Building AMERICA
U.S. Department of Energy

PARR
The Partnership for Advanced Residential Retrofit

NorthernSTAR
A Building America partner in research, innovation, and real home solutions.

Combustion Safety Webinar

12/16/15

Larry Brand – Gas Technology Institute

Dave Bohac – Center for Energy and Environment

Acknowledgements

- Several other organizations doing important work in this area:
  - ISTC – Paul Francisco
  - Seventhwave – Dan Cautley
  - LBNL – Brett Singer et. al.
  - CEE – Jim Fitzgerald
  - American Gas Association
  - AHRI
  - BPI
  - RESNET

Agenda

1. Introduction
2. Indoor air measure guideline
3. Outdoor air measure guideline
4. Recent research
    1. Introduction – Combustion Safety Simplified Test Procedure
    2. Survey results
    3. Short term test and monitoring
5. Looking forward - harmonization
6. Q&A

Introduction - What is Combustion Safety?

- Generally refers to natural draft appliances creating a draft in the vent within a short time period after ignition, i.e., no excessive spillage
- Also applies to common vented fan-assisted and draft hood appliances – no flow from one to the other
- Good practice means that the appliance(s) are properly installed and operating
  - Sufficient air for combustion and dilution
  - Vent is properly sized and installed
  - CO within safety certification limits

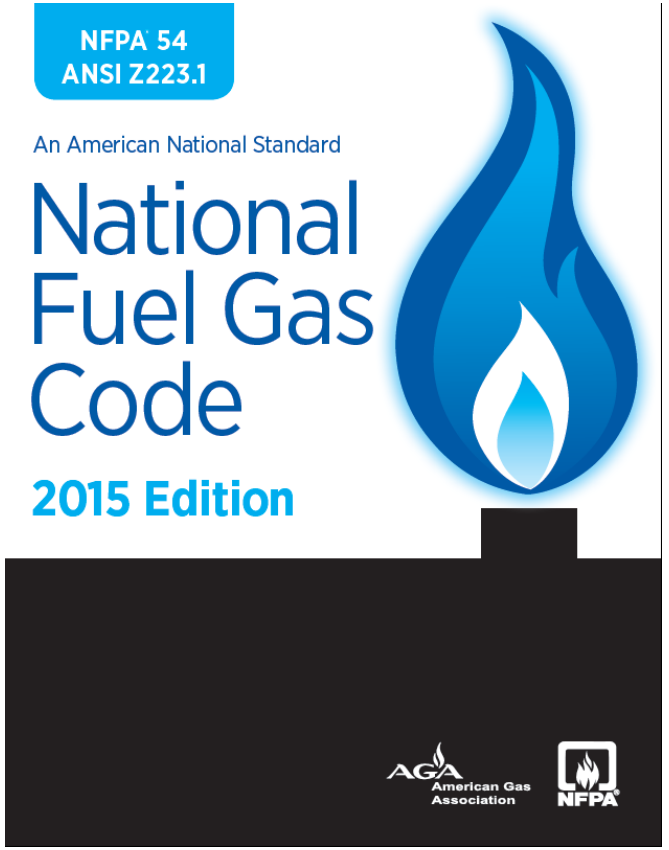
Start with the Code

Combustion air requirements and vent sizing tables the same in all model fuel gas installation codes

ANSI Standard since 1974

All Category I appliances

2015 Update to Annex G



Code enforceable when adopted by the authority having jurisdiction.

Category I Natural Gas Appliances

- Fan-assisted or draft-hood equipped
- Negative vent pressure
- Not condensing

Check the Label

U.S. Manufacturing Company, Inc.

Certified as a forced air furnace **CAT I**

Equipped for use with natural gas at altitudes from 0 to 2000 ft. above sea level

Installation only in buildings constructed on site.

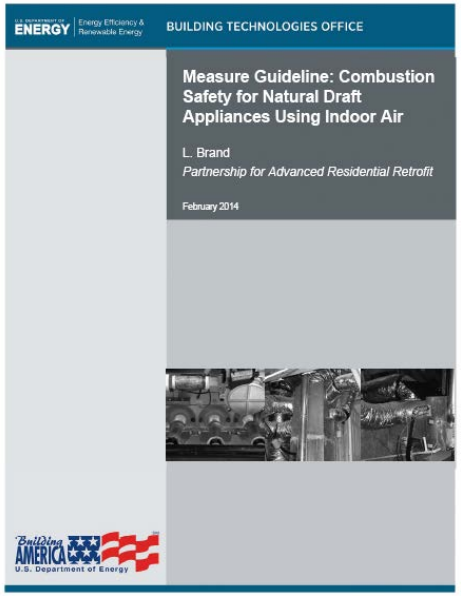
Model No.	CSX123-4	
Serial No.	1234567890	
Power Supply	115 V	
	Natural Gas	**LP Gas**
Heating Input Rating	100,000	80,000
Output Capacity	80,000	60,000
Temperature Rise	35 – 65	35 – 65

- Draft-hood equipped water heaters are not categorized, but are considered Category I appliances for venting and combustion safety

The Equipment was Properly Installed

1. Clearances to combustible materials
2. Combustion air requirements
3. Testing

>Focus on #2 and #3



Building America Measure Guidelines

Air

9.3* Air for Combustion and Ventilation.

9.3.1 General.

9.3.1.1 Air for combustion, ventilation, and dilution of flue gases for appliances installed in buildings shall be obtained by application of one of the methods covered in 9.3.2 through 9.3.6. Where the requirements of 9.3.2 are not met, outdoor air shall be introduced in accordance with methods covered in 9.3.3 through 9.3.6.

Exception No. 1: This provision shall not apply to direct vent appliances.

Exception No. 2: Type 1 clothes dryers that are provided with makeup air in accordance with Section 10.4.3.

9.3.1.2 Appliances of other than natural draft design and other than category I vented appliances shall be provided with combustion, ventilation and dilution air in accordance with the appliance manufacturer's instructions.

9.3.1.3 Appliances shall be located so as not to interfere with proper circulation of combustion, ventilation, and dilution air.

9.3.1.4 Where used, a draft hood or a barometric draft regulator shall be installed in the same room or enclosure as the appliance served so as to prevent any difference in pressure between the hood or regulator and the combustion air supply.

9.3.1.5 Where exhaust fans, clothes dryers, and kitchen ventilation systems interfere with the operation of appliances, makeup air shall be provided.

Combustion Air from Indoors, part 1

9.3.2 Indoor Combustion Air. The required volume of indoor air shall be determined in accordance with method 9.3.2.1 or 9.3.2.2 except that where the air infiltration rate is known to be less than 0.40 *ACH*, the method 9.3.2.2 shall be used. The total required volume shall be the sum of the required volume calculated for all appliances located within the space. Rooms communicating directly with the space in which the appliances are installed through openings not furnished with doors, and through combustion air openings sized and located in accordance with 9.3.2.3, are considered a part of the required volume.

