The Latest Developments in Residential Combustion Safety Testing

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ABSTRACT

Combustion safety testing standards for residential retrofit have recently changed. Additionally, there has been substantial alignment between standards and guidelines from different organizations, including the National Fire Protection Agency (NFPA), the Building Performance Institute (BPI), and Air-Conditioning Contractors of America (ACCA). This has been the result of a significant effort to include all stakeholders in the development of the new procedures. The changes have simplified the process while retaining the evaluation of those issues that are most likely to present problems to homes. These changes will impact practices for residential retrofit programs going forward. This paper describes the changes that have been made, provides the ratiobale for these changes, and details the alignment between organizations that has occurred. In addition, results from a field study and survey of combustion safety failures in retrofit homes, which were conducted as a part of a Building America project, will be discussed.

INTRODUCTION

Combustion safety testing is a standard diagnostic in residential energy efficiency work. This testing is intended to ensure that combustion appliances such as water heaters and furnaces do not spill combustion products into the living space. The combustion products include water vapor at a level that can create condensation and mold risks in many homes, and carbon monoxide and nitrogen dioxide may be emitted at levels that present a health hazard in many homes, when extended and/or frequent spillage occurs.

Many organizations have set combustion safety testing standards and guidelines. Historically, these standards and guidelines have been inconsistent (Rapp et al., 2015). Some of the inconsistency can be attributed to the focus of the organization; for example, until recently NFPA and ACCA have focused more on new construction and appliances whereas BPI focused on the retrofit market. However, in recent years all of these organizations have taken existing homes and appliances into consideration. This has led to efforts to improve the alignment across specifications and to clarify when various requirements apply.

The desire to align these procedures also resulted in a careful look at the value of specific requirements. For example, the procedure in the 2010 BPI Building Analyst standard (BPI 2010) was considered by many to be overly complex. On the other hand, the procedure in NFPA 54 (NFPA 2012) did not consider the impact of duct leakage, considered by some practitioners to be the most important cause of excessive spillage.

Parallel to these standards-making efforts, a project was undertaken through DOE's Building America program

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to evaluate the potential for a simplified test procedure. The goal of the project was to determine if a challenge other than the currently used "worst-case" condition of all exhaust fans and potentially also the air handler being operated at the same could be used to distinguish appliances that will or will not operate safely under normal operation. The study involved long-term monitoring of natural draft gas appliances in occupied residences to determine the frequency and duration of sustained spillage (2 minutes or longer) under normal operation for appliances that failed the worst-case test but passed various levels of an alternative challenge test wherein exhaust fans were operated at flow rates other than maximum.

An additional task of this project was a survey of retrofit programs to collect data on the frequency and causes of combustion safety test failures. This survey was disseminated primarily to state weatherization programs.

This paper provides a brief overview of the recent changes and alignment in combustion safety test procedures along with summary results from the field study and survey.

CHANGES TO TEST PROCEDURES

Variations among test procedures focus on the following aspects:

- Is there a limit to how much depressurization is permitted regardless of whether there is spillage?
- Is draft pressure in the flue measured in addition to testing for spillage?
- How much time must elapse before spillage is considered as sustained? It is generally acknowledged that some exhaust gases will spill for a short period after burner firing, but it is expected to be brief.
- Are the impacts of furnace fan operation on pressure considered? Duct leakage and inadequate return air pathways can impact pressures.
- Are the positions of interior doors considered, and if so, how are they arragned in the test? Door positions can impact pressures if there are inadequare return air pathways.
- Is the impact of the position of the door to the combustion appliance zone (CAZ) evaluated in the test procedure?

Prior to 2014, none of these were handled the same by all three of the relevant standards/guidelines: NFPA 54 (NFPA 2011), ACCA QH-12 (ACCA 2011), BPI-101 (BPI 2010). The BPI-101 standard was the only one that had limits for allowable depressurization, required draft testing, used 1 minute for spillage instead of 5 minutes, and required an evaluation of the impact of the operation of the furnace fan. All of these were due in large part to the focus on existing homes and systems. NFPA 54 and ACCA QH-12 treated door positioning differently, with ACCA QH-12 requiring an evaluation of the impact of door positioning and NFPA 54 ignoring door position other than requiring that the door to the CAZ be closed.

