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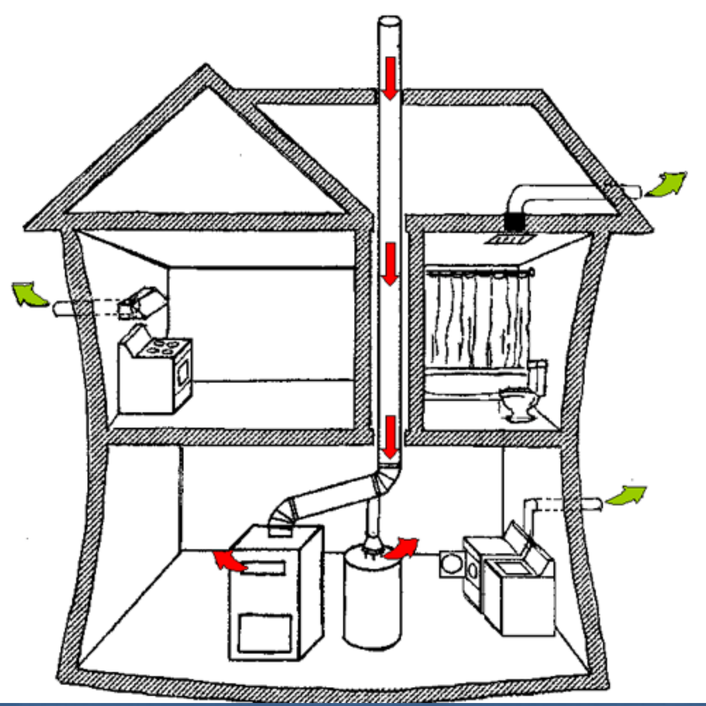
LAWRENCE BERKELEY NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

Assuring Combustion Safety

Rethinking Testing

Iain Walker



February 16th, 2015

San Diego, CA

Why do we conduct combustion safety tests?

What are we worried about?

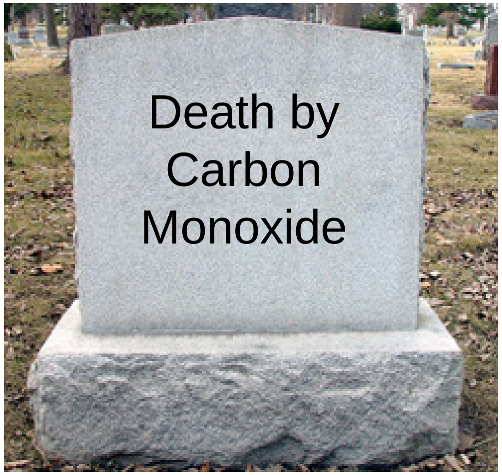
What are we trying to prevent?

What are the most <u>severe</u> combustion appliance hazards?

What are the most <u>common</u> combustion appliance hazards?

Natural draft appliance + airtight home = DANGER

IS THIS TRUE?



Source: Moore, Rich (2011). CAZ Pressure Testing. ACI Presentation, March, Denver, CO.

Combustion Pollutants

Direct Health Problems:

- **Carbon Monoxide – CO**
- **Nitrogen Dioxide – NO_2**
- **Particles**
- **Formaldehyde**
- **Acrolein**

Life-Safety and Acute Short Term (Carbon Monoxide, Nitrogen Dioxide)

Chronic – Long term (Particles, Formaldehyde, Acrolein)

Other Stuff:

Carbon Dioxide – CO_2

Water Vapor – H_2O

Health Risks

Life-Safety

- CO at level that impairs judgment, creates risk of more severe effects including death (100+ ppm CO)

Acute

- Impacts sensitive individuals when CO & NO_2 exceed outdoor air quality standards

(10-50 ppm CO; 100-200 ppb NO_2)

Chronic

- Low-level exposures over periods of weeks or more (5-10 ppm CO)

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Health hazards associated with combustion appliances

Life-Safety: Must NEVER happen

- Requires extreme failure of burner and venting; not just depressurization-induced spillage

Acute: Costly to eliminate; must manage

- Sustained spillage + problem with combustion

Chronic: Minimal risk achievable

- Requires routine spillage + compromised combustion
- Moisture can still be a problem even if CO low

Acute ambient CO levels that could result in hospitalization or death

Ambient Concentration	Exposure	Symptoms
100 ppm	2-3 hours	Slight Headache
200 ppm	2-3 hours	Headache, Nausea
400 ppm	2-3 hours	Life threatening
800 ppm	2 hours	Death

GOLDSTEIN,M.Carbonmonoxidepoisoning.*JournalofEmergencyNursing34*,6(December2008), 538–542.

CO standards to protect sensitive sub-populations of general population

Organization	1 hour average (ppm)	8 hour average (ppm)
National Ambient Air Quality Stds	35	9
California Ambient Air Quality Stds	20	9
Health Canada	25	10**
Consumer Product Safety Commission	25	15

