Building America: Aerosol Sealing of Building Envelopes in New Construction

Curtis Harrington, PE
UC Davis, Western Cooling Efficiency Center

EEBA High Performance Home Summit: October 11, 2017
Presentation Overview

• Air Sealing Benefits
• Basic Concept
• Development Timeline
• Building America Project
• Path Forward
• AeroBarrier Update
Energy Benefits of Air Sealing

• Large fraction of energy use for heating and cooling
  – 48% in residential
  – 35% in commercial
• Reducing envelope leakage could reduce HVAC energy use by 30%
• Better insulated envelopes increase fraction of heating & cooling associated with infiltration/ventilation
•Envelope tightness standards were fairly recently included in U.S. codes
• Cost-effective approaches to sealing envelope leakage would improve and simplify adherence to code
IECC Codes Around U.S.

More stringent codes are forcing builders to change the way they build their homes.

Chart courtesy of Oldcastle® Architectural
Single Family Envelope Air Tightness

LBNL Air Leakage Database
Health Benefits of Air Sealing

• Better control of air flow and reduced infiltration of outdoor air and outdoor pollutants (e.g. PM 2.5 or Ozone)

• Facilitates use of Mechanical Ventilation
  – HRV or ERV and filters
  – Putting HRV/ERV on leaky building doesn’t save energy or reduce uncontrolled infiltration
Health Benefits of Air Sealing (Large Buildings)

• NIST measurements of large building leakage suggest that more air is needed for pressurization than for ventilation

• Better and more efficient air flow control in sensitive spaces
  – Elimination of outdoor chemical infiltration
  – Contagious disease spaces
  – Clean rooms
  – Laboratories
  – Schools in non-compliance areas (have current CEC project on HVAC and IAQ in schools)
Other Benefits of Air Sealing (Multifamily and Hotels)

- Reduce noise transfer
- Reduce smell transfer
Basic Concept

- “Blower Door” creates and maintains positive pressure difference between indoors and outdoors
- Sealing performed by fogging a space with aerosolized sealant particles
- Particles carried to leaks by escaping air flow
- Entire sealing process is tracked and displayed in real time and documented electronically
- Finds and seals leaks missed or inaccessible by manual trial-and-error methods
Basic Concept

Seal formed between gap in foam
Development Timeline

- **2011**
  - Proof-of-concept in laboratory
  - First single-family homes sealed

- **2012**
  - First multifamily sealed
  - First single-family retrofit

- **2013**
  - New multipoint injection system developed

- **2014**
  - First multifamily retrofits

- **2015**
  - Technology licensed to AeroSeal
  - First installation by AeroSeal

- **2016**
  - First non-residential building retrofit

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**UC Davis**

**Western Cooling Efficiency Center**
Proof-of-Concept Testing

• Adapted duct sealing technology
• Started out sealing 4’ by 8’ by 8’ box
• Independent variables tested
  – Injection rate
  – Enclosure pressure
• Dependent variables recorded
  – Sealing rate
  – Sealant use efficiency

Seal formed between gap in foam
Demonstrations with Habitat for Humanity

• First demonstration in real building
• Determined need for multiple injection point
• It worked!
Honda Smart Home

- Implemented temp/humidity control

![Graph showing ACH50 values for different test periods and 2009/2012 IECC standards.]

<table>
<thead>
<tr>
<th></th>
<th>2009 IECC</th>
<th>2012 IECC</th>
<th>Pre Test 1</th>
<th>Post Test 1</th>
<th>Pre Test 2</th>
<th>Post Test 2</th>
<th>Goal (Passive House)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009 IECC</td>
<td>7</td>
<td>3</td>
<td>4.15</td>
<td>2.61</td>
<td>2.56</td>
<td>0.79</td>
<td>0.6</td>
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</tbody>
</table>

Manual sealing accomplished by 3 contractors over 8 hours.
New York Apartments (Building America)

- Sealed multiple apartments in a day
- Side-by-side application humidity analysis
  - Better seal quality with higher RH
- Measured sound transmission reduction
- Determined no prep required
Single Family Sealing on Production Scale (Building America)

- Sealed two houses per day
- Tracked time and materials

![Graph showing leakage flowrate at 50 Pa (CFM) over elapsed time (minutes). Seal formed between gap in foam.](image-url)
Minneapolis Apartments

