Remote Duct Sealing in Residential and Commercial Buildings:

“Saving Money, Saving Energy and Improving Performance”

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Presentation Overview

• Introduction to Duct Leakage
  - Single-family residences
    - leakage rates, energy impacts, other impacts
  - Larger buildings
    - Duct leakage in codes, standards and utility programs

• Diagnosing and Repairing Duct Leakage
  - Leakage testing
  - Aerosol-based duct sealing
    - Technology
    - Single-family residences
      - low-income weatherization to new construction
  - Larger buildings

• National Impacts
National Energy-Use Overview

- **Residential – 2005**
  - Space heating - 6.7 Quads
  - Space cooling - 2.7 Quads

- **Commercial - 2005**
  - Space Heating - 2.6 Quads
  - Space Cooling - 2.3 Quads
  - Ventilation - 1.1 Quads

- **One Quad = $10-20B**
- **More than 50% of this energy use passes through ducts**
Residential Duct Leakage

**Basement Ducts**
- Rectangular metal ducts
- Many joints = many leaks
- ~30% leakage on each side of fan
- 50% recovery of lost energy
- Un-insulated = grille temperatures impacted by leaks

**Attic/Crawlspace Ducts**
- Round metal or flex ducts
- Less joints = less leaks
- ~15% leakage on each side of fan
- Insulated, but outside = 90% of lost energy not recovered
Residential Duct Leakage

SEER Loss Due to Attic Duct Leakage
(Fresno, CA) 2-speed impacts

- Loss of SEER vs Overall Duct Leakage
  - 10 SEER
  - 12 SEER
  - 14 SEER
Residential Duct Leakage

Capacity Loss Due to Attic Duct Leakage
(Fresno, CA)

Change in Capacity [Tons]

Overall Duct Leakage

5-ton
4-ton
3-ton
Savings from Sealing Residential Duct Leakage

**Basement Ducts**
- Heating/Cooling energy savings from duct sealing \(~10\%\)

**Attic/Crawlspace Ducts**
- Heating/Cooling energy savings from duct sealing \(~15-20\%\)
- Peak electricity demand savings from duct sealing \(25+\%\)
Duct Leakage - Large Buildings

- Impacts depend on Building/System Type
  - Small Rooftop Packaged Units
    - Thermal losses from ducts above ceiling insulation
  - Exhaust Systems (Toilet, Sleeping Rooms, Laboratory)
    - Fan power scales with cube of flow rate
    - Extra flow creates extra heating and cooling loads
Duct Leakage - Large Buildings

• Impacts depend on Building/System Type
  – Office VAV Supply System
    • Leaks act a short circuit to fan
    • Fan power scales with flow rate to power 2.4
  – Laboratory/Hospital Supply Systems
    • Fan power impacts
    • 100% outside air creates large heating/cooling loads
Duct Leakage - Large Buildings

• Why care about duct leakage in an office building?
  • Maintain tenants
    • reduce energy costs
    • reduce complaints
  • Address increased loads

• Why care about duct leakage in a hospital or manufacturing facility?
  • Airflow safety
    • spread of contaminants and biohazards
    • smoke, pressure and humidity control
    • clean-up after contamination
  • Energy savings (100% outside air)
Duct Leakage - Large Buildings

- Why care about duct leakage in a hotel, dormitory or apartment building?
  - Kitchen and Bath Exhaust
    - Excessive fan power and heating/cooling loads
    - Tenant complaints (smoke, smells, moisture)
    - Ventilation and safety codes
# Large-Building Exhaust Duct Leakage

