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Standard Guide for Assessing Depressurization-Induced Backdrafting and Spillage from Vented Combustion Appliances[1]

This standard is issued under the fixed designation E 1998; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide describes and compares different methods for assessing the potential for, or existence of, depressurization-induced backdrafting and spillage from vented residential combustion appliances.

1.2 Assessment of depressurization-induced backdrafting and spillage is conducted under either induced depressurization or natural conditions.

1.3 Residential vented combustion appliances addressed in this guide include hot water heaters and furnace. The guide also is applicable to boilers.

1.4 The methods given in this guide are applicable to Category I (draft-hood- and induced-fan-equipped) furnaces. The guide does not apply to Category III (power-vent-equipped) or Category IV (direct-vent) furnaces.

1.5 The methods in this guide are not intended to identify backdrafting or spillage due to vent blockage or heat-exchanger leakage.

1.6 This guide is not intended to provide a basis for determining compliance with code requirements on appliance and venting installation, but does include a visual assessment of the installation. This assessment may indicate the need for a thorough inspection by a qualified technician.

1.7 Users of the methods in this guide should be familiar with combustion appliance operation and with making house-tightness measurements using a blower door. Some methods described in this guide require familiarity with differential-pressure measurements and use of computer-based data-logging equipment.

1.8 *This guide does not purport to address all safety concerns, if any, associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.* Carbon monoxide (CO) exposure or flame roll-out may occur when performing certain procedures given in this guide. See Section 7, for precautions that must be taken in conducting such procedures.

2. Referenced Documents

2.1 *ASTM Standards:*

D 1356 Terminology Relating to Sampling and Analysis of Atmospheres[2]

E 631 Terminology of Building Constructions[3]

E 779 Test Method for Determining Air Leakage Rate by Fan Pressurization[3]

E 1827 Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door[4]

2.2 *CGSB Standard:*

51.71 The Spillage Test—Method to Determine the Potential for Pressure-Induced Spillage from Vented, Fuel-Fired; Space Heating Appliances; Water Heaters, and Fireplaces[5]

2.3 *ANSI Standard:*

Z21.47 Gas-fired Central Furnace[6]

2.4 *NFPA Standard:*

54 National Fuel Gas Code[7]

3. Terminology

3.1 *Definitions*—For definitions of terms used in this guide, refer to Terminologies E 631 and D 1356.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *air leakage*, *n*—the movement or flow of air through the building envelope which is driven by a pressure differential across the envelope.

3.2.2 *air leakage rate*, *n*—the volume of air movement per unit time across the building envelope.

3.2.3 *airtightness*, *n*—the degree to which the building envelope resists flow of air.

3.2.4 *blower door*, *n*—a fan pressurization device incorporating a controllable fan and instruments for airflow measurement and building pressure difference measurement that mounts securely in a door or other opening.

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[2] *Annual Book of ASTM Standards*, Vol 11.03.

[3] *Annual Book of ASTM Standards*, Vol 04.11.

[4] *Annual Book of ASTM Standards*, Vol 04.07.

[5] Available from the CGSB Sales Centre, Ottawa, Canada K1A 1G6.

[6] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

[7] Available from the National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269.

3.2.5 *Category 1 appliance*, *n*—an appliance that operates with non-positive static pressure and with a vent gas temperature that avoids excessive condensate production in the vent (see NFPA 54).

3.2.6 *Category III appliance*, *n*—an appliance that operates with a positive vent pressure and with a vent gas temperature that avoids excessive condensate production in the vent (see NFPA 54).

3.2.7 *Category IV appliance*, *n*—an appliance that operates with a positive vent pressure and with a vent gas temperature that may cause excessive condensate production in the vent (see NFPA 54).

3.2.8 *combustion system spillage*, *n*—entry of combustion products into a building from dilution air inlets, vent connector joints, induced draft fan case opening, combustion air inlets, or other locations in the combustion or venting system of a vented combustion appliance (boiler, fireplace, furnace, or water heater), caused by backdrafting, vent blockage, or leaks in the venting system.

3.2.9 *continuous pressure differential*, *n*—the incremental house depressurization due to fans that can be operated continuously, such as furnace blower or supply/exhaust ventilator.

3.2.10 *downdrafting*, *n*—the reversal of the ordinary (upward) direction of air flow in a chimney or flue when no vented combustion appliances are operating (as opposed to backdrafting, which occurs when vented combustion appliances are operating).

3.2.11 *house depressurization*, *n*—the situation, pertaining to a specific location in a house, whereby the static pressure at that location is lower than the static pressure in the immediate vicinity outside the house.

3.2.11.1 *Discussion*—The pressure difference between indoors and outdoors is affected by building tightness (including the distribution of leakage sites across the building envelope), indoor-outdoor temperature difference, local winds, and the operation of indoor appliances such as exhaust fans, forced-air system fans, and vented combustion appliances (boilers, fireplaces, furnaces, or water heaters). Thus, the existence and extent of house depressurization at a specific location varies over time, depending on outdoor conditions and the operation of indoor appliances.

3.2.12 *induced conditions*, *n*—conditions for house depressurization created with the use of exhaust fans or blower door.

3.2.13 *induced draft (ID) fan*, *n*—a fan used in a venting system that removes flue gases under non-positive static vent pressure.

3.2.13.1 *Discussion*—An appliance with an ID fan is a Category I appliance, as its venting system is under non-positive static vent pressure.

3.2.14 *intermittent pressure differential*, *n*—the incremental house depressurization due to fans that are operated intermittently, such as clothes dryer, kitchen exhaust or bathroom fan.

3.2.15 *natural conditions*, *n*—outdoor temperature and wind conditions that create house depressurization.

3.2.16 *pressure differential*, *n*—pressure difference across the building envelope, expressed in pascals (inches of water or pound-force per square foot or inches of mercury).

3.2.17 *vented combustion appliance*, *n*—includes fossil-fuel-fired furnace, boiler or water heater vented to outside.

3.2.17.1 *Discussion*—The term vented combustion appliances in this standard excludes fireplaces and gas logs vented to outside. Also, it does not include appliances such as gas ranges or unvented space heaters.

4. Summary of Guide

4.1 This guide summarizes different methods for assessing backdrafting and spillage from vented combustion appliances. For each method the equipment needed, test procedures, data reporting, results and interpretation, and technician and test time required are presented. Advantages and uncertainties of each method are discussed.

4.2 Assessment of depressurization-induced backdrafting and spillage is conducted under either induced depressurization or natural conditions. Depressurization is induced in a residence by deliberately operating exhaust fans or a blower-door fan. Assessments conducted under induced conditions can indicate only the potential for backdrafting and spillage. Assessments under natural conditions can indicate actual backdrafting and spillage events. Assessments under either induced or natural conditions may not be valid for weather, house tightness, or operational conditions beyond those encountered during the period of measurements.

4.3 The guide includes four types of short term tests conducted under induced conditions: (*1*) house depressurization test with preset criteria; (*2*) downdrafting test; (*3*) appliance backdrafting test; and (*4*) cold vent establishment pressure (CVEP) test. A continuous backdraft test to identify backdrafting events under natural conditions, which involves continuous monitoring of vent differential pressures, is also described. For identification of spillage events or consequences thereof under natural conditions, a continuous spillage test that involves continuous monitoring of spillage-zone temperatures and indoor air quality is described. Because they are conducted under a variety of naturally occurring conditions, the continuous methods can provide more definitive results for conditions under which tests are conducted. However, the continuous methods also can be more time-consuming and resource-intensive to apply.

4.4 A purpose of the guide is to encourage the use of consistent procedures for any selected method.

5. Significance and Use

5.1 Although a number of different methods have been used to assess backdrafting and spillage (see NFPA 54,, CAN/CGSB-51.71, and **1-4**) a single well-accepted method is not yet available. At this point, different methods can yield different results. In addition, advantages and drawbacks of different methods have not been evaluated or described.

5.2 To provide a consistent basis for selection of methods, this guide summarizes different methods available to assess backdrafting and spillage. Advantages and limitations of each method are addressed.