- New and existing apartments
- Applied in cold weather

**Results from 18 New Apartments**

**Results from 9 Existing Apartments**

- Pre-Sealing
- Post-Sealing

Seal formed between gap in foam
Pre-Sheetrock Sealed leaks

Seal formed between gap in foam
Post-Sheetrock Sealed Leaks

Seal formed between gap in foam
Building America Project Goals

Integrate aerosol envelope sealing into home building process

• Determine appropriate time for applying
• Measure performance relative to conventional methods
• Determine existing sealing efforts that could be avoided
• Determine cost-effectiveness
Building America Project Team

• Project Partners:
  – Center for Energy and Environment
  – Building Knowledge Inc.
  – University of Minnesota’s Cold Climate Housing Program
  – Aeroseal LLC

• Builders:
  – Two in California
  – Two in Minnesota
Building America Project Approach

House Leakage Assessment
- Review existing sealing practices
- Aerosol sealing demonstration

Develop Two Sealing Options
- Meet with builder to go over options
- Pick two promising approaches

Perform Aerosol Sealing
- Seal at least two homes under each option
- Evaluate impact relative to baseline

Refine Sealing Options
- Refine most promising option

Perform Aerosol Sealing
- Seal 3-4 homes under refined option
# Air Sealing Assessment

<table>
<thead>
<tr>
<th>Category</th>
<th>Component</th>
<th>Who does sealing?</th>
<th>Material used for sealing?</th>
<th>Can AeroBarrier Replace?</th>
<th>Quality of seal work</th>
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</thead>
<tbody>
<tr>
<td>Ceiling/Attic</td>
<td>Attic access panels</td>
<td>Gasketed Door</td>
<td>No</td>
<td>Excellent</td>
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<tr>
<td></td>
<td>Drop down stairs</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td></td>
<td>Whole-house fans</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
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<tr>
<td></td>
<td>Recessed lighting fixtures</td>
<td>N/A</td>
<td>Gasketed fixture</td>
<td>Yes</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Drop ceiling/soffit</td>
<td>Insulation Contractor</td>
<td>Closed Cell Spray Foam</td>
<td>Yes</td>
<td>Excellent</td>
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<tr>
<td>Walls</td>
<td>Exterior Walls</td>
<td>Insulation Contractor</td>
<td>Gasket/OSB</td>
<td>N/A</td>
<td>Excellent</td>
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<tr>
<td></td>
<td>Sill Plate</td>
<td>Carpenter</td>
<td>Gasket/OSB</td>
<td>Yes</td>
<td>Acceptable</td>
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<tr>
<td></td>
<td>Top Plate</td>
<td>Insulation Contractor</td>
<td>Gasket</td>
<td>Yes</td>
<td>Acceptable</td>
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<tr>
<td></td>
<td>Drywall to top plate</td>
<td>Insulation Contractor</td>
<td>Gasket</td>
<td>Yes</td>
<td>Excellent</td>
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<tr>
<td></td>
<td>Interior partition wall to exterior wall</td>
<td>Carpenter/Insulation Contractor</td>
<td>Solid Blocking/Can Foam</td>
<td>Yes</td>
<td>Excellent</td>
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<tr>
<td></td>
<td>Knee walls</td>
<td>Carpenter</td>
<td>OSB</td>
<td>Excellent</td>
<td></td>
</tr>
<tr>
<td>Windows, skylights and doors</td>
<td>Rough openings</td>
<td>Window Installation Contractor</td>
<td>Can Foam</td>
<td>Yes</td>
<td>Excellent</td>
</tr>
<tr>
<td>Rim joists</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ducts</td>
<td>Insulation Contractor</td>
<td>Can Foam/Open Cell Spray Foam</td>
<td>No</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Flues</td>
<td>Insulation Contractor</td>
<td>Can Foam/Open Cell Spray Foam</td>
<td>No</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Shafts</td>
<td>Insulation Contractor</td>
<td>Can Foam/Open Cell Spray Foam</td>
<td>No</td>
<td>Excellent</td>
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<td></td>
<td>Plumbing</td>
<td>Insulation Contractor</td>
<td>Can Foam/Open Cell Spray Foam</td>
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<td>Piping</td>
<td>Insulation Contractor</td>
<td>Can Foam/Open Cell Spray Foam</td>
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<td>Excellent</td>
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<td></td>
<td>Wiring</td>
<td>Insulation Contractor</td>
<td>Can Foam/Open Cell Spray Foam</td>
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<td>Excellent</td>
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<td></td>
<td>Exhaust fans</td>
<td>Insulation Contractor</td>
<td>Can Foam/Open Cell Spray Foam</td>
<td>Yes</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td></td>
<td></td>
<td>N/A</td>
<td></td>
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<tr>
<td>Garage separation walls</td>
<td>Floor cavities aligned with garage separation walls</td>
<td>Carpenter/Insulation Contractor</td>
<td>Blocking/Open Cell Spray Foam</td>
<td>No</td>
<td>Excellent</td>
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<tr>
<td></td>
<td>Shower/tub on exterior wall</td>
<td>Carpenter/Insulation Contractor</td>
<td>OSB/Open Cell Spray Foam</td>
<td>Yes</td>
<td>Excellent</td>
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<td></td>
<td>Stair stringer on exterior wall</td>
<td>None</td>
<td>Yes</td>
<td>N/A</td>
<td></td>
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<tr>
<td></td>
<td>Fireplace on exterior wall</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
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<td></td>
<td>Electrical/low voltage boxes on exterior walls</td>
<td>None</td>
<td>Yes</td>
<td>N/A</td>
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<td></td>
<td>HVAC register boots that penetrate building thermal envelope</td>
<td>N/A</td>
<td>Yes</td>
<td>N/A</td>
<td></td>
</tr>
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</table>

