

FINAL REPORT

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Universal Vent Test Report

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Executive Summary

In principle, the Universal Vent accommodates the common venting of a Category IV furnace (positive pressure, condensing) with a natural draft water heater into a Category I Type B common venting (negative pressure, non-condensing). Within the tee is an integrated aspirator oriented such that whether the water heater is firing or not, sufficient warm dry air is drawn into the water heater draft hood such that the flue products from the condensing furnace (a) will not condense within the common vent and (b) will not spill indoors via the water heater draft hood.

This Universal Vent tee itself is based upon prior work by GTI/Battelle in 2002, testing the impact of aspirator diameter, and by GTI in 2010, simulating the impact of aspirator elevation and verifying acceptable venting with a limited experimental test program. As a continuation of this ongoing development, the Gas Technology Institute generated the current set of test results of the Universal Vent concept for (a) a larger, modulating furnace paired with a natural draft water heater and (b) with an approximately 10 mph wind applied at the vent exit. In addition to verifying acceptable venting through parametric testing with and without wind applied at the vent exit, current testing also examined the performance of a single stage furnace with a blocked vent. The operating conditions for the 14 tests are shown below which are performed as a worst-case scenario whereby the common vent is sized at 90% of the requirement per the National Fuel Gas Code and with mild ambient conditions.

Test Matrix

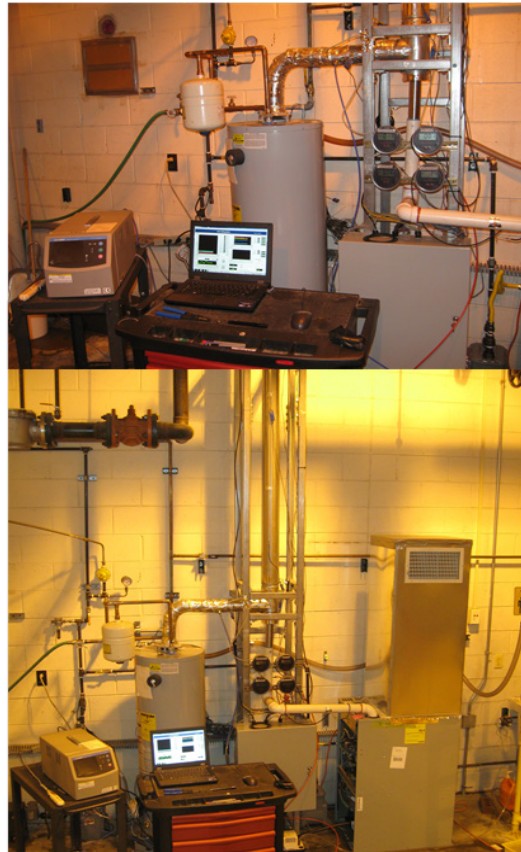
Test Condition	Furnace Type	Unit Operational State		Vent Exit Conditions
		Furnace	Water Heater	
1	Modulating	Max	On	Wind Applied
2	Modulating	Mid	On	
3	Modulating	Min	On	
4	Modulating	Max	Standby	
5	Modulating	Mid	Standby	
6	Modulating	Min	Standby	
7	Modulating	Max	Standby	No Wind
8	Modulating	Max	Off	
9	Modulating	Min	Standby	
10	Modulating	Min	Off	
11	Modulating	Off	On	Wind Applied
12	Modulating	Off	Standby	Wind Applied
13	Single Stage	On	Standby	Blocked Vent
14	Single Stage	On	Off	

Overall, results indicated that stable venting could be achieved without risk of condensation within the common vent for this worst case testing under Tests 1 through 12. With simultaneous firing and wind applied (Tests 1-3), furnace firing without wind applied (Tests 7-10), and water heater firing or standby with wind applied (Tests 11-12), stable venting is observed without issue. With wind applied, furnace firing, and water heater off or in standby, stable venting is observed only in Test 4 with the furnace at its maximum firing rate. Temporary backdrafting, defined as an interruption of drawing dilution air through the water heater vent connector that does not result in spillage of combustion products from the furnace through the water heater

draft hood, is observed. While this infrequent and brief backdrafting condition does not result in spillage at the draft hood, it highlights a potential instability under the conditions tested.

Simulating a blocked vent for the final set of tests, with the water heater off and in standby, framed the challenge of identifying and reacting to a blocked vent condition. Up to roughly a 58% blocked vent, the venting system was able to vent stably without risk of backdrafting or spillage. With a 64% blocked vent, unstable venting was observed with intermittent spillage through the water heater vent connector detected through gas sampling. At a 68% blocked vent, continuous spillage was observed.

Considering methods of detected a blocked vent condition, typically the furnace operation is disabled when the measured vent back pressure exceeds a maximum value. A Universal Vent-equipped furnace cannot use this method of detection as flue products will spill out the water heater draft hood before back pressure in the common vent will build up. Also measurement of temperature at the water heater draft hood is not feasible, proposed under the expired Universal Vent patent no. 4,768,444, as the high-efficiency furnace flue gas temperatures were often cooler than warm air wafting through the water heater central flue.



Photos of Laboratory Setup

Suggested methods of detection within the water heater vent connector are (a) static pressure measurement, to ensure drafting of dilution air as indicated by negative differential pressures referencing the indoor space and (b) CO₂/O₂ sensors in the vent connector detecting departures from ambient conditions when the water heater is not firing, provided long-life reliable gas sensors are available.

While the current set of Universal Vent test results show adequate venting performance under progressively more challenging conditions than prior 2010 testing, the following next steps are suggested to continue vetting this concept:

- Under some test conditions, the Type B common vent had positive static pressure. Identify design changes to Universal Vent and/or vent system restrictions (e.g. common vent height) that maintain negative pressures within the common vent.
- Evaluate methods of detecting a blocked vent to assure effective control while minimizing nuisance shutoffs.
- Demonstrate acceptable venting under typical ambient conditions for the heating season.
- Solicit review of vent manufacturers and identify remaining technical and market barriers.

Introduction

With almost half of residences in the U.S. heating with natural gas or propane-fired warm air furnaces (RECS, 2009) and a continued market push towards condensing efficiency (AFUE \geq 90%) with more condensing efficiency products sold annually than non-condensing efficiency products, the retrofittability of a condensing efficiency Category IV furnace into an existing negative pressure, non-condensing Category I rated venting system presents an economic challenge to the end user. While the Energy Star [®] criteria promoting condensing efficiency furnaces, and the incentives based on these criteria, have largely driven this market shift, a proposed jump in the minimum allowable efficiency by the U.S. Department of Energy (DOE) will drive this shift significantly. This proposed regional minimum standards for non-weatherized warm air furnaces is currently on hold pending resolution of litigation, which may require an increase in minimum AFUE from 78% to 90% in states with population-weighted heating degree days greater than 5,000 (See Figure 1), and may be resolved by late 2014 at time of writing.

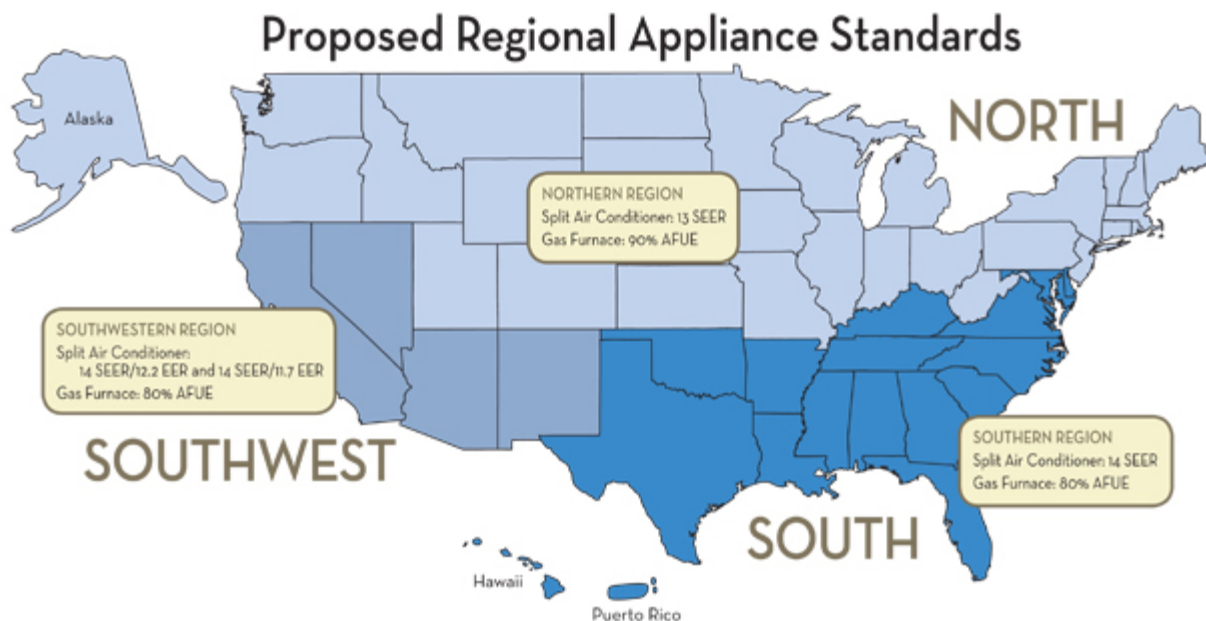


Figure 1: Proposed Regional Standards for Gas Furnaces (ACHR, 2011)

