SURVEYS ON DEPRESSURIZATION-INDUCED BACKDRAFTING AND SPILLAGE

D T Grimsrud[1], D E Hadlich[1], M D Koontz[2], R J Hemphill[3], N P Leslie[3], Z Li[4] and N L Nagda[4]

[1]University of Minnesota, Minneapolis, MN, USA
[2]GEOMET Technologies, Inc, Germantown, MD, USA
[3]Gas Research Institute, Chicago, IL, USA
[4]ENERGEN Consulting, Inc., Germantown, MD, USA

ABSTRACT

Surveys on depressurization-induced backdrafting and spillage were conducted in three different areas of the United States using a common protocol, primarily to assess the correspondence between short-term tests and one week of continuous monitoring per house. The short-term tests, under induced conditions, can only indicate whether there is a possibility that backdrafting or spillage might occur, whereas real-time monitoring under natural conditions can give a true indication of backdrafting and spillage events. The common protocol used in the surveys included four types of short-term tests and two types of continuous monitoring tests. Sustained backdrafting events were rare during the real-time monitoring conducted under this study -- this outcome was counter to the short-term test results, but consistent with results of prior Canadian research. Based on the study data for three areas in the U.S., short-term tests under induced conditions do not appear to predict "real-life" backdrafting events and significantly overstated the likelihood of such occurrences.

INTRODUCTION

Residences can be depressurized by exhaust equipment such as kitchen or bathroom fans, clothes dryers, and fireplaces. Imbalances in the air distribution of a forced-air heating/cooling system, building tightness, indoor-outdoor temperature differences, and the speed or direction of local winds can affect the indoor-outdoor pressure difference further.

Downdrafting, which can result from house depressurization, is the reversal of the ordinary (upward) direction of airflow in a chimney or flue when no vented combustion appliances are operating. Appliance backdrafting generally occurs when a vented combustion appliance, such as a gas furnace or water heater, starts up against a downdrafting chimney and cannot establish draft. When the natural/induced draft or thermal buoyancy cannot overcome downdrafting, 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.

Considerable research on appliance backdrafting has been conducted in Canada during the 1980's [1]. To understand the implications for the U.S. housing stock, the Gas Research Institute (GRI) has initiated the following types of research activities: workshop on research needs in the area of house depressurization, backdrafting, and indoor air quality [2]; critical review of literature on house depressurization, backdrafting, and spillage from vented gas appliances [3]; and development and publication of a common protocol for use in conducting initial field surveys on house depressurization and appliance backdrafting and spillage [4].

The methods in the common protocol for assessing backdrafting and spillage, which recently have been published as ASTM E1998-99 [5], can be divided into two groups: those conducted under induced house depressurization; and those conducted under naturally occurring conditions. Methods under induced conditions can indicate only whether there is a possibility that backdrafting might occur, whereas methods under natural conditions can give a true indication of backdrafting/spillage events if continuous monitoring is conducted over a sufficient period of time. The tests under induced conditions require much less time to conduct and, thus, are termed short-term tests.

The primary objectives of the efforts described in this paper were to conduct initial surveys in several different areas of the United States using the common protocol, to assess the extent of correspondence between results of short-term tests and longer-term continuous monitoring. These surveys were conducted in the service territories of three local distribution companies (LDCs) for natural gas: Washington Gas (Washington, DC); Metropolitan Utilities District (Omaha, NE); and Minnegasco (Minneapolis, MN). This paper describes the study methods, selected measurement results, and their implications.

METHODS

It was planned that initial surveys would be conducted in several areas, to cover a range of housing styles and climate conditions. A telephone interview was used as a screening tool to identify selected features of residences and to determine the willingness of respondents to participate in later stages of the study. In selecting respondents for subsequent stages, some preference was given to residences with indications of building tightness or with multiple exhaust appliances, to obtain some buildings with characteristics thought to increase the likelihood of backdrafting. LDC technicians, visiting selected study homes, recorded baseline data on the house, exhaust appliances, and the venting system. They also conducted a safety inspection for the furnace/boiler, water heater, and venting system, checking for compliance with applicable codes. Some residences visited by LDC technicians were selected for further testing by our technicians. Six tests outlined in Table 1 were conducted.