5.3 One or more of the methods described in this guide should be performed when backdrafting or spillage from vented combustion appliances is suspected to be the cause of a potential problem such as elevated carbon monoxide (CO) levels or excessive moisture.

5.4 The following are examples of specific conditions under which such methods could be performed:

5.4.1 When debris or soot is evident at the draft hood, indicating that backdrafting may have occurred in the past,

5.4.2 When a new or replacement combustion appliance is added to a residence,

5.4.3 When a new or replacement exhaust device or system, such as a downdraft range exhaust fan, a fireplace, or a fan-powered radon mitigation system, is added,

5.4.4 When a residence is being remodeled or otherwise altered to increase energy efficiency, as with various types of weatherization programs, and

5.4.5 When a CO alarm device has alarmed and a combustion appliance is one of the suspected causes of the alarm.

5.5 Depending on the nature of the test(s) conducted and the test results, certain preventive or remedial actions may need to be taken. The following are examples:

5.5.1 If any of the short-term tests indicates a potential for backdrafting, and particularly if more than one test indicates such potential, then the appliance and venting system should be further tested by a qualified technician, or remedial actions could be taken in accordance with 5.5.3

5.5.2 If continuous monitoring indicates that backdrafting is occurring, and particularly if it indicates that spillage is occurring that impacts indoor air quality (for example, elevated CO concentrations or excessive moisture in the house), then remedial action is indicated.

5.5.3 Possible remedial actions include the following:

5.5.3.1 At a minimum, a CO alarm device could be installed in the house.

5.5.3.2 Limiting the use of devices or systems that increase house depressurization, such as fireplaces and high-volume exhaust fans. Proper sealing of any air leakage sites, especially at the top floor ceiling level, can also reduce house depressurization at the lower levels of the house.

5.5.3.3 Partially opening a window in the furnace or appliance room, if available. Keeping the door nearest the appliance room open at all times or putting louvers in the door.

5.5.3.4 Providing increased makeup air for the appliance (for example, by providing a small duct or opening to the outdoors near the appliance).

5.5.4 If remedial actions are not successful, then consideration can be given to correcting or replacing the venting system or, if necessary, replacing the spilling appliance with one that can better tolerate house depressurization.

5.6 The understanding related to backdrafting and spillage phenomena is evolving. Comprehensive research using a single, reliable method is needed to better understand the frequency, duration, and severity of depressurization-induced spillage in a broad cross section of homes **(5)**. In the absence of a single well-accepted method for assessing the potential for or occurrence of backdrafting or spillage, alternative methods are presented in this guide. The guide is intended to foster consistent application of these methods in future field work or research. The resultant data will enable informed decisions on relative strengths and weaknesses of the different methods and provides a basis for any refinements that may be appropriate. Continued efforts along these lines will enable the development of specifications for a single method that is acceptable to all concerned.

6. Principles and Methods

6.1 *Background*—Residences can be depressurized due to operation of exhaust equipment and imbalanced air distribution systems, as well as local weather. The extent of house depressurization depends on the capacity of the exhaust equipment, the degree of imbalance in the air distribution system, and the airtightness of the building envelope. Outdoor temperatures also can affect the depressurization of the house. For example, the natural depressurization of a house would be a few to several pascals greater under winter conditions in the northern parts of the country than during summer. The changes in depressurization of the house due to outdoor conditions (temperature and wind) often can be greater than changes caused by exhaust appliances. Downdrafting, which can result from house depressurization, is the reversal of the ordinary (upward) direction of air flow in a chimney or flue when no vented combustion appliances are operating. Backdrafting generally occurs when an appliance starts up against a downdrafting chimney and cannot establish draft. Vented combustion appliances equipped with draft hoods or diverters or induced-draft fans depend on hot flue gases to create a thermal buoyancy that exhausts combustion products through a chimney. When the natural or induced draft or thermal buoyancy cannot overcome backdrafting, there will be spillage of combustion products including carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x) and water vapor into indoor spaces.

6.2 *Principles of Vent Operation and Backdrafting*—A schematic of one typical installation of a water heater and furnace connected to a common B-vent (chimney) through vent connectors is shown in Fig. 1. There can be a number of variations

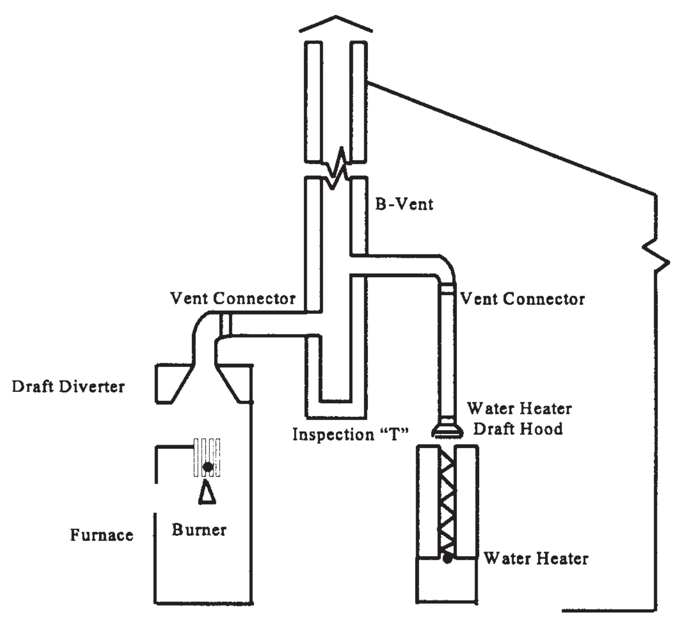

FIG. 1 Schematic of Combined Water Heater and Furnace Venting System

to this example, including vent connectors that are connected to a masonry chimney, or separate venting systems for each appliance. Draft-hood or induced-draft combustion appliances depend on the thermal buoyancy of hot flue gases related near the chimney. In the case of backdrafting, or reversal of the ordinary vent flow, hot flue gases tend to follow the path with the smallest pressure or least resistance. For draft-hood-equipped appliances, the path of least resistance is the draft hood or diverter. For induced-draft furnaces, this path could be either at the draft hood of the other appliance (for example, water heater) that is connected to the common vent, or around leakage points in the vent system, especially at connections.

6.3 *Principles of Assessment*—Since the upward flow in the chimney or venting system depends on pressure differentials created by the buoyancy of hot flue gases, measurement of the static pressure in the vent system (relative to that in the room where the appliance is located) is one basic measurement parameter to indicate backdrafting. Spillage of the flue gases around the draft hood or diverter can be observed visually or inferred from a temperature sensor. (The visual test, which provides a reliable indication of backdrafting, can be accomplished by using a smoke pencil or a small flame created by a cigarette lighter to indicate the flow direction of the flue gases.) Quantitative assessment of the impact of spillage at the draft hood or diverter cannot be accomplished without special equipment, because of the temperature and moisture content of flue gases. However, the consequences of spillage can be assessed by measuring air quality in the area where combustion appliances are located.

6.4 *Methods*—The available methods for assessing backdrafting and spillage can be divided into two major groups: those conducted under induced depressurization and those conducted under natural conditions. Methods used under induced conditions can provide an indication of the potential for backdrafting. The tests conducted under induced conditions require less testing time than those under natural conditions and, thus, are termed short-term tests. Ideally, short-term tests should be repeated under different weather conditions. Methods used under natural conditions detect actual backdrafting and spillage events but require continuous monitoring over a period typically one week or longer. The period of continuous monitoring, ideally, should be long enough to cover a range of weather conditions. Relationships between the results of short-term tests under induced conditions and continuous monitoring under natural conditions have been investigated **(6, 7, 8)** but are not yet qualified or established.

6.5 The methods included in this guide are grouped under two categories: induced conditions and natural conditions.

6.5.1 Induced Conditions include house depressurization test with preset criteria, downdrafting test, appliance backdrafting test, and cold vent establishment pressure (CVEP) test.

6.5.1.1 The following general rules apply in conducting tests under induced conditions: (*1*) when such tests are initiated, the temperature of the common vent should be close to the temperature of the mechanical room, so that the test approximates a cold vent condition; and (*2*) testing of a water heater should precede furnace or boiler testing, as the water heater has a lower heat output and will require a correspondingly shorter time to cool the common vent following its operation.