For furnace retrofits, a typical home will have an atmospheric gas-fired water heater common vented with the non-condensing gas-fired warm air furnace. Both appliances are Category I, per National Fuel Gas Code (NFGC) guidance, meaning flue gases are at negative pressure and well above condensing temperatures. The replacement high-efficiency warm air furnace is generally a Category IV condensing appliance, with sealed and pressurized combustion requiring dedicated venting for combustion air and products. In addition to the cost of upgrading venting for the furnace, the post-retrofit atmospheric gas-fired water heater will be “orphaned” in the venting system, which can decrease vent performance and increase the potential for condensation on vent surfaces.

To minimize the cost of new Category IV venting with a high-efficiency furnace retrofit, an added cost, a “Universal Vent” prototype venting configuration is under investigation, which can safely common vents Category I atmospheric water heaters with high-efficiency Category IV warm air furnaces with a low cost installation. It is a venting tee, which the furnace flue gases enter through an aspirator, designed to eliminate the opportunity for (1) condensation within the common vent and (2) spillage of flue gases into the space through the water heater draft hood during furnace-only operation, and (3) safe venting during water heater-only operation. The Universal Vent uses the principle that an expanding gas jet into a larger cavity will create low pressure entrainment regions. The aspirator is oriented such that whether the water heater is simultaneously firing or not, the condensing furnace will not produce condensation within the common vent or spillage through the water heater draft hood. Additionally, the water heater is not prevented from safely venting during individual operation. The smaller diameter furnace vent is the jet, ejecting into the larger diameter Universal Vent tee with the water heater vent connector to the tee near the resulting low pressure regions.

1.1 Prior Universal Vent Research

Initially, the concept was evaluated under a 2002 GTI project *Universal Vent Systems for High-Efficiency Furnaces and Draft Hood Water Heaters* with work performed by Battelle Columbus Laboratories (Talbert et al., 2002). This limited set of test results were promising, with both horizontal and vertical Universal Vent orientations evaluated, indicating that in the vent configurations tested the Universal Vent met the three criteria outlined in the previous paragraph. This initial work was concerned primarily with the diameter of the aspirator section, varying between 1” to 2” in diameter exiting into a 4” round Universal Vent tee. It was determined that the elevation of the aspirator exit be fixed to flush with the bottom of the water heater vent connector, so as not to interfere with the hydrodynamics of gases leaving the water heater vent connector. Results indicated that a 2” aspirator diameter provided sufficient aspiration at a minimum pressure drop penalty.

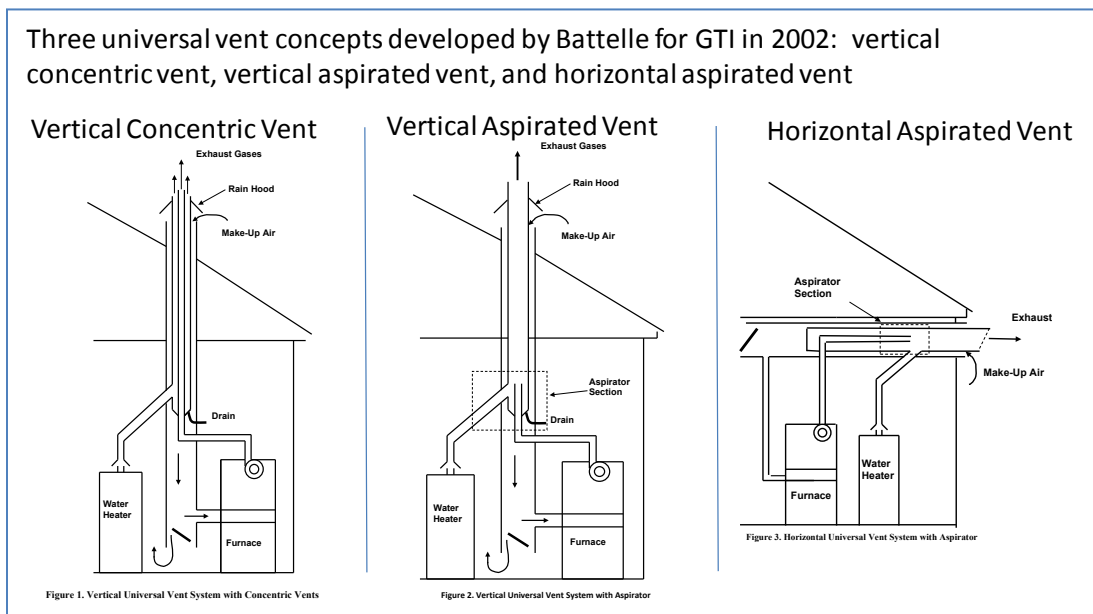


Figure 2: Universal Vent Configurations used in 2002 GTI/Battelle Study

As a continuation of this initial testing, in 2010, GTI explored further interactions between the aspirator height relative to the water heater common vent connector using computational fluid dynamics (CFD). Under worst-case operating conditions, results for furnace-only operation showed that aspirators at or above the plane flush with the water heater vent connector bottom were sufficiently high to aspirate between 40% to 45% of the furnace flue gas flow rate through the draft hood of the water heater. Temporary condensation was shown to be likely downstream in the common vent, however either 15% more entrained flow or increasing entrained air temperatures from 70°F to 80°F was sufficient to prevent in-flue condensing.

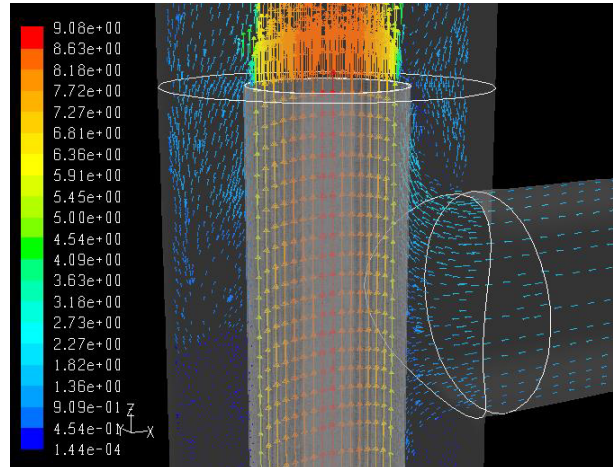


Figure 3: Velocity Vectors for Aspirator 3.0” Above Horizontal Connector Centerline

Using the optimum design at the cusp of acceptable performance, a Universal Vent was fabricated and used to common vent a representative Category I gas-fired atmospheric water heater and Category IV condensing warm air furnace in GTI’s Venting Laboratory. Put through six operating scenarios, varying firing combinations of the two appliances, safe venting and non-condensing conditions were observed in each case. These data points are summarized in *Appendix A: Data Summary from 2010 GTI Testing*, which indicate that under these conditions (a) sufficiently hot flue gases in the common vent prevent condensation, (b) the water heater had sufficient draft to operate individually, and (c) no spillage occurred at the draft hood while the water heater was off or in standby.



Test Condition	Unit Operational State	
	Furnace	Water Heater
1	High	On
2	Low	On
3	Off	On
4	High	Stand-by
5	Low	Stand-by
6	High	Off

Figure 4: 2010 Universal Vent Laboratory Setup and Test Conditions

As a further continuation of Universal Vent testing, this report summarizes addition parametric testing to explore installation scenarios not previously covered. While 2010 GTI testing represented worst-case conditions for a two-stage furnace demonstrating that the Universal Vent concept was viable, the following parametric conditions were performed to cover more extreme operating conditions: operating with a modulating furnace, operating with a 10 mph wind outdoors, and operating a single stage furnace with a blocked vent failure.