** 24 hour time-weighted average

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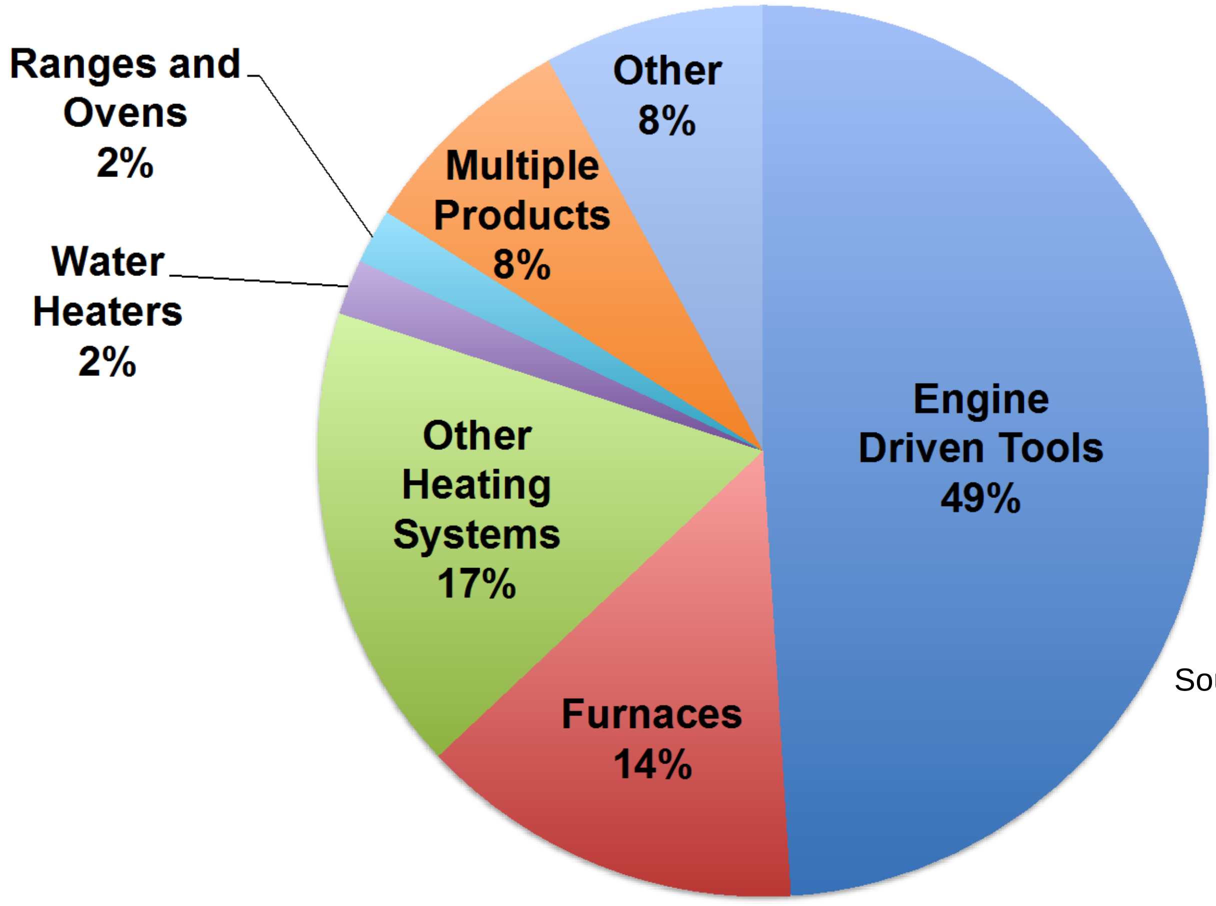
Risky Business?

U.S. average 2005-2007:
184 deaths / year from unintentional CO poisoning
Deaths from vented appliances due to poor flues/chimneys



< 32 deaths / year from water heaters and furnaces

2002-2011 average: 37 deaths / year from lightning (NOAA)

Source: Hnatov, M.V., Non-Fire Carbon Monoxide Deaths Associated with the Use of consumer Products: 2007 Annual Estimates (2011)

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To vent or not to vent….

Vented Appliances

- Furnace
- Water Heater
- Fireplace?