6.5.2 Natural Conditions include continuous backdrafting test, and Continuous spillage test.

6.6 Observations and tests for assessing hazards, given in Section 7, should be followed prior to conducting the tests. The tests for assessing backdrafting and spillage are summarized, beginning in Section 8, in terms of equipment needed, the condition of the house for testing, test procedures, technician time needed, test duration, and test outputs and their interpretation.

7. Hazards and Assessment

7.1 A major hazard in conducting the tests described in this guide is CO exposure. Flame roll-out and associated fire potential is another potential hazard **(9)**. Hazards associated with blower-door testing must also be considered. Hazards associated with blower-door testing are noted in Test Method E 779; precautions and tests for other hazards are given below.

7.2 *Carbon Monoxide Exposure*—In some situations, appliances may generate CO due to backdrafting. It is imperative that flue CO levels be measured prior to conducting any tests and that continuous CO monitoring be conducted in the mechanical room or the appliance area (test space) while these tests are occurring. The procedures for flue CO measurements are given below.

7.2.1 *Flue CO Measurements Prior to Conducting Tests*—For flue CO measurements, use a combustion analyzer that is capable of measuring flue CO levels on an air-free basis. All exhaust devices in the house, including fireplaces or wood-burning stoves, should be off during the testing period.

7.2.1.1 Place the sampling probe for the combustion analyzer under the water heater draft hood and down into the throat of the heat exchanger as far as possible. Ensure that the probe's thermocouple (if present) is not in contact with metal. Record flue CO levels at least once per min when the appliance is fired.

7.2.1.2 Turn down the furnace thermostat. Turn on the water heater by turning its thermostat to the highest setting. Open a hot water faucet to ensure that the water heater continues to fire during the test.

7.2.1.3 Wait until 5 min have elapsed since the appliance was started. Using a match or a smoke pencil, check for draft at the water heater draft hood (lack of draft indicates likelihood of a blocked vent).

7.2.1.4 Remove the sampling probe, shut off the faucet and return the water heater thermostat to its original setting.

7.2.1.5 If the furnace has an induced draft (ID) fan, drill a sampling hole just above the furnace collar and insert the sampling probe through this hole. Otherwise, place the sampling probe under the furnace draft hood and into the heat exchanger if possible. Record flue CO levels at least once per min when the appliance is fired.

7.2.1.6 Turn on the furnace and set the thermostat sufficiently high that it will continue to fire for at least 5 min.

7.2.1.7 Wait until 5 min have elapsed, and conduct a match or smoke pencil test as in 7.2.1.3.

7.2.1.8 Remove the sampling probe and return the thermostat to its original setting. If a sampling hole was drilled, insert a plug or screw to close it.

7.2.1.9 If the CO value for the water heater or furnace flue gases exceeds 400 ppm (air-free basis as described in ANSI-Z21.47), or there is evidence of a blocked vent, then further testing should be postponed until a qualified technician has visited the house to resolve any such apparent problems.

7.2.2 *CO Monitoring During the Tests*—Several levels of protection against excessive CO exposure due to induced backdrafting of combustion appliances, based on existing standards or guidelines for CO concentrations in flue gases and in ambient air, should be considered. Occupational Safety and Health Administration (OSHA) guidelines for CO exposure limit concentrations to 200 ppm for short-term (15 min) exposure and 50 ppm for 8-hour-average exposure. The sensor for CO monitoring in the test space should have a visual readout that will alert technicians to unusual concentrations in the breathing zone of their activity. Additionally, a CO alarm device is to be installed in the living area of the house during these tests.

7.2.2.1 If the CO level in the flue gas exceeds 400 ppm (air-free basis as described in ANSI-Z21.47) during the visual inspection or during backdrafting or CVEP tests, then the affected test is to be terminated. The responsible appliance should be inspected or tested or tuned by a qualified technician.

7.2.2.2 As an additional margin of safety, technicians are to observe the CO levels in the mechanical room during these tests and note any time when the ambient concentration exceeds 100 ppm for 15 min. Testing is to be terminated in such instances. It is unlikely that the ambient concentration will exceed 100 ppm when the flue-gas concentration is below 400 ppm.

7.2.2.3 Should the CO alarm activate, any test in progress should be terminated and the house temporarily evacuated and ventilated.

7.3 *Visual Assessment*:

7.3.1 Verify that there is no fuel or other flammable material stored in the mechanical room or area and that no combustible material is stored within 2 ft of the appliances (furnace or water heater) to be tested.

7.3.2 Make a visual assessment for scorch marks on the outside of the water heater near the burner to see if flame-rollout may have happened previously. If there is evidence of scorching (such as at the base of the water heater), then further testing should be postponed until a qualified technician has tested the appliance.

7.3.3 During forced backdrafting conditions flame roll-out may occur, even if there is no evidence of prior occurrences, because relatively high depressurization conditions are induced with a blower door under this method. Should flame roll-out occur, the test should be discontinued.

7.3.4 A qualified technician should visually inspect the venting system to determine that there is no blockage or restriction, leakage, corrosion, or other deficiencies that could cause an unsafe condition, check for proper size and horizontal pitch, and ensure compliance with local codes.

8. House Depressurization Test With Preset Criteria (see NFPA 54, CAN/CGSB-51.71, and Refs. 1-4)

8.1 *Summary of Procedure*—Details of this procedure are given in CAN/CGSB-51.71. In summary, the test is conducted under closed-house conditions (exterior doors, windows, fireplace or woodstove dampers, or both, closed). Interior doors on perimeter rooms that do not contain exhaust devices are closed. The water and furnace remain off throughout the test. Following baseline measurements of the indoor-outdoor pressure difference with all continuous and intermittent house fans off, the incremental house depressurization due to continuous fans (furnace blower, combined supply and exhaust ventilator, continuous air exhaust or supply systems) and intermittent fans (clothes dryer, kitchen exhaust, bathroom fans, fireplace simulator) is measured. The continuous pressure differential and intermittent pressure differential are then compared with preset criteria to determine pass or fail status.

8.2 *Equipment Needed*—A differential pressure measuring device, outdoor pressure tube, outdoor pressure averaging system, and a wood-fire simulator, are needed.

8.3 *House Conditions*—Set the house conditions according to Table 1.

8.4 *Procedures*—

8.4.1 *Set Up Differential Pressure Measurement*—Connect indoor and outdoor ports to a differential-pressure measurement device. The port for indoors should be in, or connected by tubing to, the room containing the appliance(s) to be tested. The port for outdoors should be connected by tubing to one or more outdoor sites. It is preferable to have outdoor sites on each side of the house that are connected to the outdoor port through a common manifold. To minimize the effect of local winds on the outdoor pressure measurement, and to avoid snow or rain accumulation, or both, each outdoor hose should be placed in an open-ended housing that faces downward. The housing should be attached to a vertical stake or stand near a

TABLE 1 Initial House Conditions for House Depressurization Test[A]

House Feature	Configuration
Windows	Close
Exterior doors	Close
Basement door	Close
Doors on an enclosed furnace room	Close
Interior doors on perimeter rooms not containing exhaust devices	Close
Chimney with manual damper	Close
Chimney without manual damper	Leave as is
Make-up air supply with manual damper	Close
Make-up air supply without damper	Leave as is
Woodstove or fireplace	No fire: close doors and air control dampers
Fuel-fired appliances (furnace, boiler, water heater, gas fireplace, pellet stove)	Turn down thermostats
Floor drains	Fill with water
Exhaust and supply fans	Off
Ventilating and air moving devices	Off
Clothes dryer	Off
Attic hatch	Close
Crawl space vents	Close
Broken windows and other short term openings	Tape over
Sub-slab ventilation fans or subfloor ventilation systems for soil gas control	Turn off

[A]See NFPA 54.

corner formed by the exterior wall and the ground (a stagnation region), near the midpoint of the wall.