Within the last two years, NFPA 54 (NFPA 2015), ACCA QH-12 (ACCA 2014), and the BPI standard (BPI 2015) all have been updated. (The applicable BPI standard had been BPI-101; the new standard is BPI-1200.) In the case of BPI-1200, depressurization limits and the draft test were removed, bringing it into alignment with NFPA 54 and ACCA QH-12. Depressurization limits were removed because it was considered most important to evaluate whether there was actually spillage. One of the primary resources for depressurization limits (Bohac and Cheple 2002) showed that about 20% of the time appliances drafted satisfactorily even if there was greater depressurization than what became the limit, meaning that failing an appliance based on the limits themselves would cause about 1 in 5 "remediations" to be done on appliances that didn't need it, resulting in wasted time and money. Regarding the removal of the draft test, measurement experience showed that appliances that failed draft testing also failed spillage testing in nearly all cases. Spillage, which means that some combustion gases do not go up the flue, occurs more easily than backdrafting in which air comes down the flue and all combustion gases escape into the room. Therefore it was deemed most appropriate to focus on spillage and not draft.

ACCA QH-12 2014 added a requirement to evaluate the pressure impacts of operating the air handler fan, bringing it into alignment with BPI-1200. This is because duct leakage, especially return duct leakage that is in the same zone as the combustion appliance (e.g. in a basement with a water heater) can be one of the most important mechanisms for causing spillage. The ACCA standard continued to require evaluations of door positioning including the CAZ door. NFPA 54 2015 adds a requirement to evaluate the impacts of the air handler fan, and additionally requires that the positon of the CAZ door be assessed. However, the impacts of other doors are still not considered.

Regarding door positioning, BPI-1200 continues to require a full assessment of the position of the door to the CAZ. However, in order to simplify the test procedure, other interior doors are opened or closed based on whether or not there are exhaust fans or return grilles in the room(s) past the door; there is no longer a requirement to open & close doors in various combinations to search for the highest depressurization condition.

The time to define sustained spillage has been one of the most challenging aspects of combustion safety testing. NFPA 54 and ACCA QH-12 have a 5 minute threshold. This has been based on the industry standard, which assumes a cold flue vent such as with a brand new installation. In BPI-101 the limit was 1 minute, in part based on the concept that appliances with a warm vent should begin drafting fully sooner. NFPA and ACCA have retained the 5 minute limit. However, in BPI-1200 the allowable time to last spillage now depends on whether the appliance may have a warm vent or can reliably have a cold vent. If the appliance is a water heater it is assumed that the vent is warm since water heaters operate year-round. For heating appliances the decision is based on whether the thermostat is set to “HEAT” or not. If it is set to “HEAT” then the assumption is that the vent is warm, otherwise the vent is assumed to be cold. For BPI-1200, if the vent is assumed to be cold then the industry standard of 5 minutes is followed. If the vent is assumed to be warm then the threshold for defining sustained spillage is 2 minutes.

FIELD TESTING

To be eligible for long-term monitoring homes needed to fail spillage testing when all exhausts were on maximum but pass when exhausts other than the dryer were on at lower flow rates. Recruitment was done primarily through partnering weatherization programs and via friends and family. Finding eligible homes proved exceedingly difficult, as homes with spillage test failures tended to have the cause be air handler operation and/or dryer operation regardless of whether additional exhausts were operating. The final field dataset consisted of 10 homes in Minnesota and one in Wisconsin, largely through friends and family. All tested appliances were natural draft water heaters.

Field Test Methodology

When a home was identified as a potential candidate the research team conducted short-term testing, including combustion safety testing, to confirm eligibility and collect detailed information about the home and combustion appliances. Following this short-term testing monitoring systems with sensors for temperature (for determination of burner operation, vent conditions, and indoor/outdoor conditions), carbon dioxide (for sensing spillage), pressure (for draft pressure and zone pressure measurement), and wireless pressure measurement (to detect operation of exhaust fans) were installed in each selected home. Carbon monoxide alarms were placed in the combustion appliance area of each home as a safety measure.