Laboratory Test Setup

The universal vent test rig, used during the aforementioned 2010 laboratory testing with a 2” aspirator ejecting into the Universal Vent tee flush with the bottom of the water heater vent connector, was modified to accommodate the following:

- *Simulated Wind* – For most of the test conditions simulated, an approximately 10 mph wind was simulated at the common vent outlet. This wind was produced using a large fan blowing through a section of round ducting terminating approximately 2’ from the common vent cap. Early discussions of the wind simulator suggested that due to the initially short round duct section, the velocity distribution was not uniform. This was verified using a hot wire anemometer at several points 1’ downstream of the duct outlet and remedied by extending the duct length to 10’ (see Figure 5). At the common vent end cap, wind speed and direction is measured with a cup anemometer.

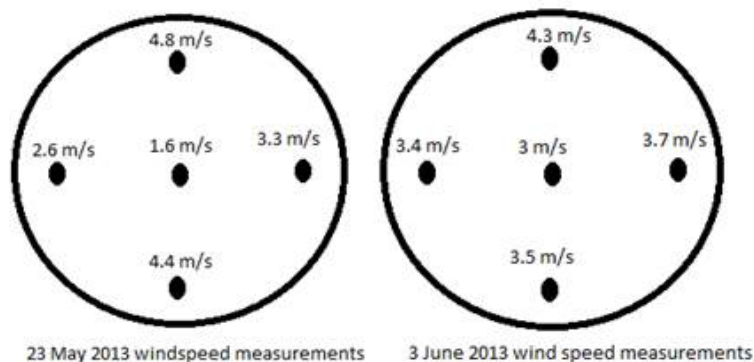


Figure 5: Initial and Final Velocity Distribution of Wind Simulator (L) and Photo (R)

- *Larger Furnaces* – As this investigation is in part motivated by potentially forthcoming regional standards, focusing on condensing warm air furnace retrofits in Northern climates, the previously tested 80,000 Btu/hr/ 90% AFUE was too small to be representative. Focusing on a 100,000 Btu/hr/95% AFUE furnace for much of the current testing required a resizing of the common vent. Keeping the vent diameters fixed and for the planned water heater and furnace firing rates, the common vent height was increased by 5 feet, to be consistent with prior testing. Per the National Fuel Gas Code venting tables (NFPA 2012), these venting systems were intentionally conservative and undersized by up to 10%, for worst-case testing.
- *Blocked Vent Testing* – In addition to testing the compatibility of a modulating high-efficiency furnace with the Universal Vent, the impact of a blocked vent for a single-stage furnace is assessed, to identify the level of vent blockage that suitable venting transitions to spillage of flue gases from the water heater draft hood, if at all.

The test conditions developed to cover these added scenarios, varying the water heater operational state, furnace firing rate, and vent exit conditions, summarized in Table 1. Photos and a diagram of the Universal Vent test rig are shown in Figure 6 with a complete listing of laboratory instrumentation shown in *Appendix B: Instrumentation Summary*.

Table 1: Test Conditions

Test Condition	Furnace Type	Unit Operational State		Vent Exit Conditions
		Furnace	Water Heater	
1	Modulating	Max	On	Wind Applied
2	Modulating	Mid	On	
3	Modulating	Min	On	
4	Modulating	Max	Standby	
5	Modulating	Mid	Standby	
6	Modulating	Min	Standby	
7	Modulating	Max	Standby	No Wind
8	Modulating	Max	Off	
9	Modulating	Min	Standby	
10	Modulating	Min	Off	
11	Modulating	Off	On	Wind Applied
12	Modulating	Off	Standby	
13	Single Stage	On	Standby	Blocked Vent
14	Single Stage	On	Off	

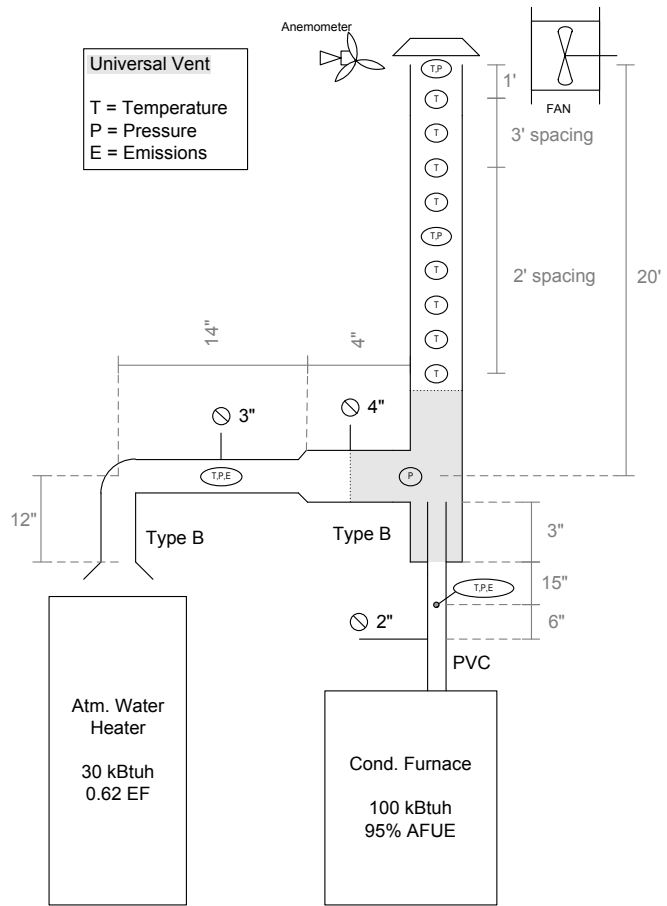
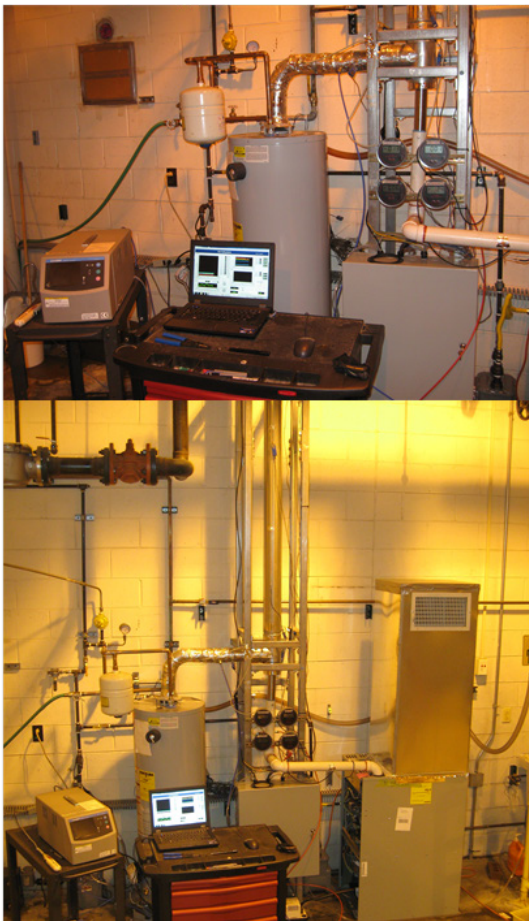


Figure 6: Photos and Diagram Indicating Measurement Points of Experimental Setup

Test Data and Analysis

Over the test conditions outlined in Table 1, with measurement points outlined in Figure 6 and Table 3, acceptable operation of the Universal Vent is determined by:

- *Favorable Pressure/Temperature Gradients* – For the instances where the water heater and furnace are operating in tandem, if there exists a positive net pressure drop from the water heater vent connector to the common vent, that is an indicator of adequate venting. Furthermore, temperature measurements within the water heater vent, furnace vent, and common vent indicate direction of flow through mixed temperatures.
- *Visual Confirmation of Spillage* – Using a smoke pen, the spillage, or reversal of flow from normal venting to have flue gas spill into the conditioned space via the water heater draft hood, is detected visually.
- *Detection of Flue Gas Species* – By monitoring gaseous species within the water heater vent connector, detection of significant concentrations of CO₂ while the water heater is off or in standby is further indication of spillage.

3.1 Modulating Furnace Testing

For the subject furnace, a modulating furnace was evaluated for much the current testing. A modulating furnace had not been tested before with the Universal Vent. Prior testing in 2002 (Battelle) and 2010 (GTI) was with a two-stage furnace with results suggesting the Universal Vent permitted safe operation under conditions tested. When the Universal Vent is to be deployed, during a retrofit from a Category I to a Category IV furnace, the likelihood that the retrofit furnace will be modulating continues to grow. Of the twelve test conditions with a modulating furnace reported, they are grouped by tests with and without simulated windy conditions at the vent exit.