Among the six tests were four types of short-term tests: house depressurization test with preset criteria; downdrafting test; appliance backdrafting test; and cold vent establishment pressure (CVEP) test. There are important distinctions among these tests, all of which involve some form of induced house depressurization. The first compares incremental house depressurization levels, due to continuous and intermittent fans or exhaust devices, with preset criteria for houses with gas-fired appliances. This test does not involve operating any of the appliances. The second (downdrafting test) assesses whether house-depressurization created by operating fans and exhaust devices results in a downward flow in the flue when the appliances are off. There are two types of downdrafting tests -- the first is performed with all interior doors open, whereas for the second a worst-case condition is created by closing interior doors to rooms not containing exhaust devices, and closing the door nearest the mechanical room and/or turning on the furnace blower, if either action further increases house depressurization. The third (appliance backdrafting test) uses the same conditions as the second, but in this case each appliance is fired to determine whether it can establish draft within five minutes. The fourth (CVEP test) also involves appliance operation.

Table 1. Summary of Test Methods

Name of Test	*Summary of Procedure*	*Basis for Interpretation*
	Tests Under Induced Conditions (Short-term Tests)	
House Depressurization Test with Preset Criteria [6]	Conduct test under closed-house conditions, close interior doors to rooms not containing exhaust appliances. Keep water heater & furnace off throughout the test. After baseline measurements of indoor-outdoor pressure differential, measure incremental house depressurization due to continuous & intermittent fans.	Comparison of house depressurization levels with preset limits.
Downdrafting Test	Conduct test under closed-house conditions, leave all interior doors open. Keep water heater & furnace off throughout the test. After turning on all continuous fans & intermittent exhaust devices, assess backdrafting with a flame lighter or smoke pencil at the appliance draft hood. Repeat the test after closing interior doors to rooms not containing exhaust appliances & choosing a condition that creates maximum house depressurization.	Visual indication of downdrafting with appliances off.
Appliance Backdrafting Test [7]	Use same conditions as for downdrafting test. After initial conditions are set, fire water heater & allow up to 5 minutes for draft to be established. Check for draft once a minute. Cool the common vent, fire furnace or boiler, & again allow up to 5 minutes for establishment of draft. Repeat the test for each appliance under worst-case condition (cool the common vent between tests).	Visual indication of backdrafting or venting with each appliance on.
Cold Vent Establishment Pressure (CVEP) Test	Conduct test under closed-house conditions. Use a blower door to depressurize house (appliance room) to 10-15 Pa. Fire water heater, then gradually relax house depressurization until venting is established. Cool common vent & repeat procedure for furnace or boiler. The level of depressurization at which the appliance establishes draft is its CVEP.	Comparison of CVEP with maximum house depressurization level.
	Tests Under Natural Conditions (Real-time Monitoring)	
Continuous Backdrafting Test	Set up sensors & data logger to monitor vent pressures (common vent &/or appliance vent connectors) & appliance status (on/off through temperature near combustion chamber). Record at frequent intervals such as every 15-30 seconds.	Review of data to isolate downdrafting (+ pressure, appliances off) & backdrafting (+ pressure, appliance on) events.
Continuous Spillage Test	Set up sensors & data logger to monitor temperatures in spillage zones, combustion products (CO & CO_2), & appliance status. Record at frequent intervals such as every 15-30 seconds.	Review of data to isolate spillage events (elevated temperature, appliance on) & IAQ consequences.

As noted earlier, the principal objective was to compare results of short-term tests with those from longer-term continuous monitoring. Real-time monitoring was conducted for approximately one week per house, and included both the continuous backdrafting test and the continuous spillage test summarized in Table 1 [5]. The parameters monitored were appliance status, vent pressures, spillage-zone temperatures, indoor CO/CO_2 levels, house depressurization level, and indoor/outdoor temperatures.