Un Vented Appliances

- Cooktop or Oven
- Fireplace
- Room Heater

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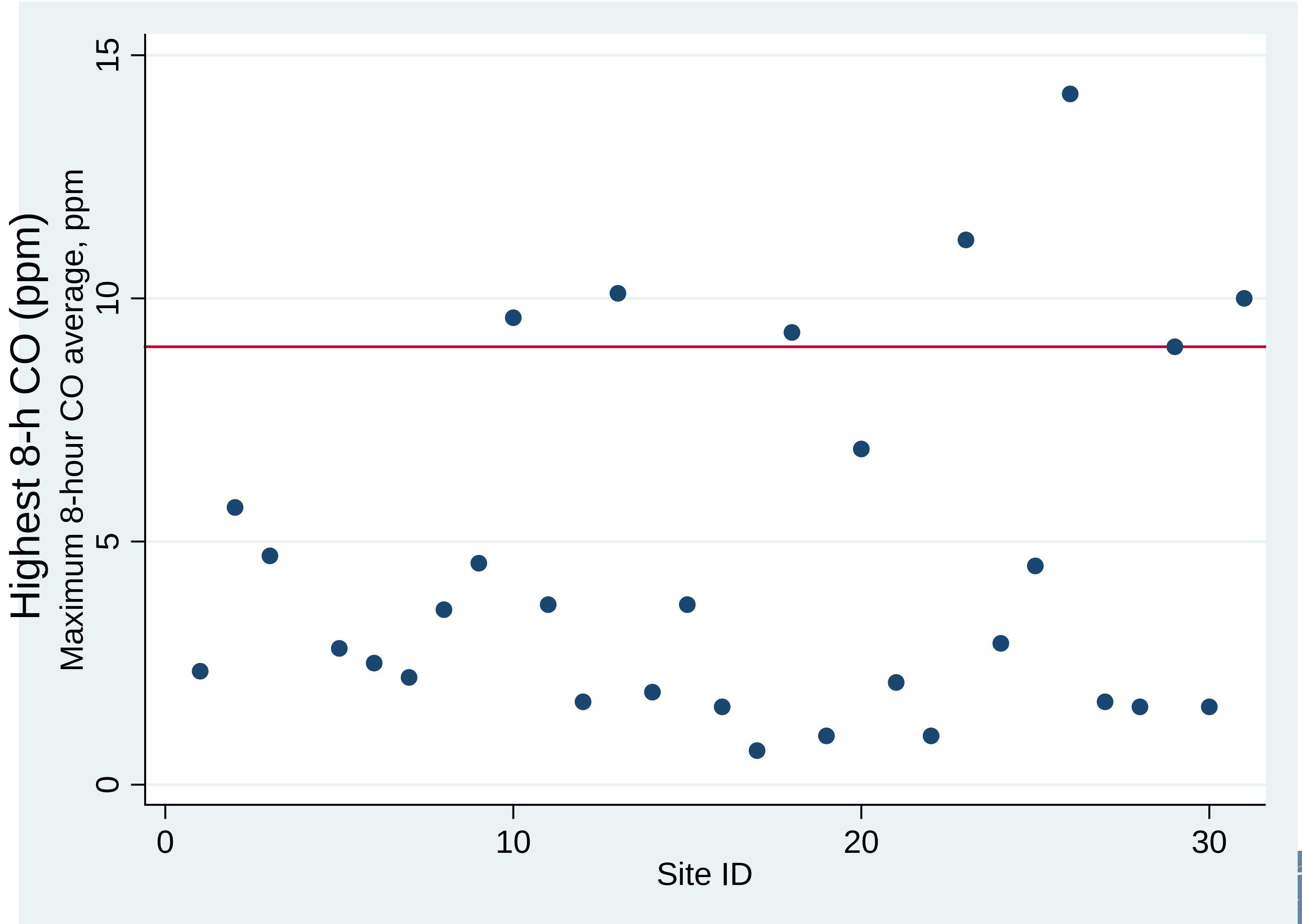
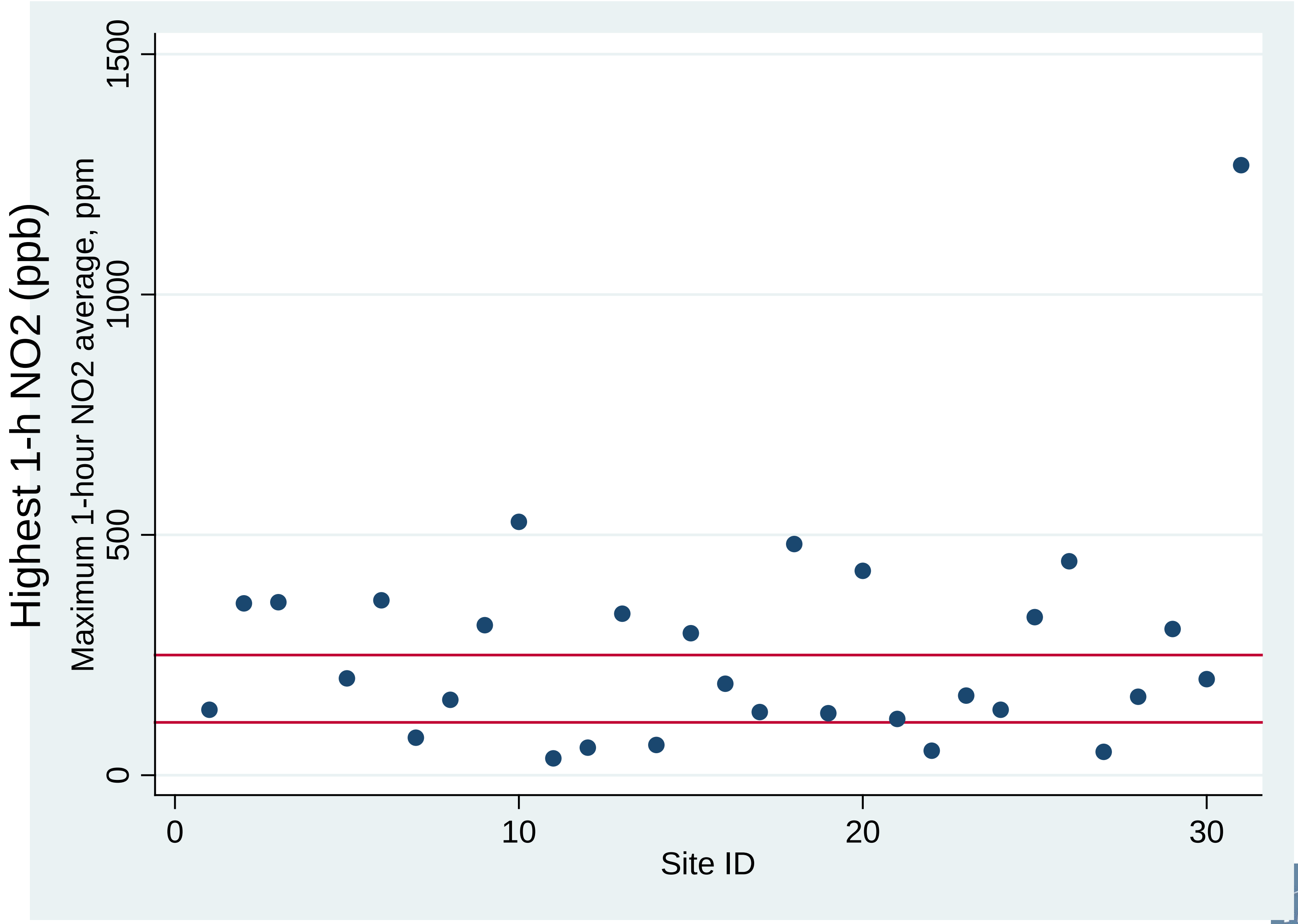
Unvented fireplaces cause CO issues



Unvented fireplaces cause NO_2 issues



Impact of Unvented Cooking Burners

Simulations for 6634 SoCal homes in 2003 RASS

	Fraction of homes above std.	Estimated number of Californians impacted	Estimated number impacted across U.S.
CO: 1-h & 8 h	7-9%	1.7M	10M
NO_2: 1-h	55-70%	12M	66M

Typical Week in Winter, Constant AER from Empirical Distribution

Logue et al., EHP, 2014

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Vented Appliance Testing: Visual Inspection

Flue code problems

http://blog.greenhomesamerica.com/2009/12/22/dont-mess-around-with-appliance-venting/

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Vented Appliance Testing: Visual Inspection

Flue failures

Vented Appliance Testing: Visual Inspection

Combustion air supply

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Vented Appliance Testing: Visual Inspection

Evidence of poor draft

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Vented Appliance Testing: Spillage

Do combustion products go up the flue?