With an approximately 10 mph wind simulated at the vent exit, Table 2 through Table 4 show results for various combinations of operating states of the natural draft water heater and modulating furnace, with the furnace operating at the maximum, minimum, and midpoint of its firing rate range. Results reported are for steady state conditions, operating for at least 15 minutes, from which the following can be concluded:

- *Simultaneous Firing of the Furnace and Water Heater Yields Acceptable Common Venting* – Similar to what was observed in prior 2010 GTI testing of a two-stage furnace without wind applied, Tests 1 through 3 show adequate common venting through (a) proper venting as indicated static pressure measurements and vent temperatures, (b) sufficient common vent temperatures to prevent formation of condensation, and (c) sufficient draft observed with smoke pen at the water heater draft hood.
- *Water Heater Can Vent Safely Individually* – Acting as a normal Category I common vent system, when operating alone in Tests 11 and 12, the water heater has adequate venting as indicated by a smoke pen observation, common vent temperature measurements, and static pressure readings.

Table 2: Firing Rates and Vent Pressures for Modulating Furnace Tests – With Simulated Wind

Test No.	Firing Rate (Btu/hr)		Vent Pressures ("WC)			
	Furnace	Water Heater	Exit	Common Vent	Furnace	Water Heater
1	97780	29660	0.0274	0.0051	0.4367	-0.0148
2	75170	29750	-0.0401	-0.0030	0.1016	-0.0281
3	51880	29670	-0.2215	-0.0012	-0.0312	-0.0148
4	97420	Pilot*	0.0747	0.0092	0.4931	-0.0081
5	75460	Pilot*	-0.0352	-0.0026	0.1075	-0.0138
6	50700	Pilot*	-0.0141	0.0011	0.0545	-0.0035
11	0	26380	-0.0622	-0.0031	-0.0307	-0.0302
12	0	480	-0.0245	-0.0022	0.0348	-0.0071

*Pilot firing rate is measured to be approximately 390 Btu/hr

Table 3: Vent Temperatures for Modulating Furnace Tests – With Simulated Wind

Test No.	Operational State		Vent Temperatures (°F)			
	Furnace	Water Heater	Exit	Common Vent	Furnace	Water Heater
1	Max	On	146.0	151.0	115.0	263.0
2	Mid	On	138.0	143.7	93.2	231.5
3	Min	On	151.6	158.5	92.5	266.9
4	Max	Standby	103.2	104.6	114.6	95.7
5	Mid	Standby	89.3	89.8	91.6	94.9
6	Min	Standby	91.9	93.1	90.9	108.9
11	Off	On	166.6	179.2	74.4	240.5
12	Off	Standby	89.3	91.5	81.7	101.9

Table 4: Vent Gas Analysis and Smoke Pen for Modulating Furnace Tests – With Simulated Wind

Test No.	Operational State		CO ₂ (% , dry)		O ₂ (% , dry)		Smoke Pen at WH Draft Hood
	Furnace	Water Heater	Furnace	Water Heater	Furnace	Water Heater	
1	Max	On	7.4%	3.7%	8.0%	14.4%	OK
2	Mid	On	9.0%	3.7%	4.9%	14.0%	OK
3	Min	On	7.9%	4.0%	7.0%	13.9%	OK
4	Max	Standby	7.4%	0.1%	7.9%	20.4%	OK
5	Mid	Standby	9.5%	0.1%	4.1%	19.9%	OK
6	Min	Standby	7.8%	0.2%	7.2%	20.4%	Intermittent Backdraft
11	Off	On	0.1%	2.8%	20.6%	16.0%	OK
12	Off	Standby	0.1%	0.1%	20.6%	20.4%	OK

- Furnace Operating with Water Heater in Standby Yields Marginally Acceptable Venting** – For Tests 4 through 6, wherein the water heater is in standby (tank at 135°F and pilot light lit) and wind is applied at the vent exit, lower furnace firing rates show signs of marginally acceptable venting. At the maximum firing rate, test 4, acceptable venting is shown from smoke pen observation, static pressure/temperature gradients, and detection of combustion products (CO, CO₂) within the water heater vent connector. At lower furnace firing rates, the middle and bottom of the modulation range, the venting system has marginally acceptable operation as evidenced by: variation in water heater vent temperatures in Test 5 and by observations of intermittent backdrafting conditions at the water heater draft hood in Test 6.

Charting static pressure measurements and measured CO₂ within the water heater vent connector for Tests 5 and 6, shown in Figure 7 and Figure 8, indicates that despite background detection of CO₂ within the water heater vent connector, indicating that flue gases from the furnace are not exiting through the water heater vent connector, brief moments wherein the vent exit pressures exceed the water heater vent connector pressures which result in a temporary reversal of flow. If these reversals are long enough, as shown for Test 6, they can be observed as backdrafting with a smoke pen at the water heater draft hood. This indicates that the pressure fluctuations at the vent exit caused by wind can yield temporary backdrafting at the draft hood, which while insufficiently long in duration to result in the spillage of flue gases at the water heater draft hood, they do highlight an inherent instability in the venting system in this worst case scenario (undersized common vent, warm outside air temperature, moderate wind at vent exit).