8.4.2 *Determine Baseline Depressurization*—Determine the value of the indoor-outdoor pressure differential with all continuous and intermittent house fans off, in accordance with the house conditions established in 8.3 (see Table 1). Pressure differences may be quite variable, especially under windy conditions; thus, an average of several values should be used.

8.4.3 *Turn on Furnace Blower*—Operate the blower at maximum speed if it can be switched on independently of other exhausts. The house depressurization level in the appliance room, relative to outdoors, should be assessed with the door to the appliance room (if any) both open and closed. The door position that results in the highest level of house depressurization should be used for the remainder of the test. If the furnace blower does not increase the house depressurization, turn it off.

8.4.4 *Turn on Combined Supply and Exhaust Ventilators*—Operate each of these devices at its highest setting and check if house depressurization increases. If it does, leave the device running; otherwise, turn it off.

8.4.5 *Turn on Continuous Air Exhaust Systems*—Turn on such devices intended for continuous use, such as subslab ventilation systems.

8.4.6 *Turn on Continuous Air Supply Systems*—Operate any of these devices intended to operate throughout the heating season.

8.4.7 *Record Continuous Pressure Differential*—Record the maximum pressure differential created by continuous ventilation systems; this differential, after subtracting the baseline depressurization value obtained in 8.4.2, is termed the continuous pressure differential.

8.4.8 *Turn on Exhaust Fans*—This includes clothes dryer, if it exhausts to the outdoors; kitchen exhaust, if it exhausts to the outdoors or in attics; and other intermittent exhaust fans rated at more than 75 L/s (159 CFM).

8.4.9 *Simulate a Fire in an Open Fireplace*—Open chimney damper. Open air combustion air supply to the fireplace. Place a wood-fire simulator (camping stove, typically 9.5 J/h or 10 000 Btu/h) in the fireplace. Temporarily open a nearby door or window to the outdoors. Light the simulator and adjust to a high rate of burn. Allow at least 5 min for the chimney to warm up. Tightly close the door or window to the outdoors.

8.4.10 *Record Intermittent Pressure Differential*—Read and record the maximum pressure differential due to exhaust fans and fire simulators, in combination with continuous ventilation systems: this differential, after subtracting the baseline value obtained in 8.4.2, is termed the intermittent pressure differential.

8.5 *Data Reporting*:

8.5.1 Record measured depressurization levels in pascals (Pa) caused by any forced-air circulating fans and combined supply and exhaust ventilators.

8.5.2 Record continuous and intermittent pressure differentials.

8.6 *Results and Interpretations*:

8.6.1 House depressurization limits specified in CAN/CGSB-51.71 are 5 Pa continuous and intermittent for open combustion appliances (buoyancy systems with draft hoods or relief-air openings, and 5 Pa continuous and 10 Pa intermittent for closed combustion appliances (systems consisting of a single appliance on a flue that has no draft hood or relief air).

8.6.2 Compare the maximum pressure differentials (continuous and intermittent) with depressurization limits for each vented, fuel-burning appliance in the dwelling.

8.6.3 This method provides results in a pass or fail form. For example, if the intermittent pressure limit is 5 Pa (this limit varies with appliance fuel and venting configuration) and the measured intermittent pressure differential is 6 Pa depressurization, then the house fails the test and is considered to be spillage-prone.

8.6.4 The method provides pass or fail results without operation of any vented combustion appliances: thus, their ability to tolerate, or overcome, the house depressurization induced during the test is not assessed.

8.6.5 The pass or fail criteria may not be appropriate for all types of homes, appliances, venting systems, and climates.

8.6.6 Results of this test for a particular home may vary with weather conditions (temperature and windspeed). The exact nature of relationship between test results and weather conditions is not fully understood at present.

8.7 *Technician and Test Time*—About 30 to 40 min of technician or testing time is required, including the time for setting up equipment.

9. Downdrafting Test (4)

9.1 *Summary of Procedure*—The test is conducted under closed-house conditions (exterior doors, windows, fireplace or woodstove dampers, or both, closed). Ideally, the test should be performed during a period of low wind speeds (less than 2 m/s or 5 mph). Interior doors on perimeter rooms that do not contain exhaust devices are open. The water heater and furnace remain off throughout the test. After all continuous fans and intermittent exhaust devices (including a fireplace simulator or a gas-log fireplace) are turned on, downdrafting is assessed visually with a flame or smoke pencil.

9.2 *Equipment Needed*—Flame lighter or smoke pencil for visual indication of downdrafting, temperature sensor for measuring vent temperature, camping stove to simulate fireplace operation are needed.

9.3 *House Conditions*—Keep the house in its (winter) closed configuration as given in Table 2. Tables 1 and 2 are similar except for the position or status of interior doors, the damper of the make-up air supply, and subslab or subfloor ventilation systems. The conditions in Table 2 are intended to represent a reasonable-worst-case scenario. For a worst-case depressurization level, add the step given in 9.4.3.6. Subslab ventilation systems are left in the condition set by occupants to minimize radon exposure.

9.4 *Procedures*:

9.4.1 Turn down furnace/boiler and water heater thermostats.

9.4.2 Allow time for cooling the common vent if either of these appliances was operating recently.

9.4.3 Set up continuous fans and intermittent exhaust devices.

TABLE 2 Initial House Conditions[A] for Downdrafting and Backdrafting Tests (4)

House Feature	Configuration
Windows	Close
Exterior doors	Close
Interior doors to basement	Open
Doors on an enclosed mechanical room	Open
Interior doors on perimeter rooms not containing exhaust devices	Open
Make-up air supply for mechanical room	Leave as is
Woodstove or fireplace	No fire: close manual dampers
Furnace and water heater	Turn down thermostats
Furnace blower	Off
Floor drains	Fill with water
Exhaust and supply fans	Off
Ventilating and air-moving devices	Off
Clothes dryer	Off
Attic hatch	Close
Broken windows or other short-term openings	Tape over
Subslab ventilation fans or subfloor ventilation systems for soil-gas control	Leave as is

[A] These conditions are intended to represent a reasonable-worse-case scenario. For a worst-case depressurization level, after setting the above conditions close all interior doors to perimeter rooms that do not contain any exhaust devices. Then choose the condition of furnace blower off versus on, and door nearest the appliance open versus closed, that maximizes house depressurization.

9.4.3.1 Leave on any continuous air supply or exhaust systems that are normally used by the occupants. Do not turn on a whole-house fan if it is normally used with windows open.

9.4.3.2 Turn on the furnace blower and all exhaust fans (bathroom exhausts, kitchen range fan if exhausted to outdoors).

9.4.3.3 Set the clothes dryer to air option (if available) or to the lowest heat setting: set timer for 30 min and start the dryer.

9.4.3.4 Open wood fireplace damper, if applicable, and simulate its operation with a camping stove. Ensure that the stove is secured in its place. Wait up to 5 min to verify that the fireplace chimney is venting.

9.4.3.5 Turn on any gas log(s) located in a fireplace after opening the fireplace damper.

9.4.3.6 For a worst-case depressurization level, close all interior doors to perimeter rooms that do not contain any exhaust devices. Then choose the condition of furnace blower off versus on, and door nearest the appliance open versus closed, that maximizes house depressurization.

9.4.4 Verify that the water heater and furnace remain off and that the common-vent temperature is near (that is, within 3 to 6 °C or 5 to 10 °F) the temperature in the mechanical room. For this verification, a temperature sensor can be attached to the outside of a metal common vent (or to the outside of a vent connector in close proximity to a masonry chimney).

9.4.5 Assess downdrafting through the water heater vent connector at the draft hood with a visual (smoke or flame) test.

9.4.6 Assess downdrafting through the furnace vent connector with a visual (smoke or flame) test by checking at the furnace draft hood. If the furnace is an induced-draft type this test can be omitted.

9.4.7 Return water heater and furnace thermostats to occupant settings.

9.5 *Data Reporting*—

9.5.1 Note the configuration during the test for each item in Table 2.

9.5.2 Note the outdoor temperature and windspeed at the time of the test by calling the telephone number that provides recorded messages of local weather conditions.