9.3.2.1* Standard Method: The minimum required volume shall be 50 ft^3 per 1,000 Btu/hr (4.8 m^3/kW).

More than 0.4 ACH (natural)?
Standard Method: 50 ft^3 per 1000 Btu/hr

Example:
120,000 Btu/hr requires
50*120 = 6000 ft^3
Or 750 sq. ft. with 8 ft. ceilings.

Combustion Air from Indoors, part 2

9.3.2.2* Known Air Infiltration Rate Method: Where the air infiltration rate of a structure is known, the minimum required volume shall be determined as follows:

(1) For appliances other than fan-assisted: calculated using the following equation:

$$\text{Required volume}_{other} \geq \frac{21 ft^3}{ACH}\left(\frac{I_{other}}{1{,}000\ Btu/hr}\right)$$

(2) For fan-assisted appliance, calculate using the following equation:

$$\text{Required volume}_{fan} \geq \frac{15 ft^3}{ACH}\left(\frac{I_{fan}}{1{,}000\ Btu/hr}\right)$$

where:

I_{other} = *all appliances other than fan-assisted input in Btu per hour*

I_{fan} = *fan-assisted appliance input in Btu per hour*

ACH = *air change per hour* (percent of volume of space exchanged per hr, expressed as a decimal)

(3) For purposes of this calculation, an infiltration rate greater than 0.60 *ACH* shall not be used in equations in 9.3.2.2 (1) and 9.3.2.2 (2).

Less than 0.4 ACH (natural)?
Known AIR Method:
Other than fan-assisted use 21 ft^3 per ACH.
Fan assisted 15 ft^3 per ACH

Example: (0.3 ACH)
120,000 Btu/hr natural draft requires 8,400 ft^3 or 1050 sq. ft. with 8 ft. ceilings
With fan assisted requires 6000 ft^3 or 750 sq. ft. with 8 ft. ceilings

CO is Within Limits

Use the ANSI Safety Certification Limits

Make the air-free adjustment

(Based on NFGC 2012 Annex G, with permission from American Gas Association)

Appliance	Threshold Limit
Central Furnace (all categories)	400 ppm[1] air free[2,3]
Floor Furnace	400 ppm air free
Gravity Furnace	400 ppm air free
Wall Furnace (BIV)	200 ppm air free
Wall Furnace (Direct Vent)	400 ppm air free
Water Heater	200 ppm air free

[1] Parts per million

[2] Air free emission levels are based on a mathematical equation (involving carbon monoxide and oxygen or carbon dioxide readings) to convert an actual diluted flue gas carbon monoxide testing sample to an undiluted air free flue gas carbon monoxide level utilized in the appliance certification standards. For natural gas or propane, using
as-measured CO ppm and O2 percentage:

$$CO_{AFppm} = \left(\frac{20.9}{20.9 - O_2}\right) \times CO_{ppm}$$

Where:

CO_{AFppm} = Carbon monoxide, air-free ppm

CO_{ppm} = As-measured combustion gas carbon monoxide ppm
O_2 = Percentage of oxygen in combustion gas, as a percentage

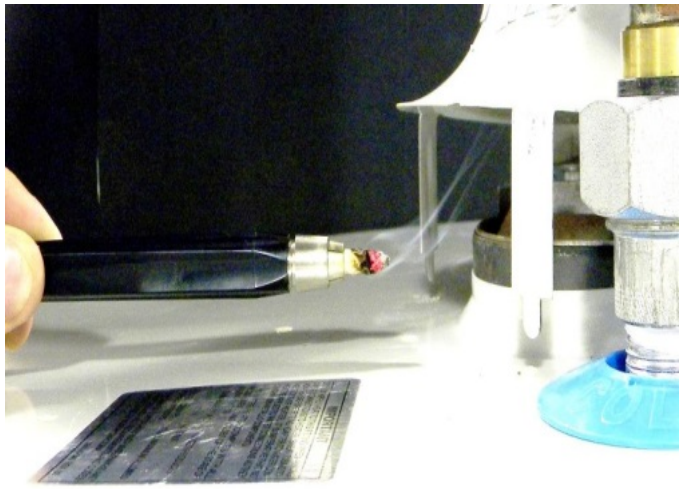
[3] An alternate method of calculating the CO air free when access to an oxygen meter is not available:

$$CO_{AFppm} = \left(\frac{UCO_2}{CO_2}\right) \times CO$$

Where:
UCO_2 = Ultimate concentration of carbon dioxide for the fuel being burned in percent for natural gas (12.2 percent) and propane (14.0 percent)
CO_2 = Measured concentration of carbon dioxide in combustion products in percent
CO = Measured concentration of carbon monoxide in combustion products in percent

Vent Sizing

- Most combustion safety incidents are related to poor sizing/installation practice
- The venting tables in the code have been around since the 1950's with an update in the 1980's
  - Time-tested
  - Will solve most problems



Venting Tables

Example:

- 100,000 Btu/hr furnace
- 40,000 Btu/hr water heater
- Common vented
- Type B double wall vent
- Type B double wall connector
- 2 ft rise
- 20 ft common vent height

Result:

- 4 inch vent connector for water heater,
- 5 inch vent connector for furnace

Table 13.2(a) Type B Double-Wall Vent

Number of Appliances:	Two or More
Appliance Type:	Category I
Appliance Vent Connection:	Type B Double Wall Connector