– Smoke test

Look for blockages

http://www.metrohome.us/

Vented Appliance Testing: Draft

Measure Pressure in Vent

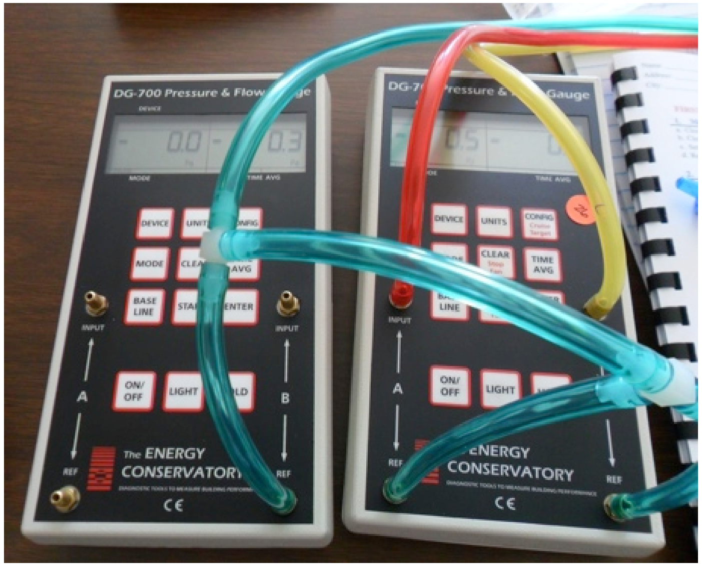
Vented Appliance Testing: CO

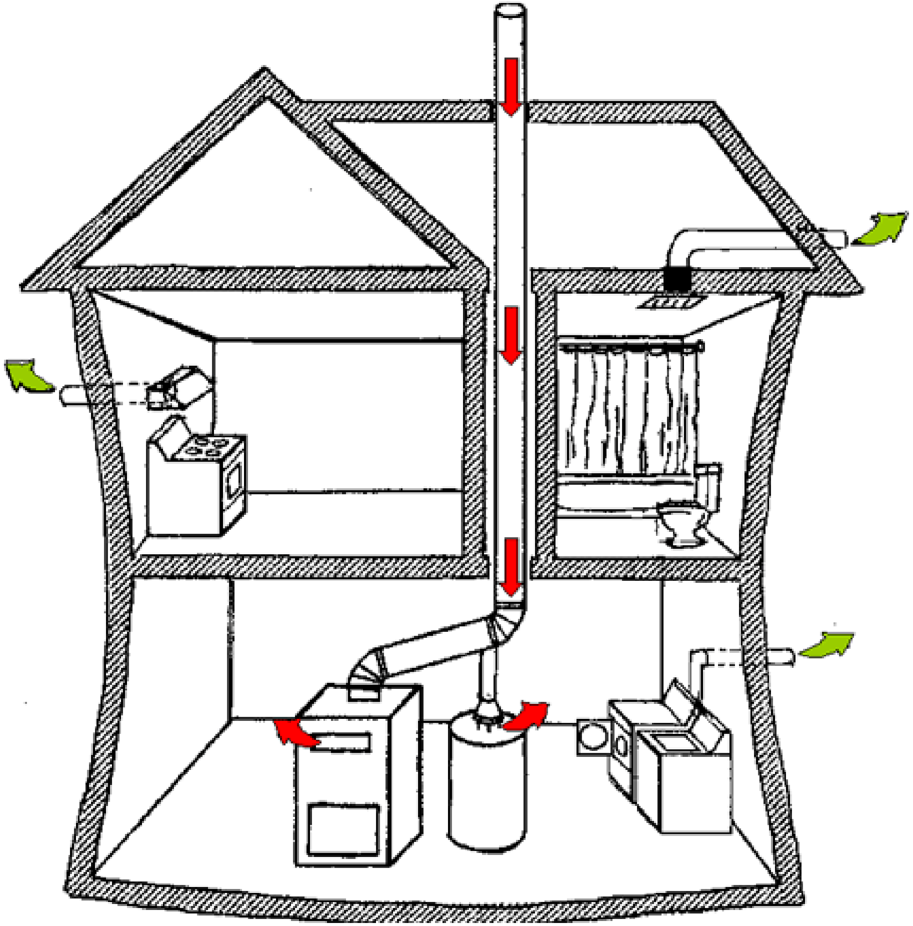
Measure in flue

http://www.htownhomeinspector.com/node/56
http://www.plumbtechnj.com/wp-content/uploads/2012/09/Carbon-monoxide-awareness.jpg

Vented Appliance Testing: CAZ Pressures

Measure house and CAZ pressures





How do we get depressurization?

This is critical, both for the risk and the mitigation options

1) Exhaust fans

Depressurize house, also increase air exchange rate which dilutes gases.

2) Door closures

Can be an issue with central returns and tight-fitting doors -> can depressurize core of the house, air then goes into return for distribution to the rest of the home. May increase house air exchange rate which dilutes gases.

How do we get depressurization?