9.5.3 For each vent connector (if applicable), note whether downdrafting has been observed.

9.6 *Results and Interpretation*:

9.6.1 The results of this test are in yes or no form, that is, whether or not downdrafting has been observed.

9.6.2 These results are specific to the venting system, house and outdoor conditions under which the tests are conducted.

9.6.3 Currently, there is no technique available for extrapolating test results to other conditions, such as a different outdoor temperature or windspeed, or both.

9.6.4 Results of this test for a particular home may vary with weather conditions (temperature and windspeed). The exact nature of relationship between test results and weather conditions is not fully understood at present.

9.7 *Technician and Test Time*—This method requires a minimum amount of time, except for cooling the vent before tests. There is no equipment to set up except for the fireplace simulator in the case of a fireplace. The time required to set house conditions to those specified in Table 2 and to conduct the test(s) requires about 10 to 20 min, not including time for cooling the vent. The time required to cool the vent will depend on the capacity of exhaust devices and the type of chimney (masonry vs. metal): cooling the vent with exhaust devices may require 15 to 30 min or more. The cooling time often can be shortened considerably by using a blower-door fan. The technician and test time are the same for this method.

10. Appliance Backdrafting Test (see CAN/CGSB-51.71 and Refs. 4 and 10)

10.1 *Summary of Procedure*—The test is conducted under closed-house conditions (exterior doors, windows, fireplace or woodstove dampers, or both, closed). Ideally, the test should be performed during a period of low wind speeds (less than 2 m/s or 5 mph). Interior doors on perimeter rooms that do not contain exhaust devices are open. After all continuous fans and intermittent exhaust devices (including a fireplace simulator or a gas-log fireplace) are turned on, the water heater is operated for a period such as 5 min. (The test described below uses a time period of 5 min which is somewhat arbitrary: other time periods such as 3 min or 10 min have been used.) Backdrafting is assessed visually with a flame lighter or smoke pencil. The vent is cooled and the procedure is repeated for the furnace.

10.2 *Equipment Needed*—Flame lighter or smoke pencil for visual indication of backdrafting, temperature sensor for measuring vent temperature, and camping stove to simulate fireplace operation are needed. If a blower door is available, it can be used to cool vents more rapidly between multiple tests of backdrafting (masonry chimneys will take a considerably longer time to cool than metal chimneys).

10.3 *House Conditions*—Keep the house in its (winter) closed configuration as given in Table 2, which is intended to represent a reasonable-worst-case scenario. For a worst-case depressurization level, add the step in 10.4.3.6.

10.4 *Procedures*:

10.4.1 Turn down furnace/boiler and water heater thermostats.

10.4.2 Allow time for cooling the common vent if either of these appliances was operating recently.

10.4.3 Set up continuous fans and intermittent exhaust devices.

10.4.3.1 Leave on any continuous air supply or exhaust systems that are normally used by the occupants. Do not turn on a whole-house fan if it is normally used with windows open.

10.4.3.2 Turn on the furnace blower and all exhaust fans (bathroom exhausts, kitchen range fan if exhausted to outdoors).

10.4.3.3 Set the clothes dryer to air option (if available) or to the lowest heat setting: set timer for 30 min and start the dryer.

10.4.3.4 Open wood fireplace damper, if applicable, and simulate its operation with a camping stove. Ensure that the stove is secured in its place. Wait up to 5 min to verify that the fireplace chimney is venting.

10.4.3.5 Turn on any gas log(s) located in a fireplace after opening the fireplace damper.

10.4.3.6 For a worst-case depressurization level, close all interior doors to perimeter rooms that do not contain any exhaust devices. Then choose the condition of furnace blower off versus on, and door nearest the appliance open versus closed, that maximizes house depressurization.

10.4.4 Verify that the water heater and furnace remain off and that the common-vent temperature is near (that is, within 3 to 6 °C, 5 to 10 °F) the temperature in the mechanical room. For this verification, a temperature sensor can be attached to the outside of a metal common vent (or to the outside of a vent connector in close proximity to a masonry chimney).

10.4.5 Verify that the water heater's pilot light is on. Turn on the water heater by setting the thermostat to its highest setting and turning on a hot water faucet. Note the exact time when the water heater turns on.

10.4.6 Assess water heater drafting with a visual (smoke or flame) test. Perform the test at the water heater draft hood until venting is established. Note the exact time when venting is established. Terminate the test if venting is not established within 5 min. Return the water heater thermostat to its lowest setting and turn off the hot water faucet. Verify that water heater and furnace pilot lights are on.

10.4.7 Cool vent to a temperature that is near (that is, within 3 to 6 °C or 5 to 10 °F) the temperature in the mechanical room by leaving the exhaust fans and appliances on for at least 5 min. Use a blower door to cool the vent if available.

10.4.8 Verify that the furnace's pilot light (if any) is on. Turn on the furnace by setting its thermostat to 30 °C (85 °F). Note the exact time when the furnace burner ignites.

10.4.9 Assess furnace drafting with a visual (smoke or flame) test by checking at the furnace draft hood. If the furnace is an induced-draft type then assess drafting at the water heater draft hood. Perform a visual test until venting is established. Note the exact time when venting is established. If backdrafting occurs and persists beyond 5 min, terminate the test.

10.4.10 Return water heater and furnace thermostats to occupant settings.

10.5 *Data Reporting*:

10.5.1 Note the configuration during the test for each item in Table 2.

10.5.2 Note the outdoor temperature and windspeed at the time of the test by calling the telephone number that provides recorded messages of local weather conditions.

10.5.3 For each appliance, record the duration of backdrafting if a draft is established within 5 min.

10.6 *Results and Interpretation*:

10.6.1 The results of this test are in yes or no form, that is, whether or not venting is established within 5 min (or the nominal cycle time for the appliance) after the appliance is turned on.

10.6.2 These results are specific to the appliance, venting system, house and outdoor conditions under which the tests are conducted.

10.6.3 Currently, there is no technique available for extrapolating test results to other conditions, such as a different outdoor temperature or windspeed, or both.

10.6.4 Results of this test for a particular home may vary with weather conditions (temperature and windspeed). The exact nature of relationship between test results and weather conditions is not fully understood at present.

10.7 *Technician and Test Time*—This method requires a minimum amount of time, except for cooling the vent before or between tests. There is no equipment to set up. The time required to set house conditions to those specified in Table 2 and to conduct the test(s) requires about 20 to 30 min, not including time for cooling the vent. The time required to cool the vent will depend on the capacity of exhaust devices and the type of chimney (masonry vs metal): cooling the vent with exhaust devices may require 15 to 30 min or more. The cooling time often can be shortened considerably by using a blower-door fan. The technician and test time are the same for this method.

11. Cold Vent Establishment Pressure (CVEP) Test (3, 6)

11.1 *Summary of Procedure*—The test originally developed by Timusk **(1)** is conducted under closed-house conditions (exterior doors, windows, fireplace or woodstove dampers, or both, closed). Ideally, the test should be performed during a period of low wind speeds (less than 2 m/s or 5 mph). A blower door is used to moderately depressurize the house to a level such as 12 or 15 Pa. The water heater is fired and the house depressurization is gradually relaxed until venting is established. After the vent is cooled, the procedure is repeated for the furnace. The level of depressurization at which the appliance establishes venting is its CVEP. The appliance CVEP value is compared with a worst-case house depressurization level created by turning on continuous fans and intermittent exhaust devices, and by closing the door closer to the appliance area and interior doors to rooms not containing exhaust devices.

11.2 *Equipment*—A CVEP test requires a blower door, a device capable of measuring pressure differences in the range of 0 to 50 Pa, and a smoke pencil or lighter. A device to measure either flue-gas or room CO concentrations is highly recommended for the safety of technicians and occupants.

11.3 *House Conditions*—Use blower door to cool the vent as necessary. Keep the house in its (winter) closed configuration as given in Table 2.

11.4 *Initial Setup Procedures*:

11.4.1 Turn down furnace/boiler and water heater thermostats.

11.4.2 Allow time for cooling the vent if any of these appliances were operating recently.

11.4.3 Install a differential-pressure measurement device to determine house pressurization or depressurization with respect to that outdoors. Follow the guidelines given in 8.4.1 for configuring indoor and outdoor ports.