<table>
<thead>
<tr>
<th>Building</th>
<th>Fan Flow [cfm]</th>
<th>Leakage [%]</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condominium (40-Story)</td>
<td>950</td>
<td>74%</td>
<td>Building-Cavity Bathroom Exhaust</td>
</tr>
<tr>
<td>NYS University Dorm (10-story)</td>
<td>2,300</td>
<td>70%</td>
<td>Bath/Shower Exhaust</td>
</tr>
<tr>
<td>NYS University Dorm (7-story)</td>
<td>2,050</td>
<td>54%</td>
<td>Bath/Shower Exhaust</td>
</tr>
<tr>
<td>Navy BEQ (10-story dorm)</td>
<td>6,300</td>
<td>18%</td>
<td>Ducted Supply w/heat wheel</td>
</tr>
<tr>
<td>Navy BEQ (10-story dorm)</td>
<td>6,470</td>
<td>54%</td>
<td>Building-Cavity Exhaust w/heat wheel</td>
</tr>
<tr>
<td>Barracks (8 3-story buildings)</td>
<td>20,000</td>
<td>20%</td>
<td>Bath/Shower Exhaust</td>
</tr>
<tr>
<td>Office Toilet Exhaust (3-story)</td>
<td>8,700</td>
<td>9%</td>
<td>No pre-qualification of leakage</td>
</tr>
<tr>
<td>Hospital Exhaust (9-story)</td>
<td>8,200</td>
<td>19%</td>
<td>Sterilization room riser</td>
</tr>
<tr>
<td>Seven NYC Apartment Exhausts</td>
<td>2,450</td>
<td>36%</td>
<td>Kitchen/Bath Exhausts</td>
</tr>
<tr>
<td><strong>AVERAGE</strong></td>
<td></td>
<td><strong>39%</strong></td>
<td></td>
</tr>
</tbody>
</table>
Exhaust Duct Leakage Impacts

- Fan Power and Thermal Losses
  - Pressure varies with square of flow for ventilation
  - Duct leaks and/or imbalances create a need to move more air to meet minimum zone flow requirements

- Example
  - 36% exhaust leak $\Rightarrow$ 56% excess flow $\Rightarrow$
  - 281% excess fan power
  - Sealing 86% of leakage $\Rightarrow$ 69% reduction in fan power
  - PLUS
  
  15% reduction in heating/cooling loads from exhaust
Savings Opportunity for Multifamily Exhaust

- Change in New York City codes allow lower bath and kitchen exhaust flows

  - **CURRENT**
    - 20 CFM bath
    - 25 CFM kitchen
  
  - **PREVIOUS**
    - 50 CFM bath
    - ~100-150 CFM kitchen

- Flow imbalances and leaky ducts make it hard to capture energy savings from reducing exhaust fan flow
Integrated Solution for Multifamily Exhaust

- **Constant-Flow Grilles** maintain pressure-independent flow, but require a minimum pressure to work.

- **Leaky Ducts** cannot maintain adequate grille pressures without increasing leakage and fan flow dramatically, thereby wasting energy.
Integrated Solution for Multifamily Exhaust

- Economics of reducing 36% leakage by 86% for 175 cfm of total kitchen plus bathroom exhaust from an apartment (measured at the roof pre-sealing)
  - Keeping the same apartment exhaust flows after sealing
  - At $0.15/KWH for fan, $0.2/KWH for air conditioning, and $1.5/Therm
  - Savings is $208/year per apartment
  - To realize 2-year payback, can pay up to $1250 per shaft sealed

- Economics of reducing 112 cfm (post-sealing) of total kitchen plus exhaust from an apartment (measured at the apartment) to 45 cfm
  - Using same utility rates, and duct pressure increase from 25 to 50 Pa
  - Savings is $130/year per apartment
  - To realize 2-year payback, can pay up to $130 per CAR grille installed
Measured Savings in Office Buildings

- **California Office Building**
  - LBNL study of Sacramento Office Building
  - 25-35% increase in fan energy use due to 15% duct leakage added on top of 5% leakage

- **Florida Office Building** (Ceiling-Plenum Return)
  - 5.4 year payback from measured savings in Navy Office Building from sealing 92% of 19% leakage downstream of VAV boxes
Duct Leakage in Codes, Standards and Utility Programs

• California Title-24 Energy Efficiency Code
  o Has required duct leakage testing and sealing since 2001
  o Expanded requirements to existing duct systems in 2005
  o Complicated enforcement mechanisms

• Other States
  o Some requirements, but uneven enforcement
Duct Leakage in Codes, Standards and Utility Programs

