Home Performance Science

Your HOUSE is a SYSTEM
Symptoms of a Sick House

- Too hot/too cold rooms
- Respiratory problems
- Headaches/nausea
- Smoky fireplace
- Foggy windows
- Stuffy air and lingering odors
- Peeling paint
- Constant dust problems
- Back drafting
- Moisture
- Structural integrity
Combustion Safety & Worker Safety
Lead Paints

• Found in interior and exterior paints used prior to 1978.
• Friction surfaces such as window jambs create lead dusts.
• Lead is easily transported around the home.
• Lead dusts are easily inhaled or ingested.
• 900,000 children in the U.S. have identified elevated lead levels in their blood.
Combustion Air
and “Confined Space”

Require combustion air inlets if “room” has less than 50 cubic ft. volume per 1000 BtuH input rating of combustion appliance.
Makeup Air Options In A Confined Space: From Inside the Building

The space where the appliances are located must include 2 permanent openings communicating with an unconfined space, each of which must have a minimum free area of 1 inch$^2$ per 1000 Btu/h of the total Btu/h input. One opening must be located within 12" of the ceiling, and one must be located within 12" of the floor.
Makeup Air Options In A Confined Space: From A Ventilated Attic

The space where the appliances are located must include 2 permanent openings communicating with the attic, each with a free area of 1 inch² per 4000 Btu/h of the total Btu/h input. One opening must be located within 12" of the ceiling, and one must be located within 12" of the floor.
Makeup Air Options In A Confined Space: From Outside Using Ducts

The space where the appliances are located must include 2 permanent openings communicating with the outdoors, each with a free area of 1 inch$^2$ per 2000 Btu/h of the total Btu/h input. One opening must be located within 12" of the ceiling, and one must be located within 12" of the floor.
Locate CAZ Zones

- Water Heater
- Furnace
- Fireplaces
- Range
- Others
<table>
<thead>
<tr>
<th>CO Test Result*</th>
<th>And/Or</th>
<th>Spillage and Draft Test Results</th>
<th>Retrofit Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>0—25 ppm</td>
<td>And</td>
<td>Passes</td>
<td>Proceed with work</td>
</tr>
<tr>
<td>26—100 ppm</td>
<td>And</td>
<td>Passes</td>
<td>Recommend that the CO problem be fixed</td>
</tr>
<tr>
<td>26—100 ppm</td>
<td>And</td>
<td>Fails at worst case only</td>
<td>Recommend a service call for the appliance and/or repairs to the home to correct the problem</td>
</tr>
<tr>
<td>100—400 ppm</td>
<td>Or</td>
<td>Fails under natural conditions</td>
<td><strong>Stop work:</strong> Work may not proceed until the system is serviced and the problem is corrected</td>
</tr>
<tr>
<td>&gt;400 ppm</td>
<td>And</td>
<td>Passes</td>
<td><strong>Stop work:</strong> Work may not proceed until the system is serviced and the problem is corrected</td>
</tr>
<tr>
<td>&gt;400 ppm</td>
<td>And</td>
<td>Fails under any condition</td>
<td><strong>Emergency:</strong> Shut off fuel to the appliance and have the homeowner to call for service immediately</td>
</tr>
</tbody>
</table>

*CO measurements for undiluted flue gases at steady state
Gas Leak Testing
Gas Leak Detection

- Test each fitting completely, going $360^\circ$ around each fitting and connector
- Test within the combustion chamber and vent system before firing the appliance
- Test the entire supply system of each appliance while it is operating. Test the gas supply line connector to the burner
- Verify identified leaks by using soap solution. If a detected leak blows bubbles in the soap solution, the leak should be repaired
A Cracked Heat Exchanger Can Allow Flue Gases to Mix with Conditioned Air
Typical Draft Failure Causes