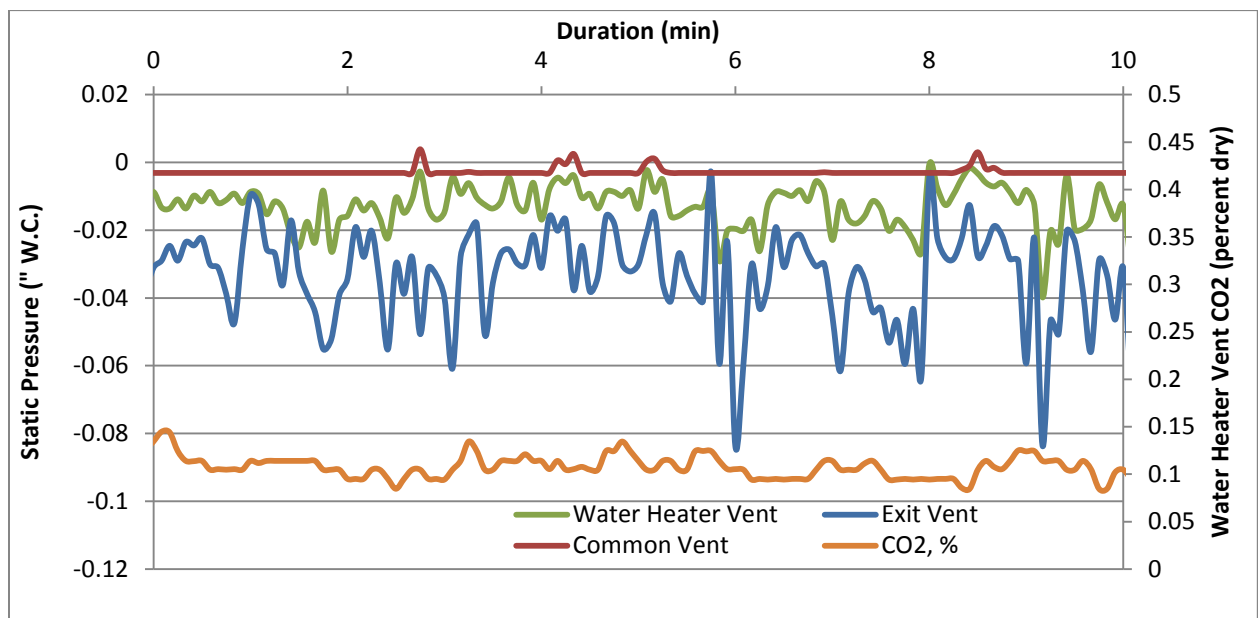


Figure 7: Static Pressures and Water Heater Vent CO₂ Measurements for Test 5

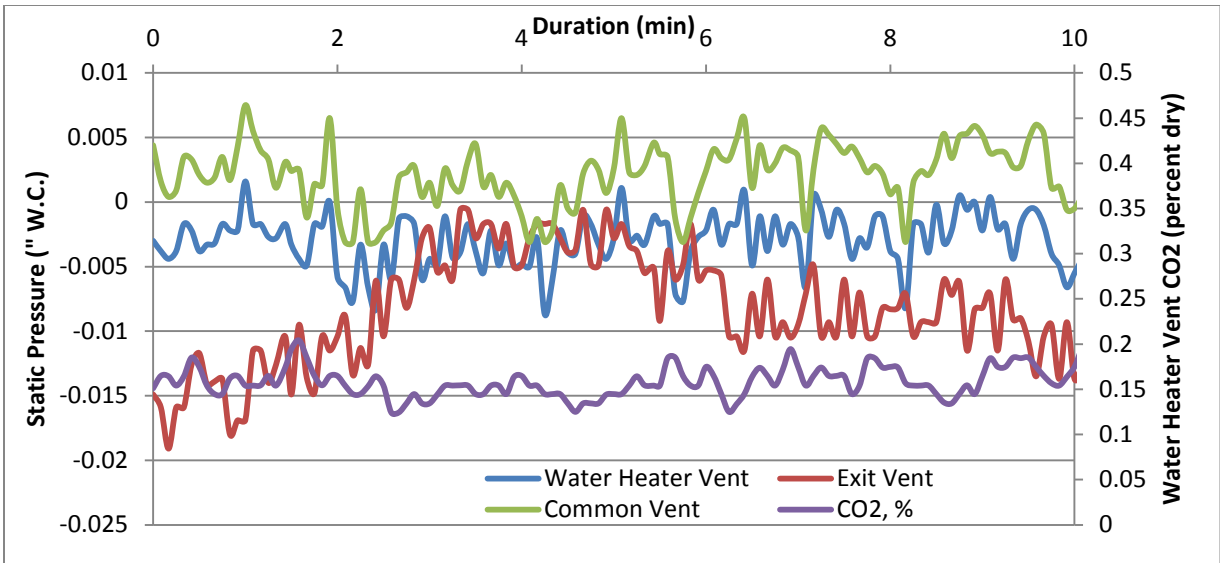


Figure 8: Static Pressures and Water Heater Vent CO₂ Measurements for Test 6

Concerning the potential for unwanted condensation within the Type B (Category I) common vent, Tests 4 through 6 do show adequate dilution to stay above the flue gas dew point temperature. While Tests 4 and 6 indicate this through measured mixed temperature conditions, where an estimated 18% to 20% of flow through the common vent is dilution air pulled in through the water heater draft hood, the vent temperature fluctuations during Test 5 (Figure 9) show mixed common vent temperatures near the furnace vent temperatures of 92°F. As the flow of dilution air through the water heater vent connector is confirmed in Test 5 through smoke pen observations and static pressure measurements, this indicates a depressed flue gas dew point within the common vent, thus condensing is not an issue.

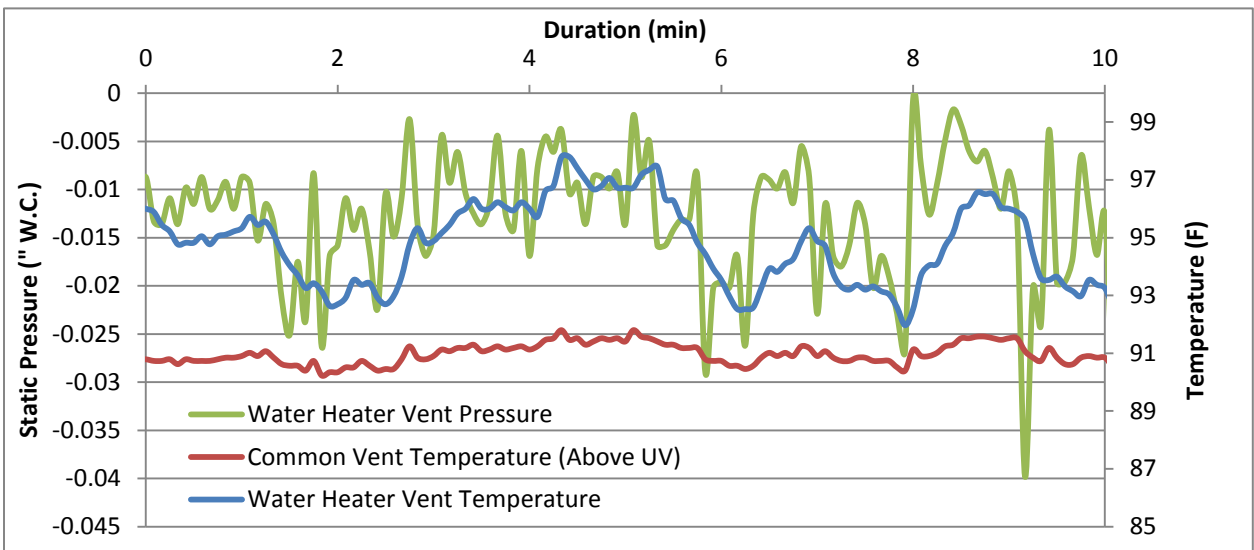


Figure 9: Static Pressures and Water Heater Vent Temperature for Test 5

Without applied wind at the vent exit, Tests 7 through 10 cover furnace operation at the high and low end of its modulating range with the water heaters off or in standby. Overall, the results shown in Table 5 through Table 7 indicate adequate venting in all cases. During testing no spillage occurs, as no measureable CO₂ (above background readings) is found within the water heater vent connector and backdrafting is not observed with a smoke pen. Additionally, temperature measurements do not confirm condensing within the common vent either directly ($T_{Exit} \approx T_{furnace}$) or through an estimate of dilution air within the common vent at approximately 44% to 40% of total common vent flow for Tests 7 and 8 respectively. These favorable results are consistent with prior 2010 GTI testing of a two-stage furnace without wind applied at the vent exit and the calculated quantity of dilution air from the water heater vent connector is within 12% of the 2010 results.

Table 5: Firing Rates and Vent Pressures for Modulating Furnace Tests – Without Simulated Wind

Test No.	Firing Rate (Btu/hr)		Vent Pressures ("WC)			
	Furnace	Water Heater	Exit	Common Vent	Furnace	Water Heater
7	97420	Pilot*	0.1385	0.0013	0.5618	-0.0141
8	97420	0	0.0855	0.0044	0.5767	-0.0112
9	48640	Pilot*	0.0369	-0.0030	0.2410	-0.0096
10	46690	0	0.0228	-0.0024	0.1199	-0.0095

*Pilot firing rate is measured to be approximately 390 Btu/hr

Table 6: Vent Temperatures for Modulating Furnace Tests – Without Simulated Wind

Test No.	Operational State		Vent Temperatures (°F)			
	Furnace	Water Heater	Exit	Common Vent	Furnace	Water Heater
7	Max	Standby	102.7	103.9	114.7	94.6
8	Max	Off	102.4	103.5	115.3	90.5
9	Min	Standby	88.5	89.4	89.1	99.5
10	Min	Off	86.1	86.8	87.4	93.7

Table 7: Vent Gas Analysis and Smoke Pen for Modulating Furnace Tests – With Simulated Wind

Test No.	Operational State		CO ₂ (% , dry)		O ₂ (% , dry)		Smoke Pen at WH Draft Hood
	Furnace	Water Heater	Furnace	Water Heater	Furnace	Water Heater	
7	Max	Standby	7.5%	0.1%	7.8%	20.4%	OK
8	Max	Off	7.4%	0.1%	7.9%	20.7%	OK
9	Min	Standby	7.8%	0.1%	7.4%	20.5%	OK
10	Min	Off	6.4%	0.1%	9.6%	20.6%	OK

3.2 Single Stage Furnace Testing with Blocked Vent

While Tests 1 through 12 have demonstrated through steady state testing that the Universal Vent concept yields acceptable venting for the common vented water heater and furnace, albeit Tests 5 and 6 have highlighted system instabilities under the worst case operating conditions, failure modes and methods of detection are also of interest. Under the final two test conditions, a 100,000 Btu/hr 96.3% AFUE single stage (on/off) furnace is tested in the Universal Vent test rig with the water heater off or in standby and with a blocked common vent. When operating with a standard Category IV vent system, the furnace detects a blocked vent as an exceedingly high back pressure on the flue gas inducer and prevents the unit from firing. When common vented to a draft hood equipped water heater via a Universal Vent, a blocked vent would not result in the same exceedingly high back pressure on the furnace inducer but rather push flue gases into the indoor space via the water heater draft hood. These tests simulate this blocked vent scenario through progressive blockage of the vent exit to the point of spillage at the draft hood, detected as intermittent presence of CO₂ within the water heater vent connector. Steady state measurements are made for levels of blockage, as percent open area coverage, just prior to and just at flue gas spillage, with results are summarized in Table 8 through Table 10.