Data were monitored over a period of several months, and analyzed to assess the frequency and duration of spillage events and the correlation of spillage with fan use.

Field Test Results

As shows in Table 1, of the 11 homes tested, only two showed frequent occurances of sustained spillage. Both had defects in the venting system. Site MN 04 has a vent system that is undersized for the capacity of the water heater, and WI 01 has a major venting defect in the form of a five inch connector that had once been the common vent attachment point. In the other nine homes, there were many instances of transient spillage, i.e. lasting for less than one minute; however, most of these appliances were spilling less than 1% of the time that the appliance was operating, with two units spilling between 1-2% of the time and one appliance spilling for about 5% of the time. These findings suggest that the condition of all exhausts being on maximum at the same time is not appropriate to assessing safety for normal operation. Instead, it may be reasonable to conduct evaluations of the impacts of other exhaust fans with those fans on speeds lower than the maximum levels. The results also reinforce the importance of identifying faulty venting systems.

Table 1. Water Heater Spillage Time by Site

	Total hours burner operating time	Hours of spillage	Percent of operating time in spillage
MN 01	243.6	4.1	1.7
MN 02	134.7	0.7	0.5
MN 03	203.2	9.9	4.9
MN 04	226.6	105.5	46.6
MN 05	189.6	1.4	0.7
MN 06	176.2	1.1	0.6
MN 07	117.1	0.5	0.4
MN 08	34.7	0.4	1.1
MN 09	100.7	0.3	0.3
MN 10	39.0	0.2	0.6
WI 01	123.1	112.6	91.4

SURVEY

The Building America study included a survey to gain insight into the causes of spillage failures in practice. This survey was primarily targeted at state agencies (subgrantees) administering low-income weatherization programs through U.S. DOE's Weatherization Assistance Program. The survey was disseminated by the National Association of State Community Service Providers (NASCSP). Responses were obtained from 15 subgrantees and one utility-sponsored program. The survey sought to understand the population of appliances in the program, the testing that was done, the causes of observed or expected spillage failures, and remedies taken.

Survey Results

Most states do not track combustion safety testing failures or causes in a detailed database. Rather, the expectation is that agencies will conduct these tests and remedy failures. While this fact clearly limits the data available for analysis, it is an important finding – and potential opportunity – in and of itself since it demonstrates that the extent and causes of spillage failures are not truly known. About one quarter of respondents provided detailed data, one quarter provided estimates based on impressions, and half did not provide failure rate statistics of any kind.

The respondents that provided detailed data or estimates indicated that approximately 10% of homes fail combustion safety testing or would be expected to fail after weatherization if no remedy was implemented. Of these, the stated cause was split about evenly between air handler operation and other exhausts. Several respondents indicated that the most common "other exhaust" to cause a problem was the dryer, not exhaust ventilation fans.

The results of the survey suggest that the condition that the field study was seeking – non-dryer exhausts that are the cause of spillage failures – is uncommon. However, there remains a dearth of detailed data conclusively demonstrating this outcome.

CONCLUSIONS

Combustion safety testing procedures have come into substantial alignment over the last few years. This alignment has been aided by a greater understanding of when different rules apply, e.g. time to last spillage, and what the major causes of failures are. This alignment has resulted in the removal of depressurization limits as a sole cause of indicating a failure, and the removal of a required draft test. These changes are likely to reduce the time required for testing and the number of appliances that are declared to have failed testing, while retaining the most common causes of serious concerns.

The field monitoring suggests that vent defects are a primary cause of frequent spillage in homes in which combustion safety testing failures are not due to dryer and/or air handler operation. The survey suggests that, overall, air handler operation and/or dryer operation are substantially more commonly causes of failures than other exhaust fans. There remains a knowledge gap regarding the frequency with which any particular cause of spillage occurs.

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