**ENERGY STAR Rater Field Checklist**
Building America Interim Results

• California Builder #1
• Homes designed with sealed attics
• Using open-cell spray foam
  – Under roof deck
  – At rim joist and other mechanical penetrations
• Fiberglass/mineral wool in wall cavity
• HRV integrated into central air handler
• Target leakage of 800 CFM50 (2.1-2.4 ACH50)
Conventional Sealing

- Can foam at seams where wood is joined
- Can foam and gasket at sill plate
- Foam gasket to seal drywall to top plate
Sealing Options

• Sealing options
  – Option 1: Seal home after open-cell spray foam insulation
  – Option 2: Seal home before spray foam insulation

• Advantage of sealing before drywall
  – Addresses outer wall surface
  – Seals less prone to damage in wall cavity
  – Easier aerosol distribution
Option 1

Foam at roof deck

Foam at rim joist
## Option 1 Results

<table>
<thead>
<tr>
<th>Stage/Option</th>
<th>Lot</th>
<th>Plan</th>
<th>Floor Area (ft²)</th>
<th>Volume (ft³)</th>
<th>Pre-Seal</th>
<th>Post-Seal</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>After Foam</td>
<td>7</td>
<td>3</td>
<td>2569</td>
<td>23121</td>
<td>1690</td>
<td>429</td>
<td>75%</td>
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<tr>
<td>After Foam</td>
<td>8</td>
<td>1</td>
<td>2032</td>
<td>22215</td>
<td>1286</td>
<td>351</td>
<td>73%</td>
</tr>
</tbody>
</table>

![Graph showing leakage over elapsed minutes]
Option 1 Example Seals

Seals formed under trusses

Seal formed at corner of wall assembly
Option 2

Exposed roof deck

Rim joist penetrations
Option 2 Pre sealing work

- Large penetrations needed to be sealed prior to aerosol sealing
- Time/materials for pre-sealing was tracked
Prepare for unexpected!
## Pre-Sealing Time/Materials

<table>
<thead>
<tr>
<th>Stage/Option</th>
<th>Sealing Penetrations</th>
<th>Sealing Gap at Eaves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Foam</td>
<td>1.5</td>
<td>3</td>
</tr>
<tr>
<td>Before Foam</td>
<td>4.5</td>
<td>6</td>
</tr>
</tbody>
</table>

*Note: Pre-sealing work performed by inexperienced staff*
## Option 2 Results

<table>
<thead>
<tr>
<th>Stage/Option</th>
<th>Lot</th>
<th>Plan</th>
<th>Floor Area (ft²)</th>
<th>Volume (ft³)</th>
<th>Pre-Seal</th>
<th>Post-Seal</th>
<th>After Foam</th>
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</thead>
<tbody>
<tr>
<td>Before Foam</td>
<td>23</td>
<td>3</td>
<td>2569</td>
<td>23121</td>
<td>5836</td>
<td>15.14</td>
<td>2569</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>828</td>
<td>2.15</td>
<td>483</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>% Reduction 86%</td>
<td>CFM50 % Reduction 15.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ACH50 483</td>
<td>1.25</td>
<td>352</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>% Reduction 42%</td>
<td>ACH50 % Reduction 42%</td>
<td></td>
</tr>
<tr>
<td>Before Foam</td>
<td>24</td>
<td>2</td>
<td>2223</td>
<td>20007</td>
<td>3005</td>
<td>9.01</td>
<td>3005</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>477</td>
<td>1.43</td>
<td>3005</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>% Reduction 84%</td>
<td>CFM50 % Reduction 84%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ACH50 352</td>
<td>1.06</td>
<td>352</td>
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<td></td>
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<td></td>
<td></td>
<td>% Reduction 26%</td>
<td>ACH50 % Reduction 26%</td>
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</table>