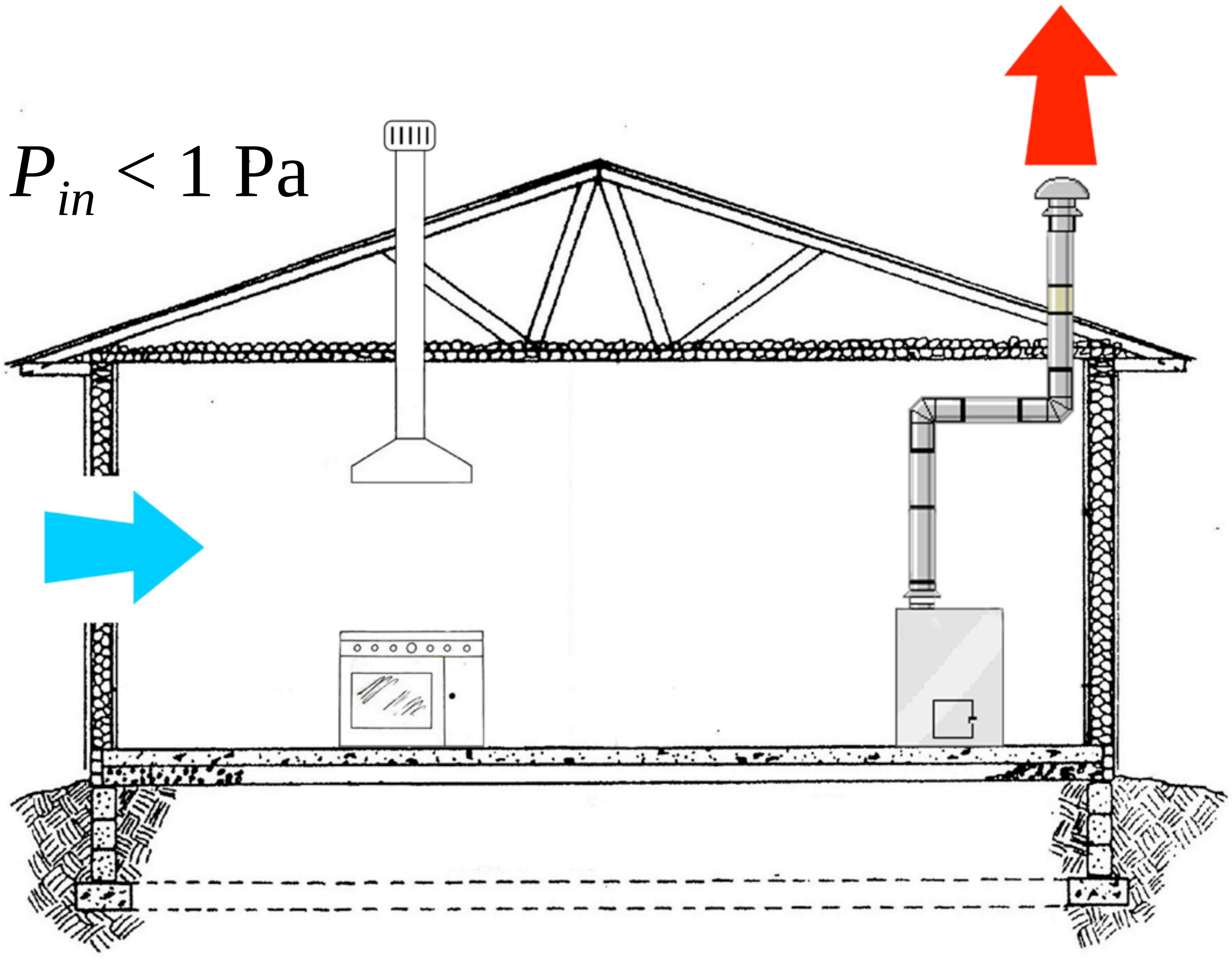
3) Duct leakage

Return in same space -> depressurizes space, entrains combustion products, distributes them, may not increase air exchange rate of home

Supply to outside -> depressurizes house, also increases air exchange rate

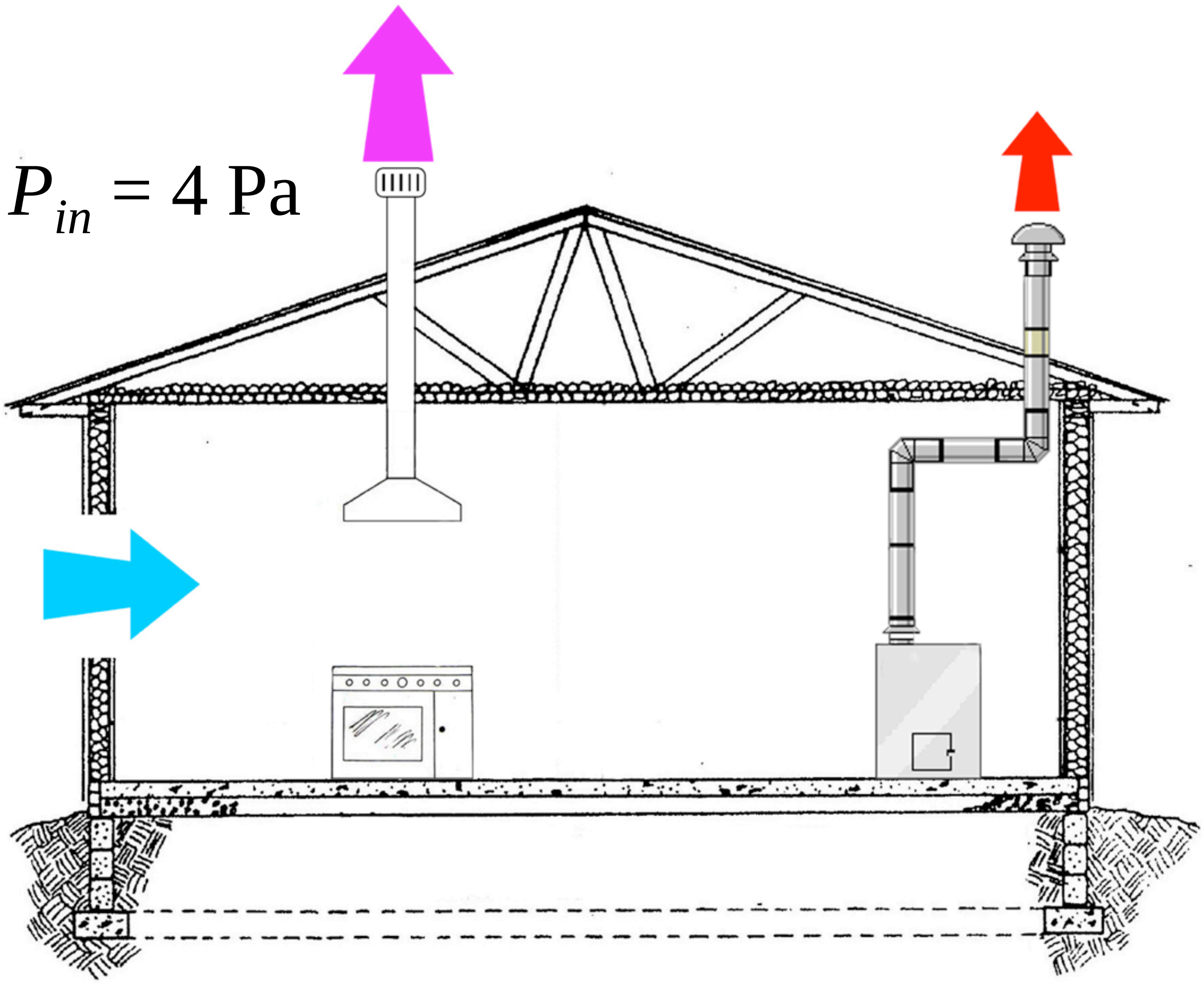
Backdrafting: consider a 6 ACH50 house with a natural draft furnace…