RESULTS

A total of 238 households -- 72 in Washington, 114 in Omaha, and 52 in Minneapolis -- were administered telephone screening questionnaires. Of these, 111 were visited by LDC technicians and 70 were visited by our technicians (16 of these homes were visited by our technicians on two separate occasions). Most homes were single-family detached residences with a full or partial basement. The residences were evenly distributed in terms of house age, with 20-25 percent built before 1950 and about 20 percent built in 1980 or later. Most had a central, warm-air gas furnace and a gas water heater, about 3/4 had a vented kitchen/range fan and one or more bathroom exhaust fan, about 60 percent had one or more fireplace, and virtually all had a clothes dryer. More than half of the furnaces were equipped with a draft hood (1/4 to 1/3 had an induced draft, or ID, fan). In most homes with both a gas furnace and a gas water heater, the appliances shared a common vent; this vent was of type B (metal construction) in about 2/3 of the cases and masonry in the remaining third.

Some of the principal findings from the study tests and measurements were as follows:

- Based on blower-door tests of house tightness, air changes per hour at 50 Pa (ACH50) averaged 7 to 8 ACH with a range of 2.5 to 16.8 ACH. The study included only existing homes, rather than new construction. The Minneapolis homes were somewhat tighter, on average, than the Washington or Omaha homes.

- Baseline house depressurization levels (i.e., with all exhaust appliances off) during our technician visits averaged -1.5 to 2 Pa and ranged from –5.2 to +0.8 Pa across houses. Incremental house depressurization, induced by operating various exhaust appliances, averaged about 4 Pa and ranged from 0.2 to 14.3 Pa.

- Failure rates for short-term tests ("failure" indicates that downdrafting or backdrafting conceivably could occur) were about 30 percent for the house depressurization test and 40 percent for downdrafting tests. Among tests involving appliance operation, failure rates for backdrafting tests were 10-15 percent for furnaces and 25-30 percent for water heaters, and for the CVEP test were 15-25 percent for furnaces and 30-40 percent for water heaters.

- Based on selected homes that were visited twice, the downdrafting tests generally had the best repeatability (75-80 % with the same outcome, i.e., "pass" or "fail"), followed by appliance backdrafting tests (81 % for furnaces, 69 % for water heaters), the house depressurization test (74 %), and the CVEP test (60 % for furnaces, 56 % for water heaters). The strongest correspondence across different types of short-term tests was between the results of the appliance backdrafting test and the CVEP test, for both furnaces and water heaters.

- The continuous backdrafting and spillage tests were started when the short-term tests were completed and, thus, had similar weather conditions. For example, the average outdoor temperature across all study homes was between 46 and 49 °F both for the short-term and the continuous tests. Real-time monitoring indicated that the study homes rarely had a positive vent pressure coincident with appliance operation during their respective week-long monitoring periods (such an outcome would be indicative of a backdrafting event). In most cases with a positive pressure during furnace operation, the furnace was equipped with an ID fan that, by design, can temporarily induce a positive draft as the appliance fires. Cases with a positive vent pressure during water heater operation typically occurred 0.1 percent of the time or less, indicative of minor, transitional spillage during appliance start-up.

- Spillage-zone temperatures were difficult to interpret -- it is difficult to distinguish, for example, between small amounts of spillage and thermal radiation from heated gases flowing near a draft diverter in a properly venting vent connector.

- Houses thought to have spillage occurrences, based on positive vent pressures and the frequency distribution of spillage-zone temperatures, were further explored in terms of CO and CO_2 concentrations. Such investigations typically led to the finding that temporarily elevated CO/CO_2 concentrations were associated with brief, transitional spillage during appliance start-up. In several cases, excursions were related to a source such as an idling vehicle in an attached garage or an unvented combustion appliance operating indoors. There also was continuous, but minor, spillage in homes where the water heaters had vent dampers; by design, such appliances spill during the off cycle when only the pilot light is on.