11.5 *Measure Worst-Case Depressurization Level*:

11.5.1 Leave on continuous air supply or exhaust systems that are normally used by the occupants. Do not turn on a whole-house fan if it is normally used with windows open.

11.5.2 Turn on the furnace blower and all exhaust fans (bathroom exhausts, kitchen range fan if exhausted to outdoors).

11.5.3 Set the clothes dryer to air option (if available) or to the lowest heat setting: set timer for 30 min and start the dryer.

11.5.4 Open fireplace damper and simulate its operation with a camping stove. Ensure that the stove is secured in place. Wait up to 5 min to verify that fireplace chimney is venting.

11.5.5 Turn on any gas log(s) located in a fireplace after opening the fireplace damper.

11.5.6 Close all interior doors to perimeter rooms that do not contain any exhaust devices.

11.5.7 Choose the condition of furnace blower off versus on, and door nearest the appliance open versus closed, that maximizes house depressurization.

11.5.8 Measure and record the worst-case depressurization level.

11.5.9 Turn off all exhaust devices and open interior doors.

11.6 *Procedures for Measuring CVEP of Water Heater*:

11.6.1 Install blower door according to manufacturer's specifications.

11.6.2 Install and turn on a device for measuring either the flue-gas CO level or the indoor CO level in the vicinity of the appliance to be tested.

11.6.3 Measure and record the depressurization level of the mechanical room.

11.6.4 Increase the blower-door fan speed until the house depressurization is 15 Pa. (Note that 15 Pa is a somewhat arbitrary starting point used in previous research: a lower or higher depressurization level can be selected.) Check water heater and furnace pilot lights. Verify that the common-vent temperature is at or below the temperature in the mechanical room.

11.6.5 Turn on the water heater by setting the thermostat to its highest setting and turning on a hot water faucet.

11.6.6 Flue gases should now spill into the house from the water heater and furnace draft hoods or leaks in the venting system. Watch CO values at least once per min during the test for safety purposes. If the flue-gas CO level exceeds 400 ppm (air-free basis) or the indoor CO level in the vicinity of the appliance and the spillage zone exceeds 50 ppm, terminate the test.

11.6.7 If there is no spillage, turn off the water heater, allow the vent to cool, and repeat 11.6.5 and 11.6.6 with the house depressurization set at 25 Pa.

11.6.8 Gradually reduce the blower-door fan speed (in increments that decrease the indoor-outdoor pressure difference by 1 Pa) until a visual draft test indicates stagnation or a reversal in backdrafting flow. The house depressurization level at which venting is established is the CVEP for that house and appliance combination.

11.6.9 Return water heater thermostat to occupant setting and turn off the hot water faucet.

11.7 *Procedures for Measuring CVEP of Furnace*:

11.7.1 Cool the vents by operating the blower door for several minutes until the vent temperature approaches the outside temperature.

11.7.2 Set the blower-door fan speed such that the house depressurization is 15 Pa. (Note that 15 Pa is a somewhat arbitrary starting point used in previous research: a lower or higher depressurization level can be selected.) Check water heater and furnace pilot lights.

11.7.3 Turn on the furnace by setting the thermostat to its highest setting.

11.7.4 Flue gases should now spill into the house from the furnace and water heater draft hoods or leaks in the venting system. Watch CO values at least once per min during the test for safety purposes. If the flue-gas CO level exceeds 400 ppm (air-free basis) or the indoor CO level in the vicinity of the appliance and the spillage zone exceeds 50 ppm, terminate the test.

11.7.5 If there is no spillage, turn off the furnace, allow the vent to cool and repeat 11.7.3 and 11.7.4 with the house depressurization set at 25 Pa.

11.7.6 Gradually reduce the blower-door fan speed (in increments that decrease the indoor-outdoor pressure difference by 1 Pa) until a visual draft test indicates stagnation or a reversal in backdrafting flow. The house depressurization level at which venting is established is the CVEP for that house and appliance combination.

11.7.7 Turn off the blower-door fan. Check water heater and furnace pilot lights. Return furnace thermostat to occupant setting.

11.8 *Data Reporting*:

11.8.1 Note the setting during the test for each item in Table 2.

11.8.2 Note the outdoor temperature and windspeed at the time of test by calling the telephone number that provides recorded messages of local weather conditions.

11.8.3 For the house depressurization test, note the maximum level of depressurization.

11.8.4 Record the CVEP for each appliance that was tested.

11.9 *Results and Interpretation*:

11.9.1 The CVEP value is indicative of the house depressurization level that an appliance or vent or house system can tolerate. Consequently, the CVEP can be compared with the maximum or worst-case house depressurization level to determine an appliance's spillage potential. For example, if the appliance can tolerate 6 Pa depressurization but the house depressurization with all fans on is 8 Pa, then that appliance has spillage potential.

11.9.2 Lake the results of the other short-term tests described, the dependence of CVEP values on outdoor conditions is not precisely known, but some variability with outdoor temperature or wind, or both, can be expected.

11.10 *Technician and Test Time*—About 60 to 90 min of technician time is required. The technician and test time are the same.

12. Continuous Backdrafting Test (2-4)

12.1 *Summary of Procedure*—Monitoring is conducted under closed-house conditions, where feasible, for a period of at least 1 week. The period of continuous monitoring should be long enough to cover a range of weather conditions. Also, ideally, this procedure should be conducted during the winter for a furnace and the summer for a water heater. Occupants are advised to carry out their normal activities. Differential pressures in the common vent or appliance vent connectors, or both, and appliance on/of status, are monitored. A data logging system is used to record monitoring results at a high rate of frequency (for example, average values every 15 s). The combination of positive vent pressure and appliance status indicates whether downdrafting or backdrafting has occurred.

12.2 *Equipment Needed*—A differential pressure measuring device with analog output, pressure tube, and data logger are needed. The data logger is needed to record measurement results continuously in an unattended monitoring mode. A strip-chart recorder could be substituted for the data logger, however, data processing will be cumbersome with such a recorder. A thermocouple or similar sensor to indicate the on/off status of the appliance(s) will aid the interpretation of monitoring results. For each monitored appliance, such a sensor can be placed near the combustion zone and connected to the data logger.

12.3 *House Conditions*—Where feasible, the house is to be monitored under closed conditions (that is, outside doors and windows closed). See Table 2 for house settings.

12.4 *Procedures*:

12.4.1 *Vent Differential Pressures*—Install a static pressure probe in the base of the common vent (inspection-T), or in an appropriate vent connector, and connect the other end of static pressure probe with a pressure tube to a differential pressure measuring device. The other port of the pressure measuring device should be open to the mechanical room or area where the appliance(s) to be tested is located. Ensure that the differential pressure measuring device has a sufficient power supply to last for the intended period of monitoring.

12.4.2 *Status Sensor*—To monitor the status of each appliance (that is, whether it is on or off), a thermocouple probe should be placed in its combustion chamber, but not directly in the pilot flame. Each appliance should be turned on individually to ensure that its status-indicating thermocouple is responding properly.

12.4.3 *Data Logging*—Data logging is necessary for recording and storing data from continuous monitoring of differential pressures and temperatures (if appliance status is monitored). Connect the analog output of each sensor to the data logger or strip-chart recorder. Turn the data logger or recorder on. Adjust the time on the data logger to correspond to the current time, or note the current time on the strip chart recorder. Ensure that the data logger or recorder has a sufficient power supply to last through the intended monitoring period. Because many backdrafting events are transient in nature, instantaneous or average values should be collected at a high frequency, at least once per min and preferably every 15 s. Start recording data, and verify that values being recorded are appropriate for each parameter that is monitored. Data logging should continue for at least 1 week.

12.5 House occupants should be advised to carry out their regular activities while monitoring is in progress.

12.6 *Data Reporting*:

12.6.1 The data recorded with a data logger should be uploaded to a computer and reviewed with a spreadsheet or other appropriate program(s).