Vent CONNECTOR Capacity

Height H (ft)	Rise R (ft)	Type B Double-Wall Connector Diameter — D in.																					
		3			4			5			6			7			8			9			10		
		Appliance Input Rating Limits in Thousands of Btu per Hour																					
		FAN		NAT	FAN		NAT	FAN		NAT	FAN		NAT	FAN		NAT	FAN		NAT	FAN		NAT	FAN		NAT
		Min	Max	Max	Min	Max	Max	Min	Max	Max	Min	Max	Max	Min	Max	Max	Min	Max	Max	Min	Max	Max	Min	Max	Max
6	1	22	37	26	35	66	46	46	106	72	58	164	104	77	225	142	92	296	185	109	376	237	128	466	289
	2	23	41	31	37	75	55	48	121	86	60	183	124	79	253	168	95	333	220	112	424	282	131	526	345
	3	24	44	35	38	81	62	49	132	96	62	199	139	82	275	189	97	363	248	114	463	317	134	575	386
8	1	22	40	27	35	72	48	49	114	76	64	176	109	84	243	148	100	320	194	118	408	248	138	507	303
	2	23	44	32	36	80	57	51	128	90	66	195	129	86	269	175	103	356	230	121	454	294	141	564	358
	3	24	47	36	37	87	64	53	139	101	67	210	145	88	290	198	105	384	258	123	492	330	143	612	402
10	1	22	43	28	34	78	50	49	123	78	65	189	113	89	257	154	106	341	200	125	436	257	146	542	314
	2	23	47	33	36	86	59	51	136	93	67	206	134	91	282	182	109	374	238	128	479	305	149	596	372
	3	24	50	37	37	92	67	52	146	104	69	220	150	94	303	205	111	402	268	131	515	342	152	642	417
15	1	21	50	30	33	89	53	47	142	83	64	220	120	88	298	163	110	389	214	134	493	273	162	609	333
	2	22	53	35	35	96	63	49	153	99	66	235	142	91	320	193	112	419	253	137	532	323	165	658	394
	3	24	55	40	36	102	71	51	163	111	68	248	160	93	339	218	115	445	286	140	565	365	167	700	444
20	1	21	54	31	33	99	56	46	157	87	62	246	125	86	334	171	107	436	224	131	552	285	158	681	347
	2	22	57	37	34	105	66	48	167	104	64	259	149	89	354	202	110	463	265	134	587	339	161	725	414
	3	23	60	42	35	110	74	50	176	116	66	271	168	91	371	228	113	486	300	137	618	383	164	764	466
30	1	20	62	33	31	113	59	45	181	93	60	288	134	83	391	182	103	512	238	125	649	305	151	802	372
	2	21	64	39	33	118	70	47	190	110	62	299	158	85	408	215	105	535	282	129	679	360	155	840	439
	3	22	66	44	34	123	79	48	198	124	64	309	178	88	423	242	108	555	317	132	706	405	158	874	494
50	1	19	71	36	30	133	64	43	216	101	57	349	145	78	477	197	97	627	257	120	797	330	144	984	403
	2	21	73	43	32	137	76	45	223	119	59	358	172	81	490	234	100	645	306	123	820	392	148	1014	478
	3	22	75	48	33	141	86	46	229	134	61	366	194	83	502	263	103	661	343	126	842	441	151	1043	538
100	1	18	82	37	28	158	66	40	262	104	53	442	150	73	611	204	91	810	266	112	1038	341	135	1285	417
	2	19	83	44	30	161	79	42	267	123	55	447	178	75	619	242	94	822	316	115	1054	405	139	1306	494
	3	20	84	50	31	163	89	44	272	138	57	452	200	78	627	272	97	834	355	118	1069	455	142	1327	555

Measure Guideline: Combustion Safety for Natural Draft Appliances Through Appliance Zone Isolation

Dave Bohac
Jim Fitzgerald

Center for Energy and Environment

http://www.nrel.gov/docs/fy14osti/61295.pdf?gathStatIcon=true

Appliance Zone Isolation

Natural draft appliances located in an enclosed area

- Physical separation from living space
  - Mechanical closets
  - Attached garages
  - Attics
- Proper air barrier isolates appliances from house depressurization
- Combustion air from outside

Eliminates need for depressurization combustion spillage testing

Five Steps

1. Combustion venting system complies with manufacturer's specifications and local codes.
2. Air seal the physical boundary to ensure that it is airtight to the living space.
3. Seal all ducts and cabinet leakage located in the zone.
4. Provide code required outside combustion air openings.
5. Remove all exhaust devices located in the area that can depressurize the zone or provide makeup air if there is a clothes dryer in the isolated zone.

2. Air Sealing the Enclosure

Make the boundary airtight

- Fill in large openings with ½" gypsum.
- Seal all joints, seams, and penetrations between the zone and living space with joint tape, sealant foam listed for use as a firestop and approved for uncovered use, or sealant caulk (see IRC 314.6).
- Door to house: weatherstrip, door sweep, self-closing/latching.
- Louvered door: replace or block off louvers

3. Duct and Cabinet Sealing

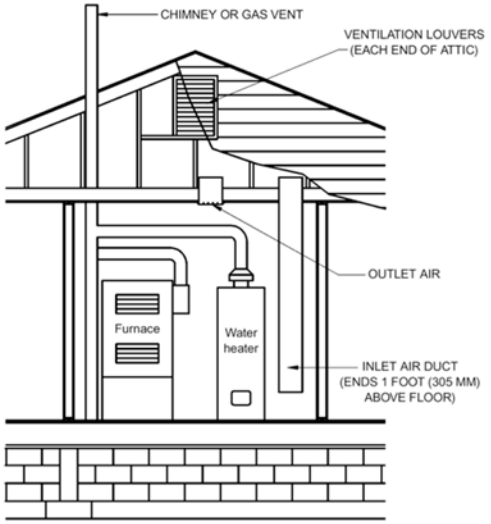
Seal joints, penetrations, openings in the ducts and cabinet

- Continuous, sealed duct from living space to blower housing.
  - Duct area = return inlet or at least 2 sq in/1,000 Btu output (Proctor, Chitwood, & Wilcox).
  - Mechanically fasten duct to blower housing
- Tape all cabinet service openings/joints.
- Seal all joints and seams with mastic and mesh tape (UL181-M) or foil tapes (UL 181 A-P and UL 181 B-FX).
- No return air from the space.

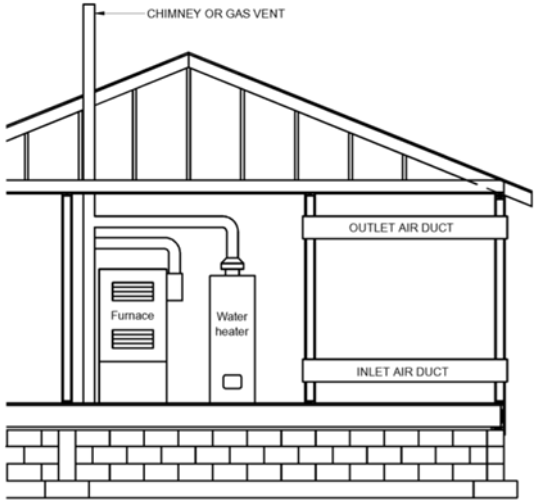
4. Combustion Air From Outside

Meet National Fuel Gas Code requirements: <u>two</u> openings

> Within 12” top and 12” bottom.