![Leakage (cfm at 50 Pa) vs. Elapsed Minutes](image)

**Elapsed Minutes**

**Leakage (cfm at 50 Pa)**
Option 2 Example Seals
CA Builder #1 Results Summary

- **79%**: Average leakage reduction
- **73%**: Tighter than baseline homes
- **56%**: Greater building tightness using Aerosols versus open-cell spray foam

![Bar Chart](Image)

**ACH50**

- **Option 1**: Pre-Seal, Post-Seal
- **Option 2**: Pre-Seal, Post-Seal, Option2 After Foam
Minnesota Builders

• Minnesota Builder #1
• Homes designed with ventilated attics
• Closed-cell spray foam at rim joist
• Interior poly wrap
• Fiberglass/mineral wool in wall cavity
• ERV integrated into central air handler
Conventional Sealing

Caulk at seams where wood is joined

Can foam at wire penetrations

Caulk at sill plate
Proposed Sealing Options

• Option 1:
  – Seal home after spray foam at rim joist
  – Reinforced poly at ceiling-attic interface
  – Maintain conventional sealing

• Option 2 (Ultimately not implemented):
  – Seal home after spray foam at rim joist
  – Reinforced poly at ceiling-attic interface
  – Do not install:
    • Airtight electrical boxes
    • Interior poly
Sealing Results

Leakage (cfm at 50 Pa) vs. Elapsed Minutes
Reinforced Poly Failure
## MN Builder #1 Results Summary

<table>
<thead>
<tr>
<th>Stage/Option</th>
<th>Floor Area (ft²)</th>
<th>CFM50 Pre-Seal</th>
<th>ACH50 Pre-Seal</th>
<th>CFM50 Post-Seal</th>
<th>ACH50 Post-Seal</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demo 1</td>
<td>3,636</td>
<td>2,200</td>
<td>3.94</td>
<td>358</td>
<td>0.64</td>
<td>84%</td>
</tr>
<tr>
<td>Blaine</td>
<td>4,470</td>
<td>2,637</td>
<td>3.81</td>
<td>728</td>
<td>1.05</td>
<td>72%</td>
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<tr>
<td>Eagan</td>
<td>3,955</td>
<td>2,300</td>
<td>3.78</td>
<td>409</td>
<td>0.67</td>
<td>82%</td>
</tr>
<tr>
<td>Plymouth</td>
<td>4,248</td>
<td>1,893</td>
<td>2.87</td>
<td>1,023</td>
<td>1.55</td>
<td>46%</td>
</tr>
<tr>
<td>Lakeville</td>
<td>4,478</td>
<td>1,959</td>
<td>2.82</td>
<td>674</td>
<td>0.97</td>
<td>66%</td>
</tr>
<tr>
<td>Demo 2</td>
<td>4,135</td>
<td>419</td>
<td>0.70</td>
<td>209</td>
<td>0.35</td>
<td>50%</td>
</tr>
</tbody>
</table>

*Percent Reduction:*

- 84%
- 72%
- 82%
- 46%
- 66%
- 50%

### Batt Insulation in Walls

- After Drywall

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*UC Davis - Western Cooling Efficiency Center*
Example Seals

Seal formed between studs

Seal formed at electrical box

Seals formed at wire penetrations

Seals formed at plumbing penetrations
Building America Project Path Forward

• Final leakage tests when homes are complete
• Refine sealing option
  – Demonstrate refined option on 3-4 homes
• Start work with Builder #2 in both CA and MN
  – Currently looking for builders in Sacramento area
• Develop guidelines for future installations
Research Path Forward

• Application in commercial buildings
  – Wrapping up project for DoD on non-res retrofits
  – Commercial buildings present challenges
    • Roof-to-wall connection
    • Supplemental manual sealing sometimes required

• Application in existing homes
  – Existing homes are leakier
  – Apply at time of tenant change
AeroBarrier Update
Recent Successes and Upcoming Projects