• Industry Standards
  – SMACNA
    – HVAC Leakage Test Manual: leakage upstream of VAV boxes
  – ACCA
    – Manual J now includes loads from duct leaks
  – ASHRAE
    – Standard 152 determines overall impacts of leaks, location and insulation
Duct Leakage in Codes, Standards and Utility Programs

• Utility Programs for Duct Sealing
  – Many residential programs in California
    – 7-year residential Aeroseal program by SMUD
    – 1-year light commercial program by SCE
    – Current utility programs help code enforcement
  – Florida, North Carolina and Texas
    – residential programs
  – New York
    – Recent NYSERDA interest in multifamily program
  – Other states??
Diagnosing and Repairing Duct Leakage
Diagnosing Residential Duct Leakage
Diagnosing Duct Leakage – Large Buildings

• Test and Balance Reports
  – Discrepancy between fan and grille/floor flows
• Direct Leakage Measurement
  – Downstream of VAV boxes
• Leakage Indicators
  – Inadequate flow performance
  – Visual/sensual evidence
Diagnosing Duct Leakage – Large Buildings

• Large Commercial Supply Leakage Diagnosis
  – Simplified Fan Pressurization for Leakage Downstream of VAV Boxes
Diagnosing Duct Leakage – Large Buildings

• Exhaust Leakage Diagnosis
  – Option 1
    • Block all grilles with exhaust fan running
    • Measure pressure at midpoint
    • Measure flow leaving exhaust system
      – time to fill a bag, exit velocity traverse, tracer gas dilution
  – Option 2
    • Block all grilles with exhaust fan running
    • Measure pressure at several grilles (e.g. top, bottom, middle)
  – Option 3
    • Measure suction pressure at all or multiple grilles during normal operation
Repairing Duct Leakage: Aerosol Sealing
Repairing Duct Leakage: Aerosol Sealing
Aerosol Sealing Technology

Yellow end
Green end

Blue end

50 foot

Red end

25 foot

50 foot
Aerosol Sealing Technology

- Does not coat the ducts
- Vinyl polymer is safe
- No lingering odors or off-gassing
- Lasts 10+ years
- Seals holes up to 1/2” across
- Sealant remains rubbery
- Need not clean before sealing
- Cleaning after sealing generally does not hurt seals
Aerosol Sealing Technology

- California Utilities (CIEE), EPRI, DOE and EPA fund Duct Research at Lawrence Berkeley National Laboratory (LBNL)
- 1994 – research yields Aerosol Sealing Technology Patent
- 1997 – Mark Modera (inventor) founded Aeroseal and received exclusive license
- 1999 - First applications by HVAC dealers
- 2001 – Aeroseal purchased by Carrier Corporation
- 2003 – Carrier-Aeroseal obtained large commercial license from LBNL
- More than 25,000 residential systems have been sealed to date
Aerosol-Sealing Technology

Sealing Process

We are now sealing, hit F5 to stop sealing, F7 to pause sealing.

Sealing Leakage Progress

Sealing Elapsed Time: 1.15 Minutes

Sealant/Water Pump

- Fluid Left: 150.10 Minutes
- Fluid Level: 99%
- Setting: 1 CCM 140
- Best Setting: 1 V 2.36

Emergency Stop: Fan, Heat, Inj

Stop (F5)  Pause (F7)

(Use the [Esc] key to Escape)

Duct Leakage (sq in) 86.8
Duct Leakage (CFM25) 452
Duct Leakage (%) 37.3
Duct Flow (CFM) 677
Duct Pressure (Pa) 49

Inlet Temp (°F) 75
Compressed Air Temp (°F) 284
Cylinder Temp (°F) 82
Inlet Humidity (%) 22

Heaters C 1 2

1.97 V

1-800-772-6459
Aerosol-Sealing Technology

Post-Sealing Leakage Test

Press F2 to redo the completed test.

or press F9 to continue to next page...