Direct/vertical: 1 sq in/4,000 Btu/hr input

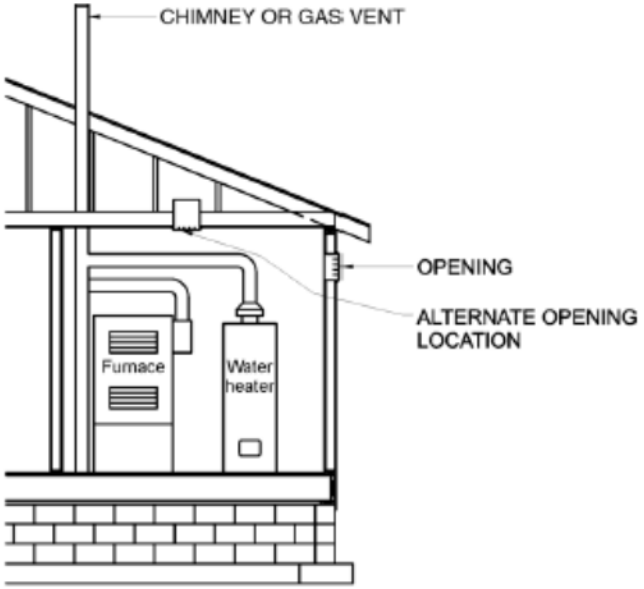


Horizontal: 1 sq in/2,000 Btu/hr input

4. Combustion Air From Outside

Meet National Fuel Gas Code requirements: one opening

> Within 12” top.



1 sq in/3,000 Btu/hr input
Not less than sum of vent connectors

Consider effect of louvers, screens, or grilles
No label? Assume 75% metal louver & 25% wood.

5. Make Up Air and Exhaust Fans

Remove or provide make up air

- Dryers:
  - 100 sq in opening
  - Can include damper with interlock
- All other exhaust fans should be removed.
- Attic: remove or disconnect powered attic fans or provide additional air inlets for fan.

Field Confirmation

- Visual inspection of air handler.
- Smoke-test duct and cabinet leakage.
  - Fan pressurization to 25 Pa
  - Theatrical fog into system
  - Seal leaks where fog comes out
- Isolation pressure test.
  - Depressurization < 5 Pa with house at 50 Pa
  - Depressurization with HVAC operation < 1 Pa
  - Depressurization with dryer < 2.5 Pa
  - Garage depressurization w/fan < 2.5 Pa

Case Studies

Measure Guideline provides case studies

- Attic furnace.
- Attached garage.
- Mechanical closet.
  - Door to bedroom or bathroom
  - Building cavity used as return

Key Detail: Return Platform

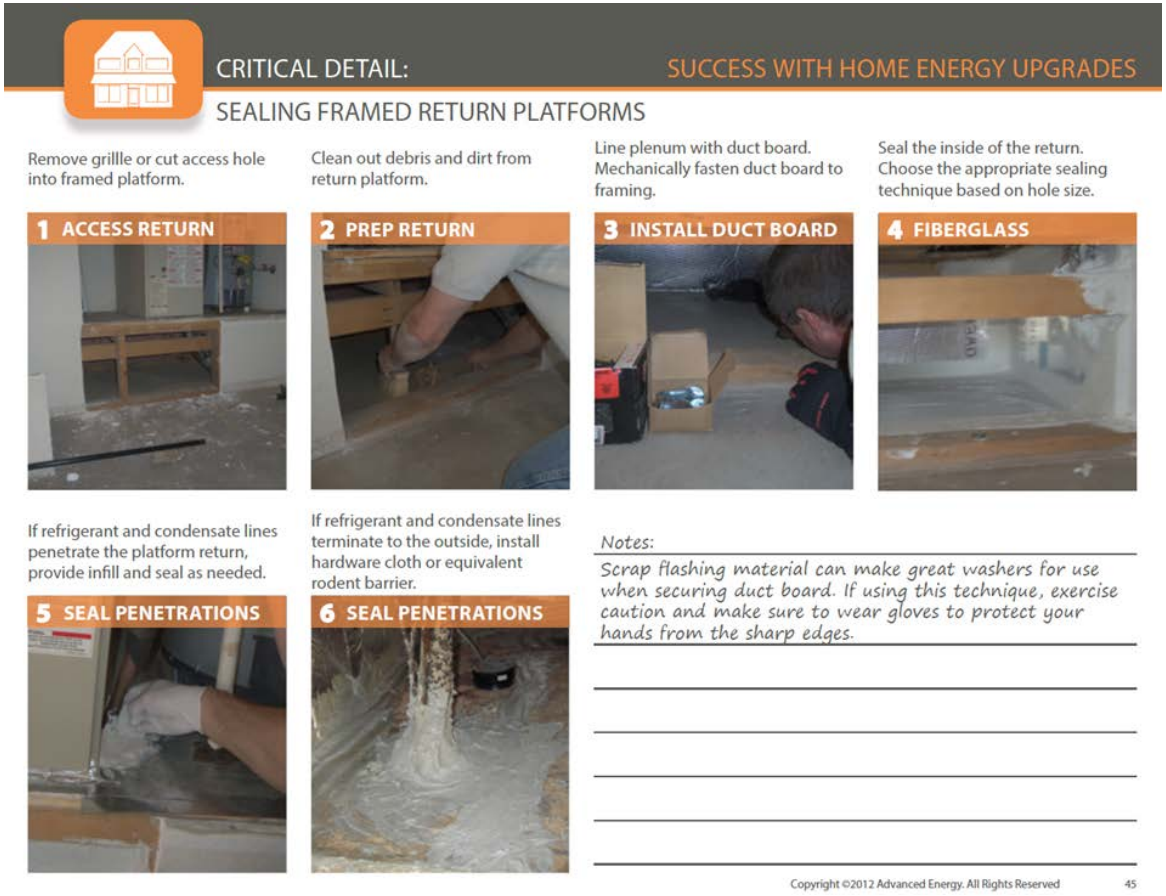


Illustration by Ray David, NREL/PIX 19500.
Photos from Warren Gretz (NREL/PIX 10929) and Iberdola Renewables Inc. (NREL/PIX 15185)

Appliance Zone Isolation

- Prescriptive measures to isolate space and provide combustion air & venting
- Inspections and tests to confirm proper isolation
- Protects natural draft appliances from house depressurization
- Eliminates need for depressurization combustion spillage testing

Recent BA Research

Field Test Procedures

Is setting up worst-case depressurization really necessary to catch combustion safety failures?

How about a simplified test procedure that has fewer false positives?