• Vent design
  – Height, lateral runs, vent diameter

• Maintenance
  – Debris in chimney, dirty air filters

• Materials deterioration
  – Degradation of masonry, corrosion of metal

• Competition for air
  – Clothes dryers, range hoods, leaky distribution systems, other venting appliances.
Carbon and Scorching Caused by High Negative Pressure in Combustion Zone
Home Air Leakage

- Opportunities
- Driving Forces
- Leakage or Ventilation?
- Blower Door - $ACH_{NAT}$
- Shell Sealing
- Zonal Pressures
- Measuring Exhaust Flows
Physics of Air Flow

Air Flow is dependant on 2 variables:

1. A *hole* and its size
2. A *pressure difference* (driving force) across the hole
What are the Driving Forces?

- Stack Effect
- Wind Effect
- Flue Effect
- Mechanical Effect
  - Exhaust fans
  - Dryer
  - Built-in vacuum
  - Air handler (Typically the Biggest)
Stack Effect

Warm less-dense air rises to the top of the home and leaks out
• Infiltration occurs low in the structure.
• Exfiltration occurs higher in the structure.
• Magnitude determined by height of structure.
• Magnitude determined by inside to outside Temp. difference.
• Effect reverses in Summer
Visible Stack Effect

- Tall building
- Big temperature difference
- Kind of like a hot air balloon
Wind Effect

- Wind pressure creates a positive pressure on the windward side of the building (air infiltration).
- Wind pressure creates a negative pressure on the leeward side of the building (air exfiltration).
Mechanical Effect (Big)

- We need to be careful of driving forces created by fans; they can be very large.
- Closed doors can create pressure imbalances and can increase air leakage.
Air Leakage

Definition:

• Random & uncontrolled volumes of air
• Derived from random sources (like moldy crawl spaces or dusty attics)
• Moving randomly through building components
Ventilation

Definition:

- Controlled amount of air
- Derived from clean, dry sources
- Moving as designed through building zones
- Contributing to the health and comfort of the occupants
Home Air Leakage

The Difference Between Air

- Opportunities
- Driving Forces
- Leakage or Ventilation?
- **Blower Door - \( ACH_{\text{NAT}} \)**
- Shell Sealing
- Zonal Pressures
- Measuring Exhaust Flows
Basic Reasons Why We Use **Blower Doors**

- **Rough estimate** of natural air leakage.
- Determine air flow’s impacts on comfort, heating and cooling costs, and air quality.
- Determine leakage sites in the home.
- Simulate exhaust fan flow.
- Great compliment to infra-red camera.
Units of Measurement

**CFM**: Cubic Feet per Minute (a rate of airflow)

**Pascal (Pa)**: A metric unit of pressure. 250 Pascals is equal to about one inch of water column. Blower door testing is usually done at -50 Pa.

**CFM\textsubscript{50}**: Airflow, in CFM, with a 50 Pascal pressure difference

**ACH**: Air Changes per Hour
## Converting Between CFM 50 and Natural Airflow: LBL Factor

<table>
<thead>
<tr>
<th>Zone</th>
<th># of stories</th>
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<tr>
<td></td>
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<td>16.7</td>
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</tr>
<tr>
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<td>18.1</td>
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<tr>
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<td>17.2</td>
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<tr>
<td></td>
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<td>19.4</td>
<td>17.4</td>
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</tr>
<tr>
<td></td>
<td>Exposed</td>
<td>22.1</td>
<td>19.8</td>
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</tr>
</tbody>
</table>

**Formula:** \( \text{CFM 50/n} = \text{Natural airflow (CFM)} \)

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*Lawrence Berkeley Laboratories*
Interpreting the Test Results in the Field

1 \(\text{CFM}_{50}\) per square foot of floor area is an average test result for a good house

- Greater than 1 \(\text{CFM}_{50}/\text{sq.ft.}\) we are probably looking for an opportunity to air seal the shell.