DISCUSSION

Sustained backdrafting events were rare during the real-time monitoring conducted under this study -- this outcome was counter to the short-term test results, but consistent with results of Canadian research. For example, one of the Canadian findings [8] was that "The limited real time spillage surveys imply that the worst case conditions occur only rarely, and that the indoor air quality degradation due to spillage will often be slight."

Based on the study data for three areas in the U.S., short-term tests under induced conditions do not appear to predict "real-life" backdrafting events and significantly overstated the likelihood of such occurrences. One reason may be that operating numerous exhaust fans simultaneously, as done under most of these tests, results in a condition that rarely, if ever, is realized. An alternative predictive approach may involve determining certain conditions such as undersized vents, long horizontal vent runs with little pitch, location near the perimeter of the house, interior versus exterior vents, or marginal height of exterior vent above roof level. Additional research, including extensive continuous monitoring, is underway to further assess the extent of correspondence between short-term tests and real-time monitoring.

The small fraction of residences in this study for which sustained backdrafting events were apparent from real-time monitoring could be partly because code compliance was checked as a part of the study protocol. Alternatively, the lack of such events could be due to an insufficiently long monitoring period, failing to capture certain conditions that might be more conducive to backdrafting. For example, sustained backdrafting events might be more likely to occur under cold-weather conditions, in part because an appliance may be starting against a cold vent (e.g., during recovery from thermostat setback when the furnace has been off for some time). However, the cold-vent situation would only occur if exhaust devices were to cause a downdraft, which would become increasingly difficult as the indoor-outdoor temperature differential (and the resultant indoor stack effect) increases. The net results would depend, in part, on how house characteristics, such as neutral pressure level, and operation of exhaust devices interact with prevailing weather conditions.

ACKNOWLEDGMENTS

The work performed under this study was sponsored by the Gas Research Institute under Contract No. 5095-280-3571.

REFERENCES

1. Fugler, D.W. 1989. Canadian residential combustion spillage monitoring. *ASHRAE Transactions,* Vol. 95, Part 1, pp. 100-106.

2. Nagda, N.L. 1992. Workshop on Depressurization, Backdrafting, and Indoor Air Quality: Issues and Research Needs. Report No. GRI-95/0403, Chicago: Gas Research Institute.

3. Nagda, N.L., Koontz, M.D., Billick, I.H., et al. 1996. Causes and consequences of backdrafting of vented gas appliances. *Journal of Air and Waste Management Association,* Vol. 46, No. 9, pp. 838-846.

4. Grimsrud, D.T., Koontz, M.D., and Nagda, N.L. 1996. Field Protocol for Determining Depressurization-Induced Backdrafting and Spillage from Vented Residential Gas Appliances (Version 2.0). Report No. GRI-96/0303, Chicago: Gas Research Institute.

5. ASTM. 1999. *Standard Guide for Assessing Depressurization-Induced Backdrafting and Spillage from Vented Combustion Appliances.* ASTM E1998-99, West Conshohocken, PA: American Society for Testing and Materials.

6. CGSB. 1995. The Spillage Test -- Method to Determine the Potential for Pressure-Induced Spillage from Vented, Fuel-Fired, Space Heating Appliances, Water Heaters, and Fireplaces. CAN/CGSB-51-71-95, Ottawa: Canadian General Standards Board.

7. International Approval Services - U.S. Inc. (formerly A.G.A.) and National Fire Protection Association. 1996. *National Fuel Gas Code,* ANSI Z223.1, NFPA 54, 1996 Edition, Appendix H -- Recommended Procedure for Safety Inspection of an Existing Appliance Installation.

8. Fugler, D. 1989. Indoor pollutants measured in combustion spillage testing. In *Combustion Processes and the Quality of the Indoor Environment* (Harper, J.P., ed.), TR-15, Air and Waste Management Association, pp. 51-60.