> Building America sponsored field research

Research Scope

- Survey of field experience
- Field testing
  - Simplified test procedure
    - Fixed door positions
    - Air handler on if it reduces indoor pressure
    - Clothes dryer on
  - Sites selected based on
    - Must fail criteria – Kitchen fan on high; next largest fan on; continuous spillage after set time
    - Must pass criteria – Kitchen fan on high or low; next largest fan on or off; no spillage after set time

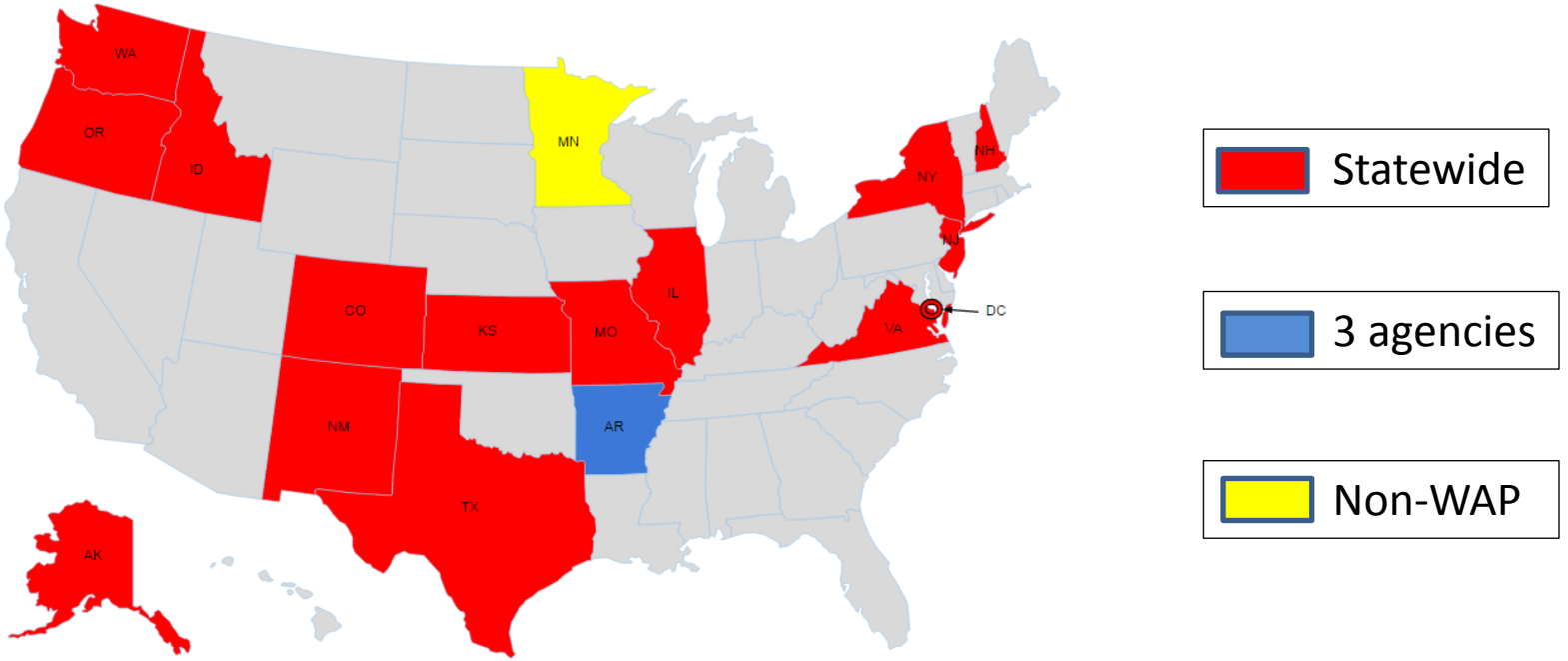
BA CS Simplified Test Procedure

- Setup –
  - Keep doors open if there is a return or exhaust in the room, otherwise close them
  - Turn on all exhausts* including dryer
  - Check with and without air handler on
  - Check with and without CAZ door open
- Test for spillage - beyond
  - 2 minutes for water heaters and furnaces in heating mode
  - 5 minutes for furnaces not in heating mode
- Check CO against ANSI certification standards

Recent Research - Survey

ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

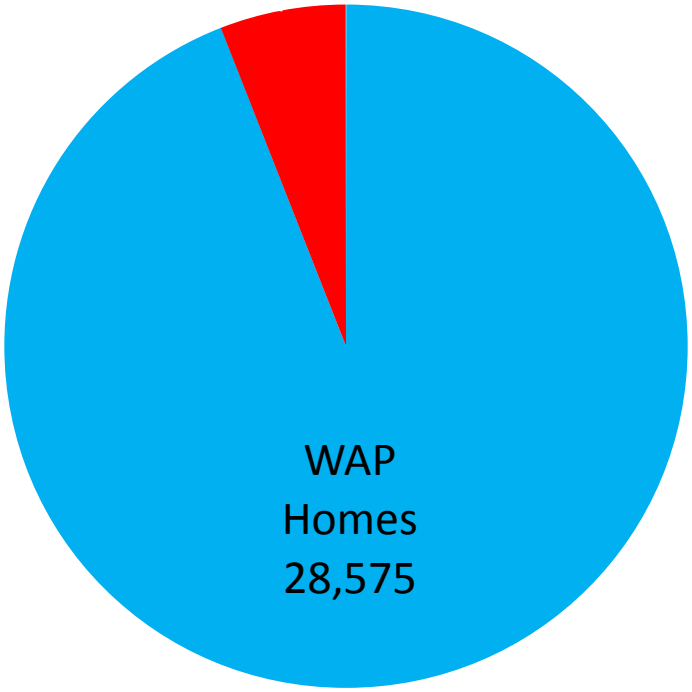
- How common are combustion safety failures?
- NASCSP Disseminated – National Association for State Community Services Programs



Survey – Parts 1&2

- Asked questions about housing (last program year)
  - How many homes treated?
  - How many use fossil fuels?
  - How many have natural draft appliances in the pressure boundary?
- Asked about test procedure – BPI, other?
- For those that failed:
  - How many due to air handler operation?
  - How many due to exhaust operation, including dryer?
  - How many had a new appliance installed to address the issue?
  - How many had a Power Vent kit installed to address the issue?
  - How many were deferred because of the issue?