- **Passive House**: Mandalay Homes (Prescott, AZ) and 9thAve. (Brooklyn, NY)
- **Multi-Family (New Build)**: 101 Apartments (Queens, NY)
- **Renovation Application**: 7 renovated apartments sealed to 1 ACH50 (Rockford, IL)
- **Apartment Compartmentalization**: 36 semi-finished apartments (Brooklyn, NY)
- **Apartment Comparison**: 3 units sealed pre drywall, 3 units to be sealed after drywall to 3 ACH50 (Dayton, OH)
- **Center for Energy and Environment and DOE project**: 34 single family houses (17 in California, 17 in Minnesota)
- **Duke Energy**: 45 rooms to 74 CFM$_{50}$ or tighter to create “safe spaces” (North and South Carolina, and Indiana)
- **Smoke Control Compartmentalization**: 202 rooms in a micro-hotel (San Francisco, CA)
Mandalay Homes became the first production builder to incorporate AeroBarrier into all of their homes

“AeroBarrier may be the most important innovation to hit the building community in years...The ability to consistently seal all the small leaks that would otherwise take countless man hours to seek and hand seal, assuming you even find them all, in just 1 automated application is simply amazing. The cost effectiveness is beyond immeasurable when you consider the total sealing solution AeroBarrier provides and all the labor saved by automating the application process. We couldn't be happier with AeroBarrier and the fine folks behind the product.”

- Geoff Ferrel
Chief Technology Officer, Mandalay Homes

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Project Overview:

Project: DOE Challenge Home
Builder: Mandalay Homes
Location: Prescott, Arizona

Results:
Pre-leakage: 3.1 ACH50
Post-Leakage: 0.4 ACH50
Reduction: 86.4%
Sealing Time: 2.5 hours
AeroBarrier Allows Engineers to Easily Attain Desired Tightness for Energy Efficiency, Comfort, and Livability.

“It was blowing people’s minds – mostly because monitoring compartmentalization in a multi-family building under construction is typically a very difficult, time consuming task. The level of coordination and commitment you need to get from all contractors on the job is as critical as it is nearly impossible to achieve. With AeroBarrier, it’s simply not a problem.”

- Chris Benedict, R.A.
  Architect - CBRA

“I don’t know of any other way to get the level of tightness we were looking for. No amount of caulking could get this type of result. Most importantly, with AeroBarrier, you know you’re going to get the results you want in the end. It’s cost-effective and highly efficient at reducing energy costs and improving livability for our tenants. There’s nothing that can compete with that.

- Justin Palmer, CEO
  Synapse Development

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**Project Overview:**

**Project:** 153rd St Apartments  
**Builder:** Synapse Development Group  
**Architect:** Chris Benedict, R.A.  
**Location:** Upper West Side, Manhattan

**Results:**
Post-manual sealing, AeroBarrier reduced unit leakage by an additional 47%, providing overall compartmentalization levels well within calculated passive house parameters.
AeroBarrier Works in Renovation Applications Too.

Low air leakage numbers can be hard to achieve in renovation applications because the exterior and framing typically stays in place. When the builder is looking to achieve 1 ACH\textsubscript{50} or less, this becomes significantly more difficult.

“Without AeroBarrier we would have spent countless hours seeking out and manually sealing all the leaks we could find. The problem was, we couldn’t see most of the leaks because they were in the walls or framing that was staying in place. So to achieve our goal of 1 ACH\textsubscript{50} with manual sealing was a very daunting, most likely unachievable task.

AeroBarrier was able to seal all 7 apartments within two days, without a problem. We even had some apartments starting as high as 17 ACH\textsubscript{50} that AeroBarrier got down to 1 ACH\textsubscript{50}. The time that was saved and the results that were achieved were amazing. We wouldn’t have been able to achieve the results we did without AeroBarrier…”

- Jason LeFleur.
President, Eco Achievers
AeroBarrier used to seal “safe havens” in industrial buildings

AeroBarrier’s versatility has been on display sealing “safe haven” rooms in a coal power plant.

If there were ever to be an airborne leak at the power plant employees can close themselves in one of these rooms and fresh air will be pumped into the space. Because of the effectiveness of AeroBarrier and the results we can achieve, the “safe havens” will keep the fresh air in the room and the chemical leak out. Allowing the employees to stay in the room up to 2 hours.

Results:

Pre-Leakage: 10.4 ACH<sub>50</sub> (1,323.2 CFM)
Post-Leakage: 0.5 ACH<sub>50</sub> (60.4 CFM)
Sealing Time: 2 hours 20 min
AeroBarrier is Available Now Anywhere in the Country.