$$D_p = P_o - P_{in} < 1 \text{ Pa}$$



Operate a 375 cfm range hood… No problem

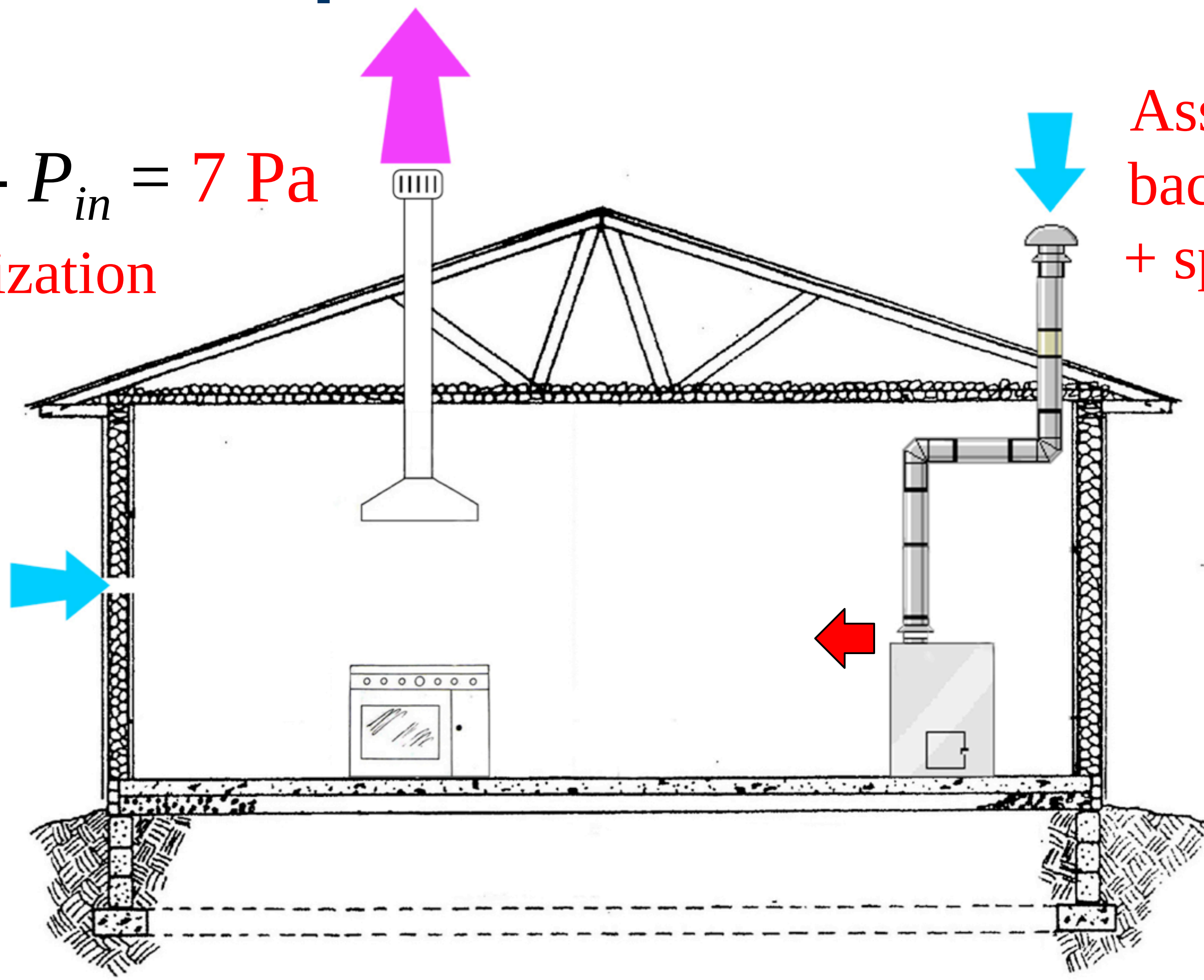
$D_p = P_o - P_{in} = 4$ Pa



Air-seal to 4 ACH50 and you are likely to fail a CAZ pressure test

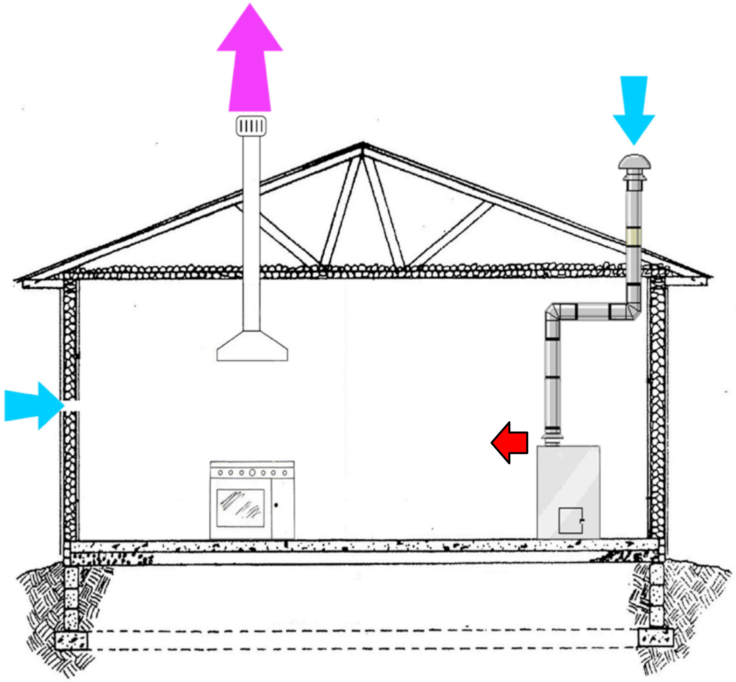
$D_p = P_o - P_{in} =$ 7 Pa

Depressurization



Assumed backdraft + spillage

What determines if there is really a problem?