Table 8: Firing Rates and Vent Pressures for Single Stage Furnace Tests with Blocked Vent

Test No.	Blockage	Firing Rate (Btu/hr)		Vent Pressures ("WC)			
		Furnace	Water Heater	Exit	Common Vent	Furnace	Water Heater
13	58%	100740	Pilot*	0.0329	0.0265	0.2254	0.0129
	64%	100860	Pilot*	0.0333	0.0281	0.2219	0.0116
14	64%	100680	0	0.0379	0.0320	0.2291	0.0144
	68%	100650	0	0.0425	0.0365	0.2317	0.0153

*Pilot firing rate is measured to be approximately 390 Btu/hr

Table 9: Vent Temperatures for Single Stage Furnace Tests with Blocked Vent

Test No.	Blockage	Operational State		Vent Temperatures (°F)			
		Furnace	Water Heater	Exit	Common Vent	Furnace	Water Heater
13	58%	On	Standby	98.3	97.6	97.2	121.7
	64%	On	Standby	97.5	96.7	96.8	108.9
14	64%	On	Off	98.3	97.8	97.8	103.6
	68%	On	Off	98.6	97.8	97.9	97.8

Table 10: Vent Gas Analysis for Single Stage Furnace Tests with Blocked Vent

Test No.	Blockage	Operational State		CO ₂ (% , dry)		O ₂ (% , dry)	
		Furnace	Water Heater	Furnace	Water Heater	Furnace	Water Heater
13	58%	On	Standby	9.4%	0.2%	4.1%	19.7%
	64%	On	Standby		2.0%		16.7%
14	64%	On	Off		0.6%		19.1%
	68%	On	Off		9.3%		4.3%

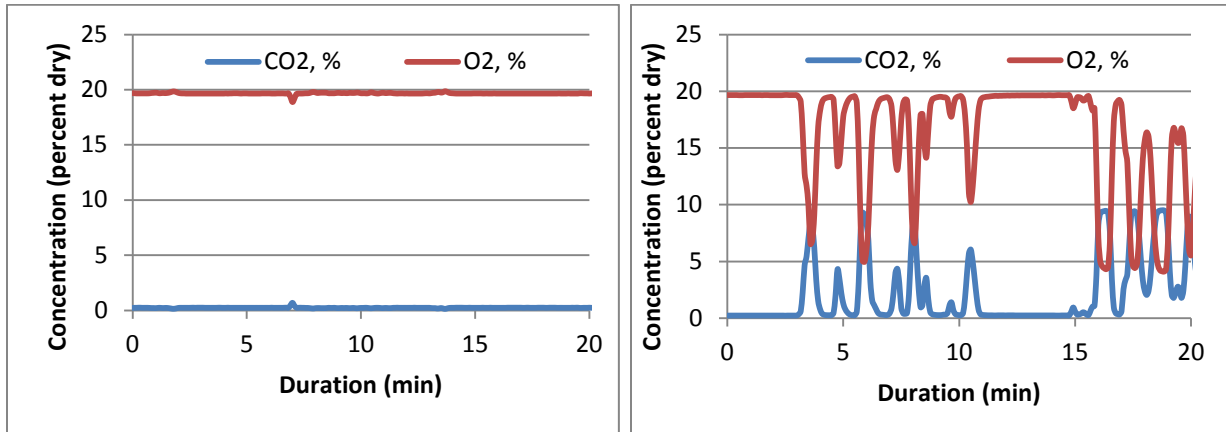


Figure 10: CO₂ and O₂ Concentration within Water Heater Vent Connector for Test 13 with 58% (Left) and 64% (Right) Exit Vent Blockage

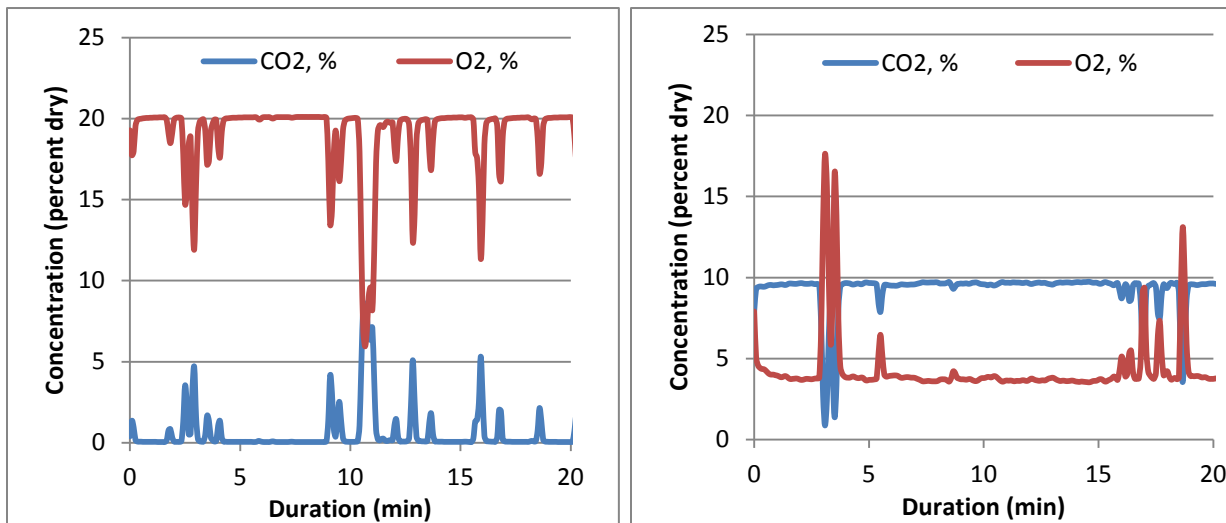


Figure 11: CO₂ and O₂ Concentration within Water Heater Vent Connector for Test 14 with 64% (Left) and 68% (Right) Exit Vent Blockage

Between Tests 13 and 14, whether the water heater is in standby or off has little impact on the effect of the blocked vent, whereby the percent blocked area similarly yield three modes: stable venting, unstable venting, and spillage. In Figure 10 for Test 13, the difference between stable and unstable venting is shown, shifting from 58% to 64% blockage of the vent exit. Unlike the

intermittent backdrafting from prior Tests 5 and 6, true spillage is observed in this instance where furnace flue gases are detected within the water heater vent connector. In Figure 11 the transition between unstable venting (intermittent spillage) and continuous spillage is shown, increasing the vent blockage from 64% to 68% for Test 14.

3.2.1 Universal Vent Control Strategy to Detect Blocked Vent

Unlike the previously patented Universal Vent Concept pictured in Figure 12 (US 4,768,444), which detected spillage of flue gases into the indoor space at the water heater draft hood through a thermocouple measurement (reference 58 in diagram), this is not feasible for high-efficiency Category IV furnaces which may have exiting flue gas temperatures below 100°F, potentially cooler than the warm air wafting up from the water heater center flue. Considering furnace vent temperatures in Table 9, these are less than the warm dilution air temperature in the water heater vent connector during stable venting in Test 13 with 58% blockage.

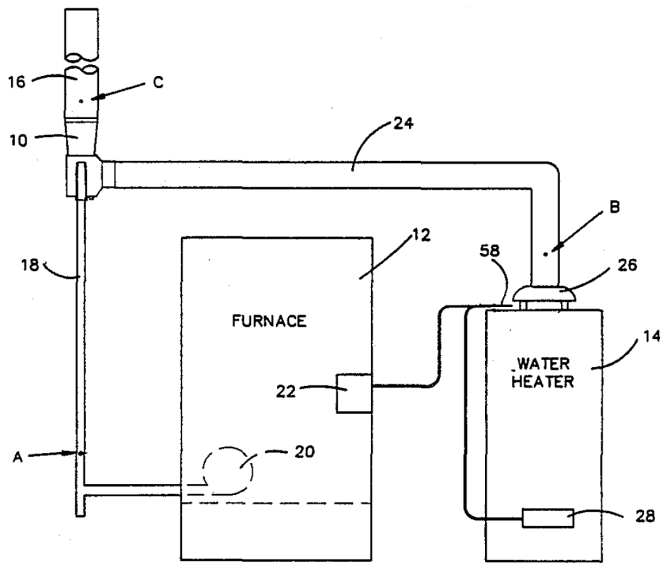


Figure 12: Early Universal Vent Control Concept (U.S. Patent 4,768,444)

Looking beyond temperature measurement within the water heater vent connector or at the entrance to the draft hood, the following options may be viable individually or in combination as a method of detecting blockage at the vent exit, thus disabling the furnace from firing and preventing sustained spillage:

- *CO₂ and/or O₂ Sensor within Water Heater Vent Connector* – When the furnace is firing and the water heater is off or in standby, departures from ambient CO₂ and/or O₂ concentrations within the water heater vent connector would be readily detectable. Such departures shown with 64% - 68% blockage in Tests 13 and 14, under unstable venting conditions, are detectable. At the time of writing, a demonstrated reliable long-life gas sensor for this application is not currently available.
- *Static Pressure Measurement within Water Heater Vent Connector and Common Vent* – Comparing Tests 1 through 12 which showed stable venting to Tests 13 and 14 with marginally stable venting to spillage, Tests 1 through 12 had consistently negative static pressures within the water heater vent connector (referenced to indoor space), whereas Tests 13 and 14 showed positive pressures.