Survey Results – Number of Homes



Total 30,385 Homes; 78% Oil, gas, propane

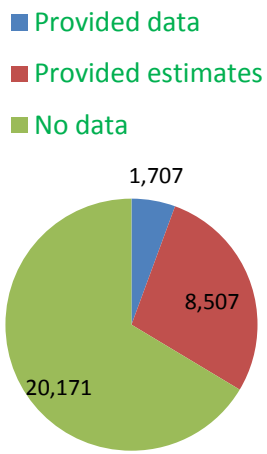
- Weatherization Assistance Program (WAP) Homes were 94% of sample
- Total 30,385 Homes
- One state did not answer further questions, saying the data were not tracked
  - this reduces that WAP sample by 213 homes (28,362 WAP homes, 30,172 total homes remaining)

Survey Results – Appliance Location

- Six (6) states that provided estimates report 41% of homes had natural draft appliances within the pressure boundary
- Four (4) states that provided precise values report 81% of homes had natural draft appliances within the pressure boundary
- Seven (7) states do not track this information
- Difference likely related to geography

Survey Results – Failure Rates

- States with data (4 states)
  - 4.3% (74 of 1,707 homes) got remediation due to EXPECTED failures
  - 5.4% (92 of 1,707 homes) got remediation due to OBSERVED spillage



- States with estimates (5 states)
  - 6% (~513 of 8,507 homes) got remediation due to EXPECTED failures
  - 16% (~1,351 of 8,507 homes) got remediation due to OBSERVED spillage
    - AK said 40-50%
    - Excluding AK, about 8%

Survey Results – Failure Causes

- States with data
  - 4% (73 of 1,707 homes) failed because of air handler operation
  - 4% (39 of 967 homes) failed due to exhausts (including dryers)
- States with estimates
  - 6.5% (~374 of 5,757 homes) failed because of air handler operation
  - 18% (~1,043 of 5,757 homes) failed due to exhausts (including dryers)

Survey Results – Failure Causes

- Compared to states providing precise data, states providing estimates
  - estimated that homes fail spillage tests at a higher rate
  - estimated that exhausts are more frequently the cause
- Could be correct – small samples, geographic differences
- Some states volunteered that many/most failures due to:
  - Improper flue sizing
  - Crushed roof cap
  - Air handler operation
  - Dryer operation

Survey Results – Remediation

- States with data
  - 31 of 967 homes got a new appliance (3.2%)
- States with estimates
  - Excluding Alaska, 150 of 6,507 homes got a new appliance (2.3%)
  - Alaska estimated about 60%.

Power vent kits installed in only about 17 of about 9,000 homes (< 0.2%)

Only 6 homes (one agency) reported to have been deferred

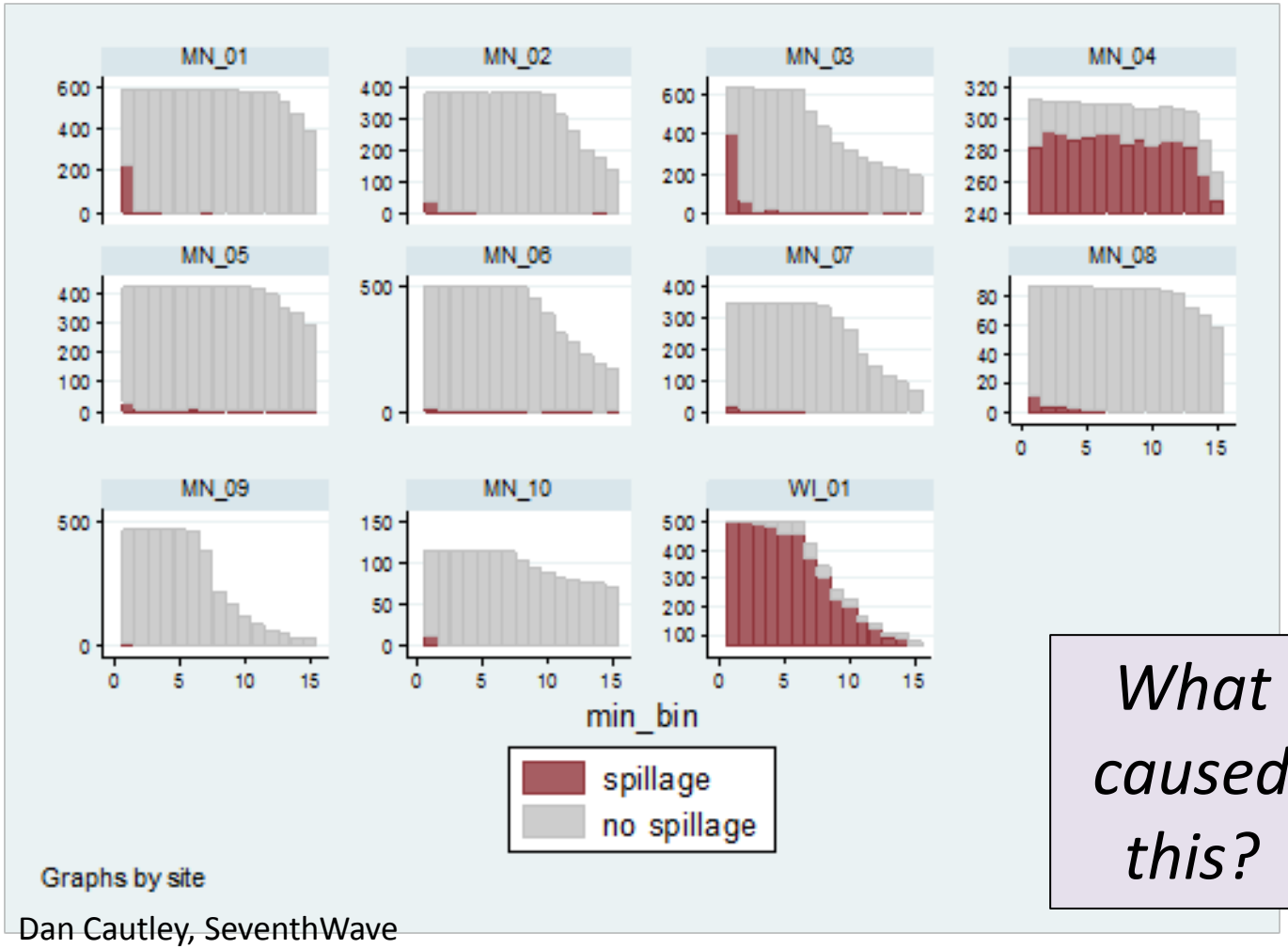
Survey Conclusions

- Combustion safety failures not as common as expected
- Combustion safety failures not often due to exhaust fans
  - Usually air handlers or dryers or vent failures
- Very little actual tracking of this information (great opportunity?)

Field Study

- 11 homes, MN and WI
- Atmospheric draft natural gas water heaters in basements
- Spillage test:
  - Fail: “simplified” depressurization conditions at 2 minutes
  - Pass: kitchen fan to low & other exhaust fans off
- Measured or observed
  - Burner operation (via temperature)
  - CO_2 near draft hood (as indicator of spillage)
  - Pressures and fan status
- Data collection for 3 to 6+ months, 1500 days of data

Spillage by minute of operation, by site



What caused this?