12.6.2 Data recorded on strip charts should be reviewed visually and converted to computer-compatible media if possible.

12.6.3 Based on the vent differential pressure, determine the number and duration(s) of downdrafting or backdrafting events, or both, during the monitoring period. (Downdrafting can be distinguished from backdrafting by monitoring the operational status of each appliance.) The start of a downdrafting or backdrafting event typically will be signified by a change in sign, from negative to positive, in the vent differential pressure.

12.7 *Results and Interpretation*:

12.7.1 As noted in 12.6.3, downdrafting or backdrafting events can be isolated by searching for transient or sustained periods when the sign of the vent differential pressure changes from negative to positive.

12.7.2 Without monitoring the operational status of each vented combustion appliance in the room serving as the reference point for the vent pressure differential, it is not possible to distinguish whether backdrafting has occurred during appliance operation. Backdrafting events (that is, those that occur during appliance operation) are more noteworthy than downdrafting events (that is, those that occur while all appliances are off).

12.7.3 A duration of 1 week of monitoring is suggested from the practical standpoint of occupant and data processing and analysis convenience. Data collection for a longer monitoring period usually will cover a broader range of weather conditions.

12.8 *Technician and Test Time*—The technician time required for installation of the sensors and a data logger or recorder is about 30 to 60 min, depending on the number of parameters monitored. Additional time of about 1 to 2 h is required for processing and analyzing the continuous data. The test time is 1 week or longer.

13. Continuous Spillage Test (2-4, 5)

13.1 *Summary of Procedure*—Monitoring is conducted under closed-house conditions, where feasible, for a period of at least 1 week. The period of continuous monitoring should be long enough to cover a range of weather conditions. Also, ideally, this procedure should be conducted during the winter for a furnace and the summer for a water heater. Occupants are advised to carry out their normal activities. Temperatures in the spillage zone for each appliance, CO and CO_2 concentrations in the appliance area, and appliance on or off status are monitored. A data logging system is used to record monitoring results at a high rate of frequency (for example, average values every 15 s). Elevated spillage-zone temperatures indicate spillage events, for which the consequences can be assessed by reviewing the CO and CO_2 concentrations during and after each event.

13.2 *Equipment Needed*—Monitoring of spillage-zone temperatures (to determine spillage events) or indoor contaminant levels (to assess spillage consequences) requires a sensor with analog output for each parameter to be monitored. As with continuous monitoring of backdrafting events, a data logger or strip-chart reorder is necessary for recording continuous measurements, and a sensor to indicate the on or off status of each vented combustion appliance will be useful for interpreting results.

13.3 *House Conditions*—Where feasible, the house is to be monitored under closed conditions (that is, outside doors and windows closed). See Table 2 for house settings.

13.4 *Procedures*:

13.4.1 *Spillage Zone Temperatures*—To effectively monitor the temperature of the spillage zone for each of the appliances, use a thermocouple with two beads that are connected through a Y type of junction. Such an approach will maximize the likelihood of detecting appliance spillage. The beaded ends should be placed such that they are not in contact with any metal and will read close to the ambient indoor temperature when the appliance is off. A removable adhesive material (such as plumber's putty) can be used to assist in the placement of the thermocouples. For draft-hood-equipped appliances, the spillage zone typically will be just below but outside the draft hood. For an induced-fan furnace, the most common spillage site is at the draft hood of a water heater sharing the same common vent, if any. Spillage can be induced with a blower door (see 11.6 and 11.7) to verify that the thermocouples are properly sensing spillage events.

13.4.2 *Contaminant Monitoring*—Both CO and CO_2 should be monitored. To effectively monitor indoor contaminant concentrations, the sensors should be placed at least 3 to 4 ft above the floor in an area near the furnace or water heater, or both. They should not be placed in a location where spilling flue gases can flow directly over the sensor heads. Portable, passive monitoring devices with analog outputs are readily available for both CO and CO_2.

13.4.3 *Status Sensor*—To monitor the status of each appliance (that is, whether it is on or off), a thermocouple probe should be placed in its combustion chamber, but not directly in the pilot flame. Each appliance should be turned on individually to ensure that its status-indicating thermocouple is responding properly.

13.4.4 *Data Logging*—As with continuous monitoring of downdrafting and backdrafting events (see 12.4.3), data logging is necessary for recording and storing data from continuous monitoring of spillage-zone temperatures or contaminant levels, or both. After the analog output for each sensor has been connected to the data logger or strip chart recorder, verify that values being recorded are appropriate for each parameter being monitored. A high frequency of recording instantaneous or average values, at least once per min and preferably every 15 s, is recommended.

13.5 House occupants should be advised to carry out their regular activities while monitoring is in progress.

13.6 *Data Reporting*:

13.6.1 The data recorded with a data logger should be uploaded to a computer and reviewed with a spreadsheet or other appropriate program(s).

13.6.2 Data recorded on strip charts should be reviewed visually and converted to computer-compatible media if possible.

13.6.3 Based on spillage-zone temperatures, determine the number and duration(s) of spillage events during the monitoring period. The start of a spillage event typically will be signified by a notable increase in the spillage-zone temperature.

13.6.4 Based on contaminant levels, assess the consequences of spillage events by determining the increase in CO or CO_2 concentrations, if any, during and immediately after such events.

13.7 *Results and Interpretation*:

13.7.1 As noted in 13.6.3, spillage events can be isolated by searching for transient or sustained periods of elevated spillage-zone temperatures.

13.7.2 Sustained spillage events typically will result in elevated CO_2 concentrations, but CO concentrations will not necessarily be elevated. (CO concentrations depend on the state of burner tune as well as other factors such as the delivery of combustion air to the combustion chamber.) CO_2 concentrations also can be elevated due to the presence of occupants in the vicinity of the monitoring area, and CO and CO_2 levels can be elevated due to other activities in the house such as use of unvented combustion appliances. Thus, without monitoring spillage-zone temperatures or appliance operational status, elevated CO or CO_2 levels cannot be confidently attributed to appliance spillage.

13.7.3 A duration of 1 week of monitoring is suggested from the practical standpoints of occupant and data processing and analysis convenience. Data collection for a longer monitoring period usually will cover a broader range of weather conditions.

13.8 *Technician and Test Time*—The technician time required for installation of the sensors and a data logger or recorder is about 30 to 60 min, depending on the number of parameters monitored. Additional time of about 1 to 2 h is required for processing and analyzing the continuous data. The test time is 1 week or longer.

14. Discussion of Methods

14.1 The six methods described in the above sections are summarized in Table 3 in terms of technician and test time and the basis for interpretation of test results. Important distinctions between the two major test categories—short-term tests under induced conditions and continuous tests under natural conditions—and among the different tests in each category are outlined in Table 4.

TABLE 3 Methods for Assessing Backdrafting and Spillage—Technician/Test Time and Basis for Interpretation

Type/Name of Test	Technician/Test Time	Basis for Interpretation of Results
House depressurization test (induced conditions)	30 to 40 min	Comparison of the maximum levels of house depressurization with pre-set depressurization limits
Downdrafting test (induced conditions)	10 to 20 min	Visual indication of downdrafting with appliances off
Appliance backdrafting test (induced conditions)	20 to 30 min	Visual indication of venting or backdrafting with each appliance on
Cold vent establishment pressure (CVEP) test (induced conditions)	60 to 90 min	Comparison of CVEP with maximum house depressurization level
Continuous backdrafting test (natural conditions)	30 to 60 min for setup: monitor at least 1 week; 1 to 2 h for analyzing data	Review of continuous monitoring data on vent pressure differentials and appliance status to isolate downdrafting or backdrafting events
Continuous spillage test (natural conditions)	30 to 60 min for setup: monitor at least 1 week; 1 to 2 h for analyzing data	Review of continuous monitoring data on spillage-zone temperatures and combustion products to isolate spillage events and consequences

TABLE 4 Important Distinctions Among Methods for Assessing Backdrafting and Spillage of Vented Combustion Appliances