While it is intuitive that negative pressure within the water heater vent conditions indicates draft, this conservative control method will control for blockage conditions where there is neutral draft within the water heater vent connector, where while spillage is not occurring, warm dilution air is not drafted into the Type B common vent to minimize the potential for condensation. As shown in Figure 13 and Figure 14 for Test 13 with 50% and 64% blockage

respectively, both cases show positive pressure within the water heater vent connector however blockage of 58% and less was shown to have no spillage (Figure 10). Detecting blockage via negative/positive pressure within the vent connector will prevent the furnace from firing in the case of Figure 13, where blockage is insufficient enough to cause spillage but is sufficient enough to stall the drafting of warm dilution air to lessen the potential for condensation within the common vent.

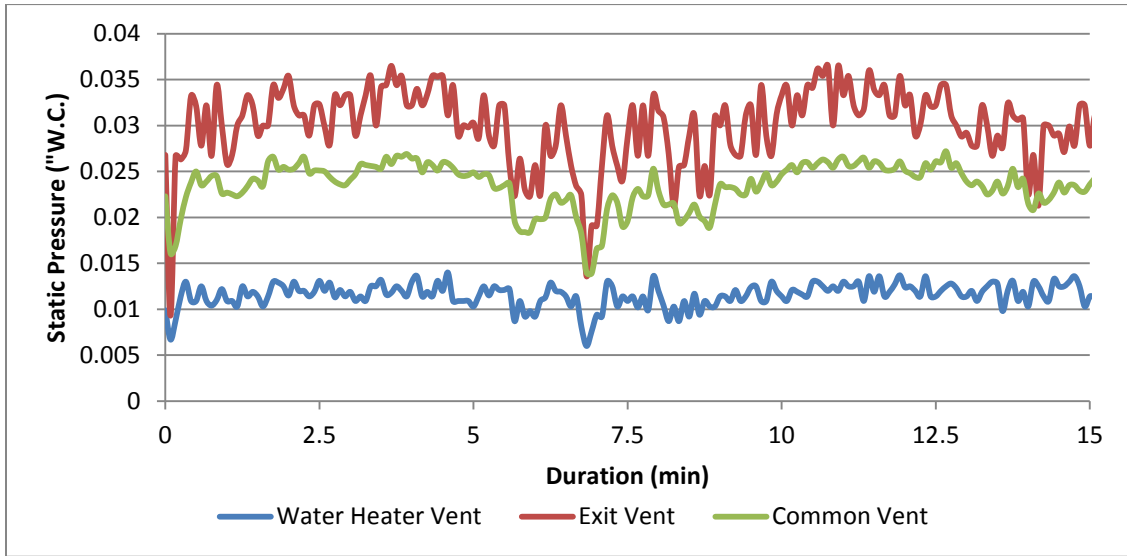


Figure 13: Static Pressures for Test 13 with 50% Vent Blockage

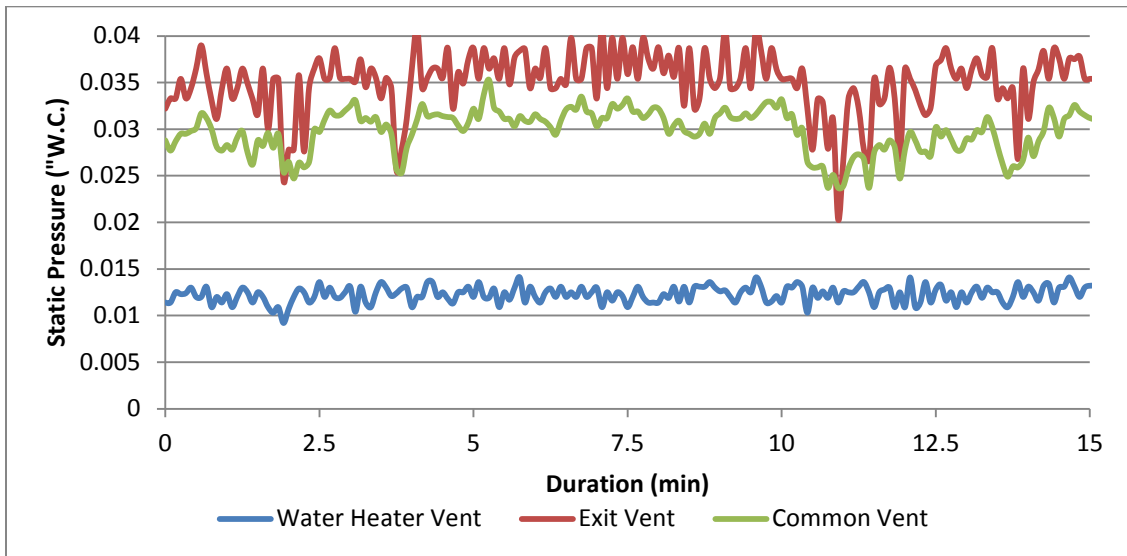


Figure 14: Static Pressures for Test 13 with 64% Vent Blockage

Conclusion

As a continuation of an ongoing development, the current test results from the Universal Vent concept demonstrate acceptable venting performance for (a) a larger, modulating furnace paired with a natural draft water heater and (b) with an approximately 10 mph wind applied at the vent exit. In addition to verifying acceptable venting through parametric testing with and without wind applied at the vent exit, current testing also examined the performance of a single stage furnace with a blocked vent.

Laboratory Test Results

As with prior GTI testing in 2010, testing is performed as a worst-case scenario, whereby the common vent is sized at 90% of the requirement per the National Fuel Gas Code and with mild ambient conditions. Overall, results indicated that stable venting could be achieved for this worst case testing, for the following test conditions:

- *Modulating Furnace without Wind Applied* – Differing from 2010 GTI testing by operating a larger modulating furnace with a proportionally taller common vent, tests with the water heater off or in standby and the furnace at the maximum and minimum of its firing range show acceptable venting without backdrafting or spillage. Measured temperatures and calculated rates of dilution air indicate no threat of condensation within the common vent.
- *Modulating Furnace with Wind Applied* – With approximately 10 mph wind applied at vent exit, tests with simultaneous firing of the furnace and water heater show acceptable venting without backdrafting or spillage and common vent temperatures sufficiently high to inhibit condensation within the flue. Tests operated with the water heater firing individually similarly indicate acceptable venting.

For tests with the water heater in standby and furnace firing, while temperatures and estimated dilution rates suggest condensation in the common vent is not an issue, marginally acceptable venting is observed. When at the maximum of its firing range, the furnace provides adequate aspiration of warm air through the water heater draft hood to promote acceptable venting without worry of condensation. However when the furnace fires at the middle and minimum of its firing range, Tests 5 & 6 respectively, intermittent backdrafting is observed via temperature fluctuations (Test 5) and with a smoke pen (Test 6). Brief instances when the static pressure of the vent exit exceeds that of the water heater vent connector stall aspiration of room air into the draft hood, however products of combustion from the furnace as CO₂ are not detected within the water heater vent connector, suggesting that spillage is not a threat under these conditions.

Simulating a blocked vent for the final set of tests, with the water heater off and in standby, framed the challenge of identifying and reacting to a blocked vent condition. Up to roughly a 58% blocked vent, the venting system was able to vent stably without risk of backdrafting or spillage. With a 64% blocked vent, unstable venting was observed with intermittent spillage through the water heater vent connector detected through gas sampling. At a 68% blocked vent, continuous spillage was observed.