Increase Fan | Decrease Fan

Leakage (CFM @ 25 Pa)

| Pre-Sealing | 471 |
| Post-Sealing | 36 |
| Improvement | 435 |

Equivalent Hole Size (square inches)

| Equivalent Size | 89.5 |
| Current Fan Flow | 84.4 |
| Current Fan Setting | 88.7% |
| Inlet Temperature | 73 |

Duct Pressure

| Current | Target |
| 24.9 | 25 |
Aerosol-Sealing Technology

- Automatic documentation
- Uploads all data over internet
Residential Aerosol-Sealing Applications
Residential Aerosol-Sealing Applications

Gen-2 vs. Gen-1 Injectors

- **Fraction Sealed [% *10]**
- **Injection Time [minutes]**
- **Average Seal Rate [cfm/h]**

- **HP Injection (16)**
- **Old Injector (995)**
Aerosol-Sealing Large Commercial Ducts

Blocking Diffusers
Aerosol-Sealing Large Commercial Ducts

Downstream of VAV boxes
Aerosol-Sealing Large Commercial Ducts

- Downstream of VAV Boxes
Aerosol-Sealing Large Commercial Ducts

Sealing Through Main Supply Fan
Aerosol-Sealing Large Commercial Ducts

- Sealing Through Pneumatic-Control Terminal Boxes
Aerosol-Sealing Large Commercial Ducts
Aerosol-Sealing Large Commercial Ducts

- Dual Deck Laboratory Supply Sealing
Aerosol-Sealing Large Commercial Ducts

- Supply Shaft Sealing
Aerosol-Sealing Large Commercial Ducts

Supply Shaft Sealing
Aerosol-Sealing Large Commercial Ducts

- Large Lab Exhaust Sealing
Aerosol-Sealing Multifamily Exhaust Ducts
## Aerosol-Sealing Large Commercial Ducts

<table>
<thead>
<tr>
<th>System Type</th>
<th>Fan Flow [cfm]</th>
<th>Initial Leakage [%]</th>
<th>Fraction Sealed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant Volume Supply</td>
<td>69,000</td>
<td>19%</td>
<td>87%</td>
</tr>
<tr>
<td>Dual Duct Supply</td>
<td>93,000</td>
<td>36%</td>
<td>78%</td>
</tr>
<tr>
<td>CV Exhaust</td>
<td>22,000</td>
<td>27%</td>
<td>85%</td>
</tr>
<tr>
<td>CV Exhaust</td>
<td>20,000</td>
<td>20%</td>
<td>93%</td>
</tr>
<tr>
<td>Constant Volume Supply</td>
<td>14,000</td>
<td>19%</td>
<td>87%</td>
</tr>
<tr>
<td>VAV Supply</td>
<td>46,200</td>
<td>19%</td>
<td>92%</td>
</tr>
<tr>
<td>CV Exhaust</td>
<td>10,000</td>
<td>10%</td>
<td>90%</td>
</tr>
<tr>
<td>VAV Induction Supply</td>
<td>16,610</td>
<td>15%</td>
<td>92%</td>
</tr>
<tr>
<td>CV Supply/Exhaust</td>
<td>10,995</td>
<td>1% - 23%</td>
<td>87%</td>
</tr>
<tr>
<td>CV Exhaust</td>
<td>8,200</td>
<td>19%</td>
<td>85%</td>
</tr>
<tr>
<td>CV Exhaust</td>
<td>4,350</td>
<td>54-70%</td>
<td>75%</td>
</tr>
<tr>
<td>Constant Volume Supply</td>
<td>63,000</td>
<td>29%</td>
<td>89%</td>
</tr>
<tr>
<td>Supply/Return Risers</td>
<td>18,000</td>
<td>17%</td>
<td>91%</td>
</tr>
</tbody>
</table>

**AVERAGE**                  |                | 23%                 | 87%             |
National Impacts of Duct Leakage

• Residential Energy Savings Potential Estimate
  - 50% of energy through ducts
  - 15% average savings
  - Estimated annual savings potential = 0.7 Quads = $10B

• Commercial Energy Savings Potential Estimate
  - 25% energy savings for ventilation
  - 10% average heating/cooling savings
  - Estimated annual savings potential = 0.7 Quads = $10B