- Less than 1 \(\text{CFM}_{50}/\text{sq.ft.}\) we are probably looking for opportunities to increase the ventilation rate in the home.
Conduct Infrared Inspection (Blower Door Assisted)

– Preferably with temperature variances of 15°F.
– Before and after blower door operation of 10 to 15 minutes (depending on temperatures).
– Identify areas where greatest temperature difference was created by blower door (probably at, or near the source of air entry).
What’s This Air Sealing Worth Anyway?

• Well, that depends on the following:
  – How much air reduction is achieved at 50Pa and what does that mean in seasonal natural flow?
  – How long will the measures last?
  – How cold/warm does it get around here?
  – What is the cost of energy?
  – What is the HVAC system efficiency?
Ventilation

Controlled Airflow For The Home
Ventilation

- Ventilation Standards
- Ventilation Design
- Ventilation Strategy
- Impacts of Moisture
- Water Vapor Transmission
Ventilation

Definition:
• Controlled amount of air
• Derived from clean, dry sources
• Moving as designed through building zones
• Contributing to the health and comfort of the occupants
How Much is Required?

That Depends on Lots of Factors:

- Occupant use of the building
- Pollutant sources and strengths
- Size of the building
- Types of combustion appliances
- General relative humidity levels (in and out)
- Occupant Health Level
ASHRAE Standard 62-89

• Per Person Requirement -- Minimum of 15 cubic feet per minute (CFM) per occupant of the building.

• Per Building Requirement -- .35 Air Changes per Hour (ACH)

Use the larger of these calculations.
Balanced System

**PROS**
- No combustion impact
- No induced infiltration/exfiltration
- Can be regulated to optimize performance

**CONS**
- More complicated design considerations
- Energy penalty unless system is HRV/ERV
- Over ventilation unless the shell is tight
- Cost
Heat/Energy Recovery Ventilator

**PROS**
- Provides equal supply and exhaust air
- Recovers up to 80% of energy in air exchanged
- Comfortable conditioned air
- Most practical in cold climates

**CONS**
- Over ventilation unless the shell is tight
- Cost
Typical Venting Rates

- Bathroom Fans – 15 to 150 CFM
- Vacuum System – 100 to 150 CFM
- Dryer – 70 to 200 CFM
- Range Hoods – 150 to 300 CFM
- Down Draft Ranges – 400 to 800 CFM
- Commercial Style Range Hoods – 1,200 CFM
Ventilation Strategy

1. Source control
2. Spot ventilation
3. Whole house ventilation
4. Pollutant removal
Common Contributors to Poor Air Quality

• High moisture levels within the building
• Poorly designed combustion vents
• Use of unvented combustion appliances
• Smoking within the building
• Volatile chemicals in building materials
• Fibers and other particles
• Lead based paints
Action Levels For Primary Home Pollutants

• Moisture – Above 50% relative humidity for extended lengths of time.
• Carbon Monoxide – Above 9 ppm in any ambient location.
• Formaldehyde – Above 1 ppm in living space.
  – Residential Energy: pp. 298 & 299
Water Vapor Air Transport

Problem Areas:
- Attics connected by thermal bypasses to wet crawl spaces
  - Dropped soffits
  - Recessed lights
  - Chimney bypasses
  - Plumbing stacks
- Pressurized and humid zones connected to wall systems with loose interiors and tight, low perm exteriors
- Leaky attic ducts
Vapor Pressure at Work
Sources of Water Vapor

- Standing water
- “Dry” crawlspaces
- People and pets
- Plants
- Showers
- Cooking
- Unvented appliances
  - Intentional and unintentional
- Others?
Moisture Impacts

• Moisture is the largest source of damage to buildings.
• Moisture has a major impact on air quality and comfort.
• Controlling moisture is essential to providing a quality living environment.
Unhealthy Levels Exceeding 60% for Extended Lengths of Time

- Promotes wood decay.
- Promotes growth of various biological organisms.
  - Molds and mildews
  - Bacteria and viruses
  - Dust mites
  - Wood rot