- How much CO emitted?

- Is appliance really not able to establish draft at -7 Pa?
  - Vent configuration
  - Atmospheric conditions
- How often is there 375 cfm of exhaust with burner on?
- Does spillage occur long enough to create a hazard?
- How does exhaust flow impact buildup of exhaust gases and pollutants?

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Major Takeaway #1

Simply comparing depressurization levels to a threshold, regardless of whether the appliance spills or backdrafts, has the potential to fail a lot of appliances that are not causing a problem

What is the risk of depressurization induced spillage?

$$Risk = P_1 \times P_2 \times P_3$$

P_1 = probability that conditions exist to cause backdrafting and spillage if the appliance operates

P_2 = probability that the appliance will operate during the time that the conditions of P_1 persist

P_3 = probability that the appliance emits pollutants at a sufficient rate to cause an IAQ problem if P_1 and P_2 occur

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Data and calculations are needed…

$$\text{Risk} = \boxed{P_1} \times P_2 \times P_3$$

The probability that conditions exist to cause backdrafting and spillage if the appliance operates depend on:

- Weather conditions throughout the year
- Existing fans and usage patterns – how LIKELY is the "worst case"*
- Duct leakage
- Appliance location

* - If you want 100% protection you need sealed combustion-

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Data can provide probability an appliance will be operating

$$\text{Risk} = P_1 \times P_2 \times P_3$$

- 143 California homes showed a maximum continuous on-time of 139 minutes in 8 hours for water heaters
- Wall furnace could operate continuously
- Data for central furnaces & boilers?

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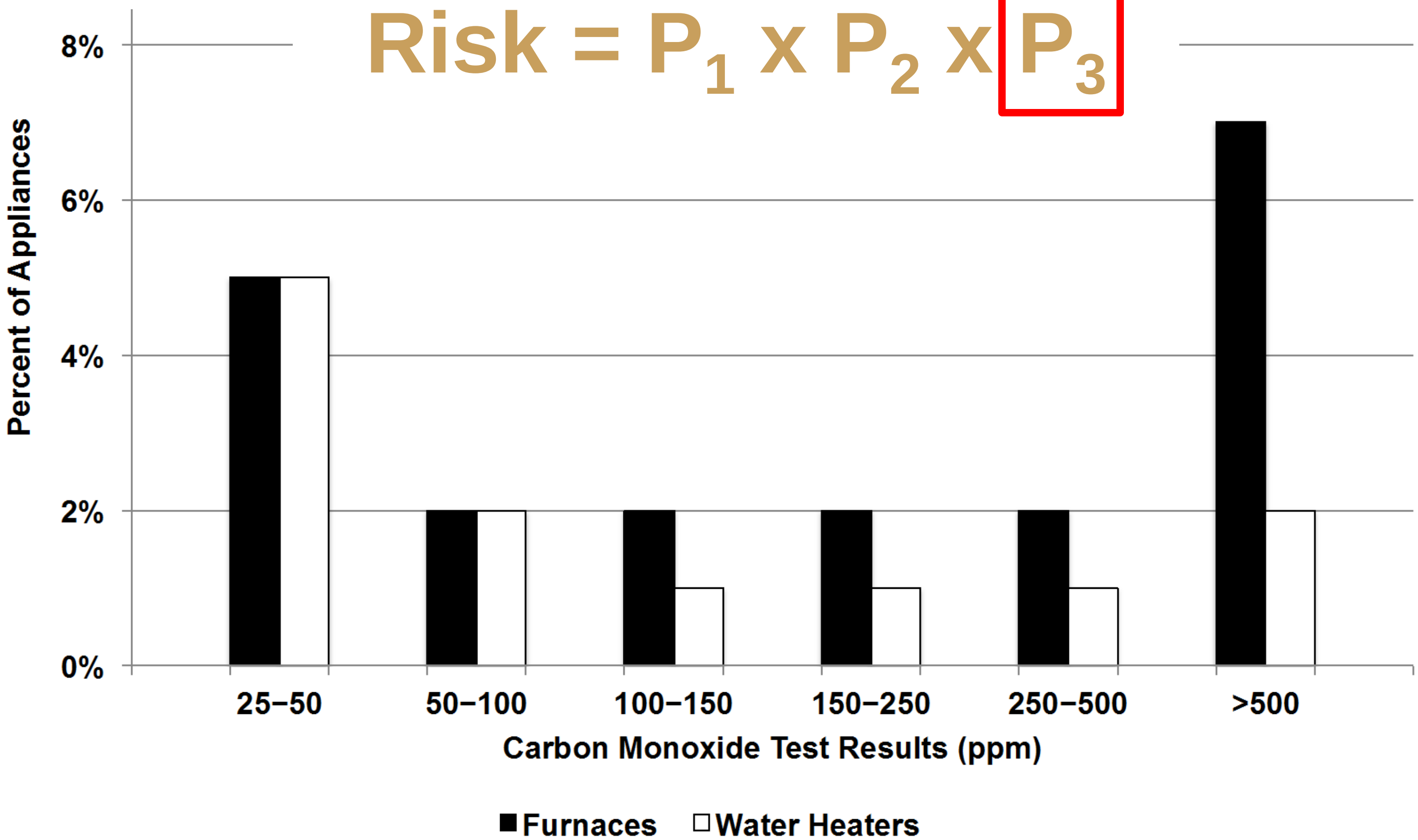
Probability of appliance pollutant emission rates

$$Risk = P_1 \times P_2 \times P_3$$



1,427 homes in Twin Cities, MN

Bohac, D., et al., Ventilation and Depressurization Information for Houses Undergoing Remodeling (2002)