Considering methods of detected a blocked vent condition, typically the furnace operation is disabled when the measured vent back pressure exceeds a maximum value. A Universal Vent-equipped furnace cannot use this method of detection as flue products will spill out the water heater draft hood before back pressure in the common vent will build up. Also measurement of temperature at the water heater draft hood is not feasible, proposed under the expired Universal Vent patent no. 4,768,444, as the high-efficiency furnace flue gas temperatures were often cooler than warm air wafting through the water heater central flue. Suggested methods of detection within the water heater vent connector are (a) static pressure measurement, to ensure drafting of dilution air as indicated by negative differential pressures referencing the indoor space and (b) CO₂/O₂ sensors in the vent connector detecting departures from ambient conditions when the water heater is not firing, provided long-life reliable gas sensors are available. Concerning the former, where negative static pressures are measured in the water heater vent connector during all tests with acceptable venting, positive pressures are observed during all blocked vent tests, even at 50% blockage where adequate venting is observed. Therefore a static pressure measurement that will detect this neutral dilution condition, where neither dilution nor spillage occurs which proceeds unstable venting and then spillage, provides a conservative strategy to disable a furnace with a blocked vent prior to spillage.

Potential Next Steps

While the current set of Universal Vent test results show adequate venting performance under progressively more challenging conditions than prior 2010 testing, the following next steps are suggested to continue vetting this concept:

- Under some test conditions, the Type B common vent had positive static pressure. Identify design changes to Universal Vent and/or vent system restrictions (e.g. common vent height) that maintain negative pressures within the common vent.
- Evaluate methods of detecting a blocked vent to assure effective control while minimizing nuisance shutoffs.
- Demonstrate acceptable venting under typical ambient conditions for the heating season.
- Solicit review of vent manufacturers and identify remaining technical and market barriers.

References

1. Department of Energy, Energy Information Administration. *Residential Energy Consumption Survey*, 2009 ed. <http://www.eia.doe.gov/emeu/recs/contents.html>
2. Air Conditioning, Heating, Refrigeration (ACHR) News, “DOE Finalizes Regional Standards”, Published 11/14/11, <http://www.achrnews.com/articles/print/118250-doe-finalizes-regional-standards>.
3. Consortium for Energy Efficiency. *CEE Residential Gas Heating Initiative: High Efficiency Specifications for Gas Furnaces and Boilers*, 2010. http://www.cce1.org/gas/gs-ht/gas_heat_specs.pdf
4. Talbert, S; Saunders, J; and Paul, D. *Universal Vent Systems for High-Efficiency Furnaces and Draft Hood Water Heaters*. Battelle Columbus Laboratories for Gas Technology Institute (2002).
5. National Fire Protection Association. *NFPA 54: National Fuel Gas Code*, ANSI Z223.1, 2012 ed.
6. U.S. Patent 4,768,444, *Common Vent Device for Positive Vent Pressure and Draft Hood Equipped Gas Appliances*, Issued September 6th, 1988. Inventors: DeWerth, D.; Deppisch, J.; Talbert, S.; and Cudnik, R. Assignee: Gas Research Institute.

Appendix A: Data Summary from 2010 GTI Testing

Table 11: Summary of Data from Universal Vent Laboratory Tests

Test	Operational State		Flue Pressures (" WC)			Temperatures (°F)			Flue Gas Analysis			Lab Conditions	
	Furnace	Water Heater	Exit	Tee	Water Heater*	Exit	Furnace	Water Heater	Gas Species	Furnace	Water Heater	Room Temp	RH
1	High	On	0.0027	0.0124	-0.0156	163.2	108.3	278.8	NO	73 ppm	39 ppm	76.7 °F	35%
									CO	31 ppm	16 ppm		
									CO2	5.89%	3.89%		
									O2	10.95%	14.52%		
2	Low	On	0.0029	0.0108	-0.0138	163.9	101.6	284.7	NO	32 ppm	40 ppm	77.0 °F	34%
									CO	112 ppm	18 ppm		
									CO2	4.41%	3.99%		
									O2	13.61%	14.35%		
3	Off	On	0.0051	0.0219	-0.0208	200.4	83.9	268.6	NO	1 ppm	42 ppm	77.0 °F	35%
									CO	2 ppm	16 ppm		
									CO2	0.07%	3.63%		
									O2	21.21%	15.01%		
4	High	Stand-by	0.0003	0.0045	-0.0066	99.6	106.9	94.0	NO	72 ppm	0 ppm	74.5 °F	37%
									CO	30 ppm	2 ppm		
									CO2	5.97%	0.09%		
									O2	10.88%	21.19%		
5	Low	Stand-by	0.0010	0.0022	-0.0053	97.5	101.8	95.5	NO	35 ppm	1 ppm	74.9 °F	37%
									CO	96 ppm	4 ppm		
									CO2	4.42%	0.12%		
									O2	13.58%	21.12%		
6	High	Off	0.0012	0.0052	-0.0085	100.3	108.8	90.2	NO	73 ppm	1 ppm	76.5 °F	36%
									CO	31 ppm	2 ppm		
									CO2	5.93%	0.05%		
									O2	10.89%	21.26%		

* Negative pressures reflect conditions as measured

Appendix B: Instrumentation Summary

Table 12: Summary of Laboratory Instrumentation

Measured Media	Quantity/Units	Measurement Point	Instrument Type	Manufacturer, Model	Accuracy
Air	Temperature, °F	Ambient, Laboratory	Thermistor	Vaisala HUMICAP	± 0.75%
	Relative Humidity, %RH		Thin-film capacitance probe		±1.7 %RH
	Pressure, hPa	Ambient, Laboratory	Electronic Barometric Pressure Transducer	Cole Parmer	± 0.3 hPa
	Wind Speed	Ambient, Roof	Cup Anemometer	Vaisala WMS301	± 0.3 m/s (± 0.6 mph)
	Wind Direction				± 3°
Natural Gas	Temperature, °F	Fuel Inlet, Water Heater & Furnace	Thermocouple, J-Type	Omega J-Type 1/8" OD	± 0.75%
	Volume Consumed, ft ³		Diaphragm Gas Meter*	METRIS, 250	40 pulses/ft ³
	Pressure, " W.C.	Fuel Pressure at Main	Mechanical Pressure Gauge	Miljoco	± 1%
	Fuel Speciation & HHV	Batch sample onsite	GTI Analytical Laboratory	n/a	n/a
Flue Gases	Temperature, °F	Vent Connector, Water Heater & Furnace	Thermocouple, T-Type	Omega, T-Type 1/8" OD	± 0.75%
		Common Vent, Multiple Elevations	Thermocouple, T-Type	Omega, T-Type 1/8" OD	± 0.75%
	Pressure, " W.C.	Vent Connector, Water Heater & Furnace	Digital Manometer with pitot tube, static pressure	Dwyer, DM-2000 Series (various ranges)	± 1.0% at Full Scale
		Common Vent, Multiple Elevations			
CO, CO ₂ , O ₂ , NO, NO ₂	Vent Connector, Water Heater & Furnace	Gas Analysis Rack	Various	± 1% (as calibrated)	

* Rotameter used for measurement of pilot light natural gas flow

Appendix C: Laboratory and Ambient Conditions during Testing

Table 13: Summary of Laboratory and Ambient Conditions

Test	Furnace Type	Unit Operational State		Vent Exit Conditions	Ambient Conditions			Wind Conditions		
		Furnace	Water Heater		Room Temp. (°F)	Outdoor Temp. (°F)	Outdoor RH (%)	Windspeed, Average (mph)	Windspeed, Maximum (mph)	Direction (0° is South)
1	Modulating	Max	On	Wind Applied	75.1	65	39%	9.5	10.7	352
2	Modulating	Mid	On		71.6	66	47%	6.8	10.7	206
3	Modulating	Min	On		73.9	65	39%	9.6	11.0	353
4	Modulating	Max	Standby		75.3	67	37%	8.9	11.0	352
5	Modulating	Mid	Standby		70.8	66	47%	6.6	9.0	237
6	Modulating	Min	Standby		74.7	65	39%	9.4	11.0	353
7	Modulating	Max	Standby	No Wind	76.9	65	45%	1.7	4.8	324
8	Modulating	Max	Off		77.4	67	42%	1.9	6.3	318
9	Modulating	Min	Standby		73.3	63	50%	1.0	2.9	345
10	Modulating	Min	Off		71.4	63	48%	1.0	3.8	316
11	Modulating	Off	On	Wind Applied	74.0	64	38%	9.5	11.0	354
12	Modulating	Off	Standby		74.6	64	38%	9.5	10.7	354
13	Single Stage	On	Standby	Blocked Vent	80.4	80.5	37%	1.8	5.9	302
14	Single Stage	On	Off		81.5	81.0	32%	2.8	9.5	292