Dan Cautley, SeventhWave

Two sites showed excessive spilling

Both systems had venting defects:

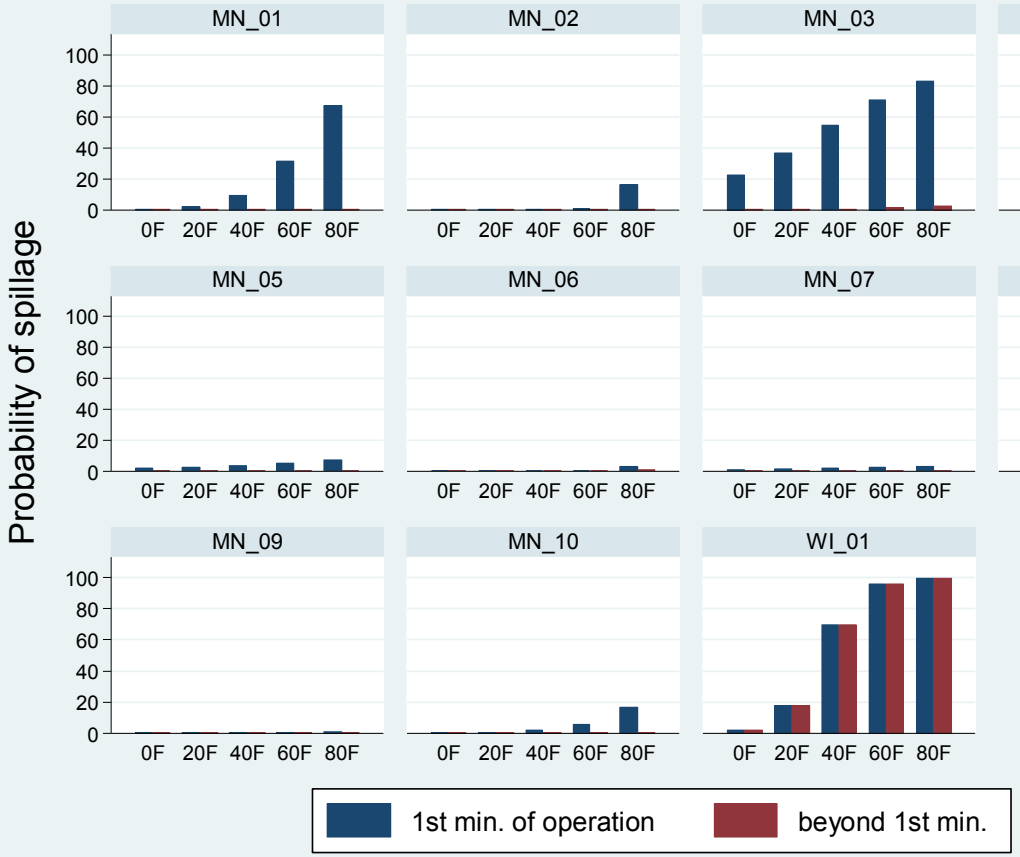
- MN_04 had an undersized water heater vent (vent capacity = 75% of burner input)

3” vent, 6’ run, 4 elbows

- WI_01 had a large opening downstream of the water heater (unused, partially repaired connection for a furnace)