Type/Name of Test	Distinctions
Tests Under Induced Conditions	Most require minimal equipment and can be performed in 30 min or less. Tests are indicative only of the potential for backdrafting, tend to over-classify homes as spillage-prone. Results can vary with test conditions such as wind and outdoor temperature.
House depressurization test with preset criteria	No operation of vented combustion appliances. Requires equipment for pressure measurements. Pass/fail criteria can be made more stringent or loose by varying the house depressurization limit (for example, 3 vs. 7 Pa).
Downdrafting test	No operation of vented combustion appliances. No measurement equipment required. Failure appears to be a necessary condition for failing backdrafting test. Pass/fail criteria can be made more loose or stringent by varying the time limit (for example, 3 vs. 5 vs. 10 min).
Appliance backdrafting test	Vented combustion appliances are operated. No measurement equipment required. Pass/fail criteria can be made more loose or stringent by varying the time limit (for example, 3 vs. 5 vs. 10 min).
Cold vent establishment pressure (CVEP) test	Vented combustion appliances are operated. Requires blower door and equipment for pressure measurements. Probably most affected by wind of the induced tests.
Tests Under Natural Conditions	Generally are more resource-intensive. Can identify actual backdrafting/spillage events as the test is conducted under normal occupancy conditions. Minimum of 1 week of monitoring is recommended; longer duration will help cover broader range of weather conditions.
Continuous backdrafting test	Requires equipment for vent pressure and appliance status (temperature) measurements. Can indicate downdrafting and backdrafting, but not spillage, events.
Continuous spillage test	Requires equipment for measurement of appliance status, spillage temperatures and combustion products (CO, CO_2). Can indicate spillage events and indoor-air-quality consequences.

14.2 The ranges of the required technician time given in Table 3 are approximate. The estimates assume that the technician has been trained to conduct such tests and has performed a similar test at least once before.

14.3 Although the tests conducted under induced depressurization (Sections 8-11) generally require less time and resources, their results indicate only the potential for depressurization-induced backdrafting and spillage. Understanding of how this potential relates to actual depressurization-induced backdrafting and spillage is quite limited. Failure of short-term tests does not necessarily indicate that an appliance is spillage-prone. By comparison, tests under natural conditions (Sections 12 and 13) are capable of isolating actual backdrafting or spillage events during the period, and under the weather conditions, of the continuous monitoring.

14.4 The number of field studies that have used both short-term and continuous tests is quite limited, precluding any formal assessment of the sensitivity and specificity of inferences derived from short-term tests of backdrafting or spillage potential. However, data from three field studies **(6, 7, 8)** indicate that actual backdrafting or spillage events based on continuous monitoring occur at a much lower frequency than the rates of failure for short-term tests.

14.5 It is not known whether a sufficient variety of naturally occurring indoor or outdoor conditions was encountered during the continuous tests in these field studies to declare their results as definitive, but in one case a follow-up study was performed. In the follow-up study **(11)**, furnaces and water heaters in nine houses (selected to provide a range of backdrafting/spillage potential) were monitored continously for backdrafting and spillage over periods ranging from two to seven months. Results of the study indicated that backdrafting and spillage events were rare, thereby adding further confidence to initial conclusions that these houses do not experience spillage and that short-term tests over-classify homes as spillage-prone. (In one home, the water heater had an isolated spillage event on the afternoon of a warm summer day.)

14.6 Because the induced conditions for short-term tests are believed to represent "extreme" or "worst-case" conditions that might be expected during a year, and because these tests tend to over-classify homes as spillage-prone, one would expect them to "catch" or predict all homes that actually experience backdrafting or spillage. However, results from two field studies **(12)** indicate that the short-term tests sometimes produced "false negatives" (that is, they indicated no backdrafting or spillage potential whereas continuous tests indicated that backdrafting and spillage in fact occurred under natural conditions). Thus, the results from short-term tests need to be interpreted with caution. Complementary approaches to provide additional insights, such as checking venting systems for compliance with applicable codes, are strongly advised.

14.7 There are several important distinctions among the methods involving induced depressurization. The method described in Section 8 compares maximum house depressurization levels with preset criteria for categories of residential venting systems (house depression limits) and does not involve operating the vented combustion appliances. This method was developed based on work in Canada and may not be universally applicable given the variability in house types, appliances, venting systems and weather conditions. The pass or fail criterion for this test can be made more stringent or loose by varying the house depressurization limits (for example, 3 versus 5 versus 7 Pa).

14.8 The method described in Section 9 (downdrafting test) assesses whether a worst-case condition of house depressurization results in a downward flow in the flue with appliances off, and the method described in Section 10 (backdrafting tests) involves a similar assessment during a cold start of each appliance. The pass or fail criterion for the backdrafting tests can be made more stringent or loose by varying the time limit (for example, venting must be established within 3 versus 5 versus 10 min).

14.9 Each of the methods described in Sections 8-10 results in a pass or fail determination, whereas the method described in Section 11 (CVEP test) involves a comparison of two values—the CVEP and the maximum house depressurization level. CVEP results also can be viewed in pass or fail terms (that is, failure is assigned when the CVEP value is less than or equal to the maximum house depressurization), and cases of near-failure can be identified because the quantities to be compared both are measured on a continuous scale. Pass or fail criteria for any of the induced methods may change as more data become available and as the scientific understanding improves.

14.10 The impact of weather conditions on the results of tests under induced depressurization has not been fully evaluated, but results from one field study **(7)** indicate that the repeatability of pass or fail results across two visits to the same house is on the order of 70 % for the test involving house depressurization limits, 75 to 80 % for the downdrafting test, 70 % for the water heater backdrafting test, 80 % for the furnace backdrafting test, and 60 % for the CVEP tests. The CVEP test appears to be the most stringent (that is, results in the highest failure rate), and a higher failure rate can be expected for water heaters than for furnaces. Failing the downdrafting test appears to be a necessary condition for failing the furnace backdrafting test, and in most cases appears to be a necessary condition for failing the water heater backdrafting test as well. The impact of weather on test results also has not been evaluated for the continuous tests under natural conditions, beyond one study **(11)**.

14.11 An important distinction between the two types of continuous tests is that the first can isolate backdrafting events whereas the second can isolate spillage events and their indoor-air-quality consequences. Each method involves two types of measurements: without both types the results can be misinterpreted. For example, under the method described in Section 12, reversal of the ordinary, upward flow in the appliance venting system can occur while an appliance is off (downdrafting) or while it is on (backdrafting). Although downdrafting events may indicate spillage potential, it is the backdrafting events that will have associated spillage. For the method described in Section 13, the spillage-zone temperatures can indicate the duration of spillage events, but without CO and CO_2 measurements the indoor-air-quality consequences cannot be assessed. Similarly, it is not sufficient to monitor either CO or CO_2: both need to be monitored, because CO levels in the vicinity of vented combustion appliances can be affected by other sources in or near the house and CO_2 levels can be affected by the presence of occupants near the appliances.

14.12 Among the measurements for continuous tests, temperature in the "spillage zone" has substantial ambiguity because of difficulty in distinguishing between small amounts of spillage and thermal radiation from heated gases flowing near a draft diverter in a properly venting vent connector **(13)**. Thus, reliance should not be placed on spillage temperatures for denoting backdrafting and spillage events. The ideal method would use a combination of measurements from the continuous backdrafting and spillage tests-vent pressures to denote backdrafting, CO and CO_2 concentrations in the appliance area to denote spillage, and appliance status to distinguish downdrafting from backdrafting and to correctly attribute elevated CO/CO_2 concentrations to a vented appliance **(14)**.

14.13 Certain appliance features can impact the results and interpretations from monitoring under natural conditions. For example, by design an induced draft fan can temporarily induce a positive vent pressure shortly before the furnace fires. Such instances can be isolated by monitoring the operational status of the furnace and inspecting the results to determine whether cases of positive vent pressure have occurred just before the furnace fired. Vent dampers, more commonly associated with water heaters, by design will result in spillage of combustion products from the water heater's pilot light during periods when the appliance is not operating. Again, such instances of apparent spillage can be isolated by inspecting the time series to assess spillage in relation to the appliance's on and off cycles.

15. Keywords

15.1 backdrafting; carbon dioxide; carbon monoxide; combustion appliances; downdrafting; draft diverter; draft hood; flue gas; house depressurization; house tightness; induced fan; nitrogen oxides; residences; spillage; water vapor

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