CO_2 removed from test room during each time interval
*($CO_{2\ (test\ room)} - CO_{2\ (adjacent\ space)}$) * (Exhaust Fan Flow + Combustion air Flow) * Scaling Factor * Duration of time interval*

Cumulative CO_2 removed from test room[6]
Cumulative Sum of CO_2 removed from test room per time interval
= 0.0175 ft^3 or 0.000496 M^3

CO_2 generated by appliance during 5 minute burner operation
*= (Input Rate [Btu/h]/1000) * (0.0167 [SCFM]/1000 [Btu/h]) * Time [minutes]*
= ((36,000 * 0.0167) / 1000) * 5
= 3.0 ft^3 or 0.0850 M^3

Spillage = (0.000447 + 0.000496) M^3 /0.0850 M^3 = 0.0111
Spillage = (0.01578 + 0.0175) ft^3 / 3 ft^3 = 0.0111

Combustion Spillage at 50 Pa depressurization = 1.1%

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[6] Refer to the data summary on the next page for the spillage calculations for each 30 second time interval and the cumulative total over the seven minute test

Transient Spillage Test at 50 Pa. Depressurization

Sample No.:	04-06-M278-1
Client:	NRCan
Test Date:	4/20/2004

CO_2 leakage per time base interval = ($CO_{2\,(test\ room)}$ - $CO_{2\,(adjacent\ room)}$)·(Exhaust Fan Flow + Appliance Exhaust Products Flow)·(Scaling Factor)

CO_2 remaining in test room at end of test = ($CO_{2\,(test\ room\ end)}$ - $CO_{2\,(test\ room\ start)}$)·(Scaling Factor)·(Test Room Volume)

CO_2 generated by appliance = (Input Rate (Btu/h)/1000)·(0.0167 SCFM/1000 Btu/h)

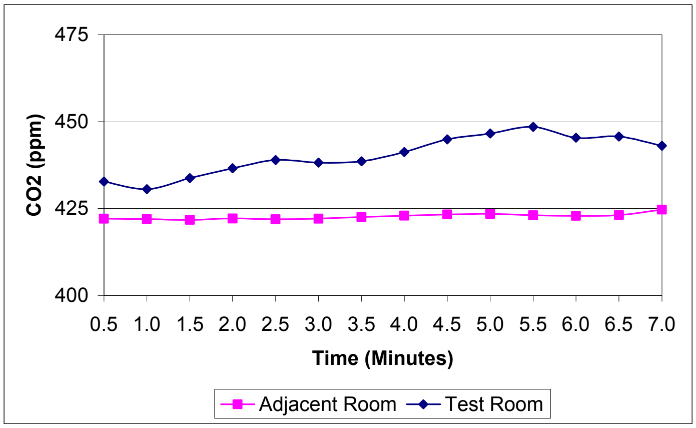
Spillage = Total CO_2 Leakage / CO_2 generated by appliance

											Post Purge	Inducer Blower Off		
Time (minutes):	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00
$CO_{2\,(test\ room,\ base)\ (ppm)}$:	430	430	430	430	430	430	430	430	430	430	430	430	430	430
$CO_{2\,(adjacent\ room,\ base)\ (ppm)}$:	422	422	422	422	422	422	422	422	422	422	422	422	422	422
$CO_{2\,(test\ room)\ (ppm)}$:	433	431	434	437	439	438	439	441	445	447	448	445	446	443
$CO_{2\,(adjacent\ room)\ (ppm)}$:	422	422	422	422	422	422	423	423	423	423	423	423	423	425
Exhaust Fan Flow (ACFM):	272.9	272.9	272.9	272.9	272.9	272.9	272.9	272.9	272.9	272.9	272.9	272.9	272.9	272.9
Exhaust Fan Flow (SCFM):	261.3	261.3	261.3	261.3	261.3	261.3	261.3	261.3	261.3	261.3	261.3	261.3	261.3	261.3
Vent CO_2 concentration[1] :	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	0.0	0.0	0.0	0.0
Combustion Products Flow (SCFM)[2] :	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	20.9	0.0	0.0	0.0
Scaling Factor:	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06
∴ CO_2 (depresurization) Leakage (ft^3) =	0.0003	0.0000	0.0005	0.0008	0.0012	0.0011	0.0011	0.0014	0.0018	0.0020	0.0024	0.0018	0.0018	0.0013

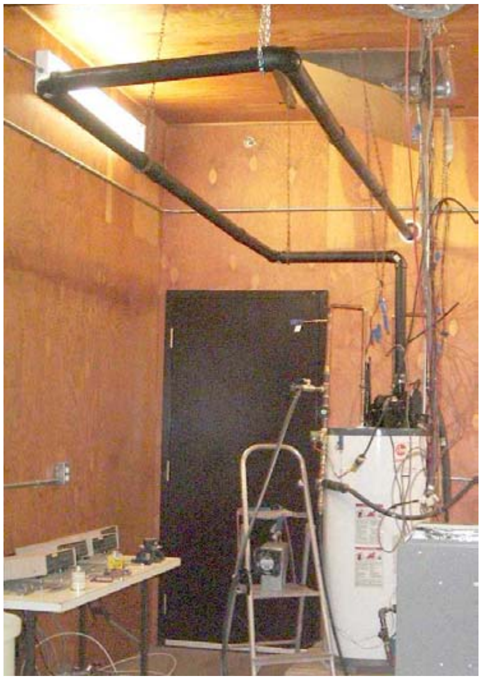
[1] Vent CO_2 concentration measured under steady state conditions

[2] Total combustion products exhausted from test room (including excess air & dilution air)

Test Room CO_2 at end of 7 minute test =	443 ppm
Test Room CO_2 at start of test =	433 ppm
Volume of test room =	1578 ft^3
CO_2 remaining in test room at end of test =	0.016 ft^3
Total CO_2 removed from test room over 7 minute test period =	0.0175 ft^3
Total CO_2 leakage =	0.0337 ft^3
CO_2 Generated by appliance during 5 minute burner ON time =	3.006 ft^3
Spillage (Total CO_2 leakage/ Appliance CO_2) =	1.12%



Attachment 4: Photographs of Selected Products in Test Room:



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