Water heater and unused furnace vent

Effect of first minute of operation and outdoor temperature

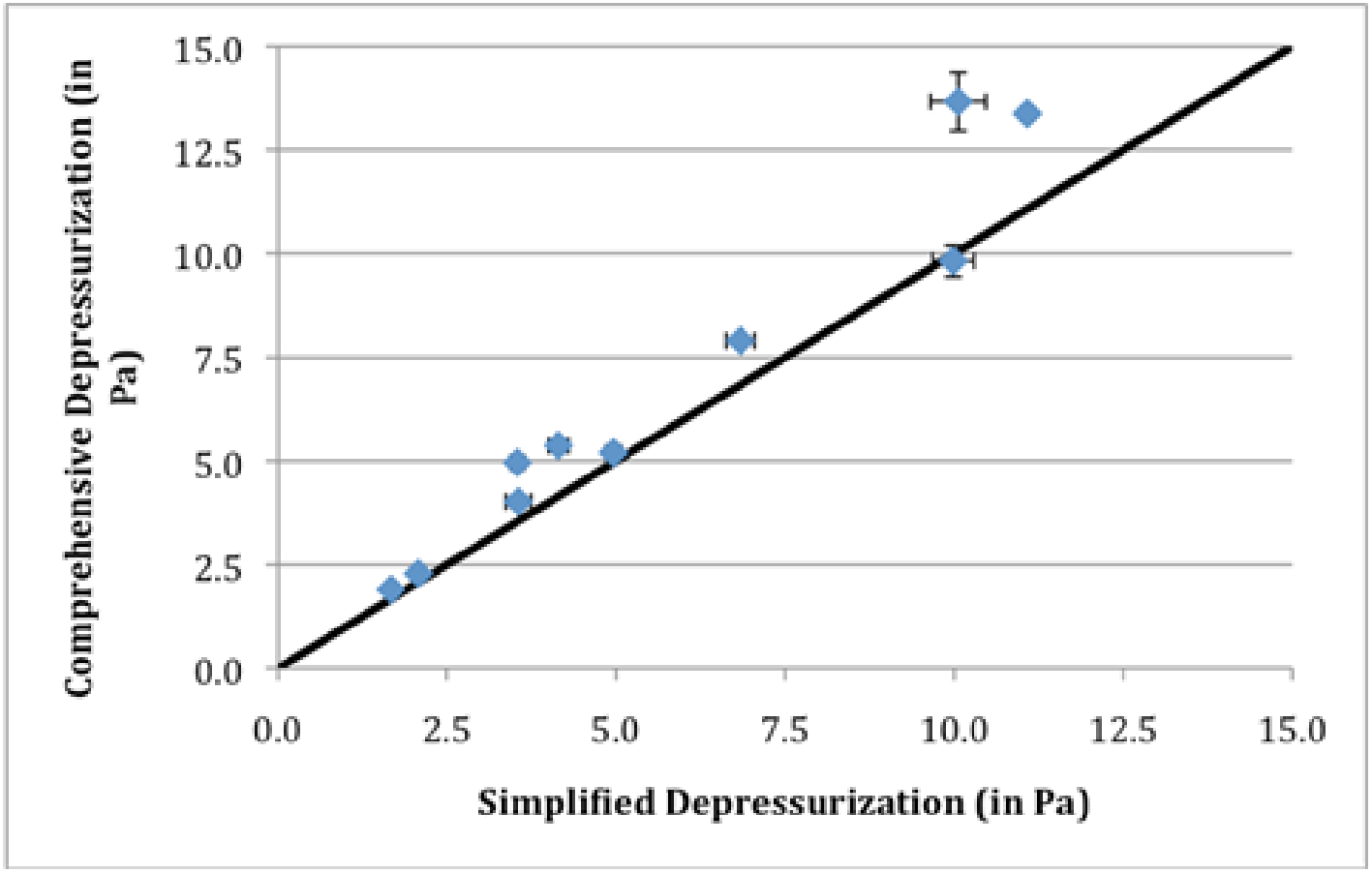


Estimated probabilities from logistic regression model

Dan Cautley, SeventhWave

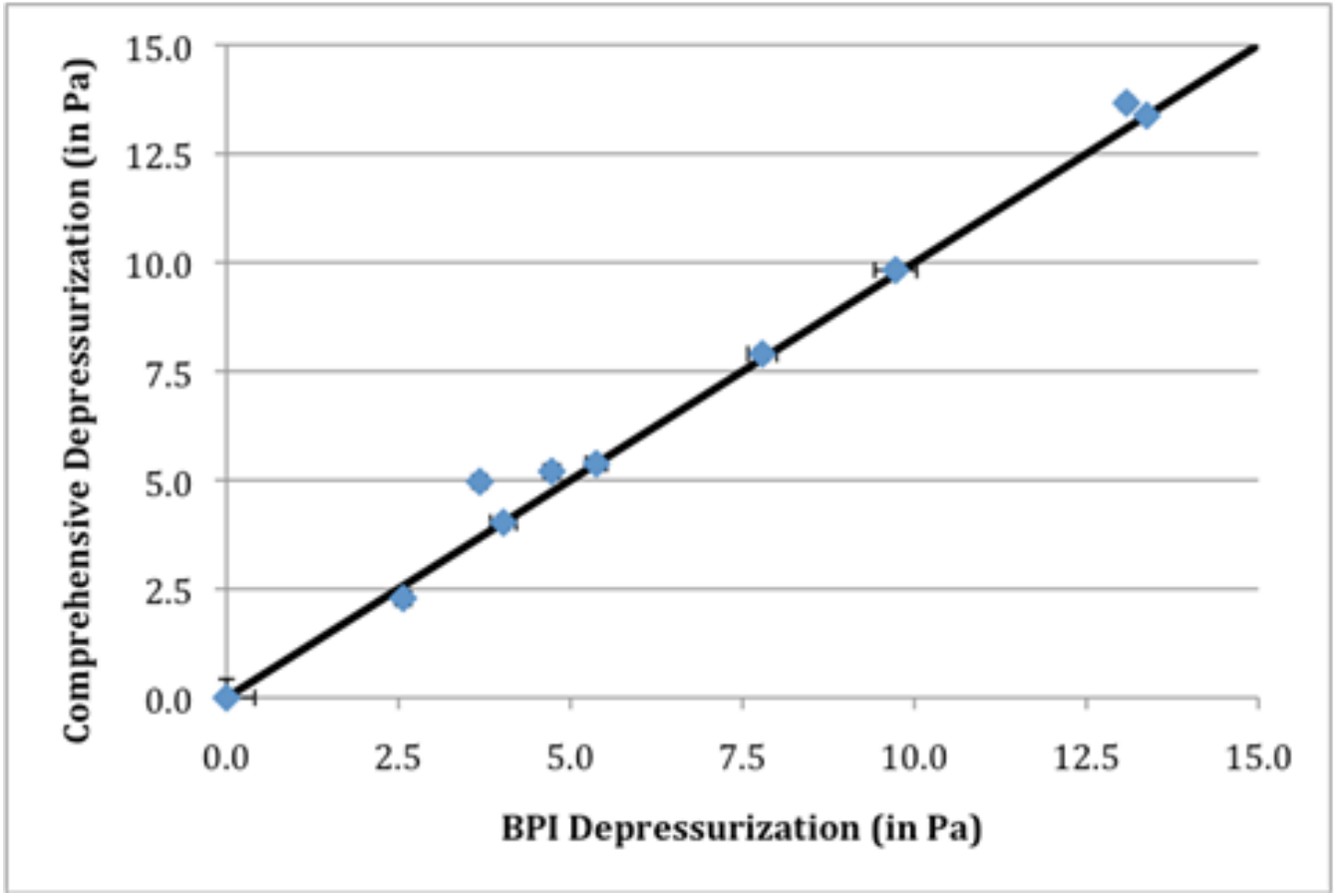
Depressurization Conditions

Comprehensive versus Simplified



Depressurization Conditions

Comprehensive versus BPI



Conclusions

- **Typical, normal systems don't spill excessively**, and don't produce much carbon monoxide
- **Vent defects are an important cause**, perhaps the largest cause, of excessive spillage. Vent inspection is critically important in evaluating safe operation.
- **Worst-case test conditions about equal** for Simplified and Comprehensive methods.
- **Large variation in level of depressurization required to cause spillage** (-1.7 to -6.1 Pa).

11 Minnesota/Wisconsin houses with water heaters in basement

Looking Forward - Harmonization

Org/ Std-Yr	Req.?	Focus appliances	CAZ door	Other doors	Air Handler[1]	Limits	Spillage	Draft
NFPA/ NFGC-2012	No	Existing furnaces and boilers	Closed	No	No	No	5 minutes	No
ACCA/ QH12-2011	Yes	Existing appliances	Test	Test Each	No	No	5 minutes	No
BPI/ 101-2011	Yes	Existing appliances	Test	Test Each	Yes	Yes	1 minute	Yes
NREL/ SWS-2011	Yes	Existing appliances	Test	Test Each	Yes	Yes	2 minutes	No
NFPA/ NFGC-2015	No	Existing appliances	Test	No	Yes	No	5 minutes	No
ACCA/ QH12-2014	Yes	Existing appliances	Test	Test Each	Yes	No	5 minutes	No
BPI/ 101-2015	Yes	Existing appliances	Test	Default	Yes	No	2 or 5 minutes[3]	No
NREL/ SWS-2015[2]	Yes	Existing appliances	Test	Default	Yes	No	2 or 5 minutes[3]	No

Combustion Safety Tips !

- Check the vent connector!
  - Replace connectors that are too long, too narrow, or corroded; consider a Type B vent connector
  - Increase the diameter of the vent connector if allowed by the tables
- Use a chimney liner when downsizing appliances
- Unblock combustion air openings to the indoors or outdoors
- Use latest test procedures to avoid false positives
- Consider a power vent kit

Photo Credit: Paul Francisco

Building America Reports

Measure Guideline: Combustion Safety for Natural Draft Appliances Through Using Indoor Air
http://www.nrel.gov/docs/fy14osti/61326.pdf

Measure Guideline: Combustion Safety for Natural Draft Appliances Through Appliance Zone Isolation
http://www.nrel.gov/docs/fy14osti/61295.pdf?gathStatIcon=true

Combustion Safety Simplified Test Protocol Field Study
http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/combustion-safety-protocol-field.pdf

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