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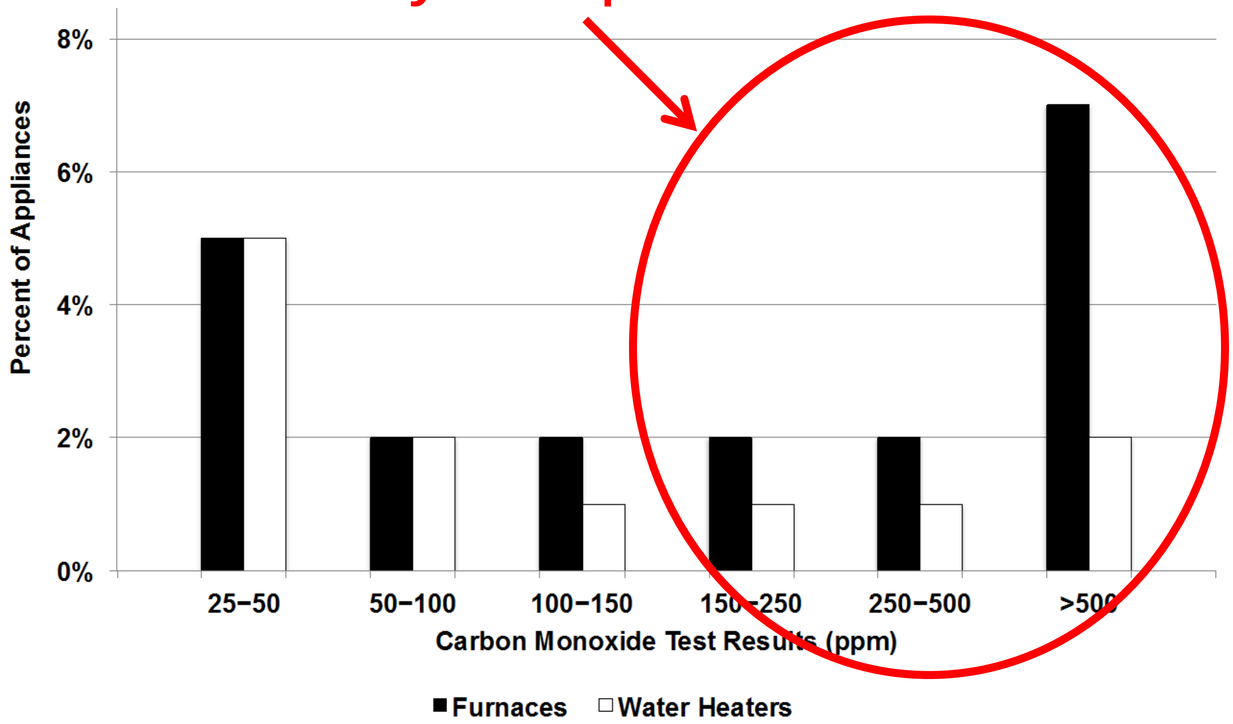
Probability of appliance pollutant emission rates

Standard "clean and tune" resolved many CO problems



1,427 homes in Twin Cities, MN

Bohac, D., et al., Ventilation and Depressurization Information for Houses Undergoing Remodeling (2002)

How do we get to danger?

Given:

40,000 btuh water heater

Per code, need roughly 1 cfm air per 2,400 btuh fuel

-> 1,000 ft^3 exhaust per hour

Assume:

400 ppm CO in exhaust

10,000 ft^3 home (1250 sf x 8 ft ceiling)

1 h of spillage with no ventilation

$$\frac{400\,ppmCO \times 1{,}000\,ft^3}{10{,}000\,ft^3} = 40\,ppmCO$$

This is not a life-safety hazard. It is a health hazard.

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Major Takeaway #2

Depressurization problems are rarely life-safety issues.

Focus should be on identifying combinations that are likely to lead to elevated levels that may cause non-fatal acute or chronic exposures.

Unvented combustion appliances pose the highest health risk

Appliance	Pollutant Exposure Risk
Induced Draft	Very Low: Unlikely to backdraft and spill
Water heater	Low: non-continuous operation; vented
Vented furnace	Medium-Low: Possible long-term operation; vented; wall furnaces can have lower draft
Range & Ovens	Medium-high: 100% spillage in living space; some venting through range hood, higher CO
Unvented heater	High: 100% spillage in living space; possible long-term operation; higher CO and NO_2

Recommendations: Combustion Safety Diagnostics

Focus first on basic safety

- Proactively check for unvented heating. Primary appliance has to work. Ask about other heaters including oven
- Inspect for gas leaks; check appliance burner, flue, combustion air to CAZ
- Check vent integrity, sizing, and horizontal runs
- Is appliance producing any CO?

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Recommendations: Combustion Safety Diagnostics

Focus on finding appliances that could backdraft often

- Depressurization draft test with exhaust fans that can run for extended periods (dryer, bathroom; no range hood on high).
- Evaluate potential for duct leakage to induce backdrafting

Consider checking CO during induced downdraft

Confirm range hood is venting & advise it be used

Install CO alarm

Recommendations: Combustion Safety Diagnostics

Replace “worst-case” test with a “Challenge” test

- Details TBA?
  - Pick two largest exhaust fans, or two most commonly used
  - Prescribe doors to be opened/closed

Don’t waste time testing appliances not well connected to conditioned spaces:

- Furnaces in vented attics, furnaces/water heaters in garages not below living space, vented closets

Do test in basements and crawlspaces

Treat cooking appliances for the unvented appliances they are:

- Kitchen ventilation essential (gas or electric)

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