Problem Statement & Project Focus

- Air leakage is a significant contributor to HVAC loads
  - ~50% in residential buildings (Sherman and Matson 1997)
  - ~33% of heating loads in office buildings (Emmerich et al. 2005)

- Airtightness of buildings listed in BTO prioritization tool

- IECC 2012 airtightness requirements

  Residential Construction
  - Zones 1 and 2: \( \text{ACH}_{50} \leq 5 \)
  - Zones 3 through 8: \( \text{ACH}_{50} \leq 3 \)

  Commercial Construction
  - Zones 1 through 3: no air barrier required
  - Zones 4 through 8:
    - Air barrier material \( \leq 0.02 \, \text{L/(s·m}^2) \) at 75 Pa or
    - Air barrier assembly \( \leq 0.2 \, \text{L/(s·m}^2) \) at 75 Pa or
    - Building enclosure \( \leq 2 \, \text{L/(s·m}^2) \) at 75 Pa
Problem Statement

Field measurements vs. IECC 2012

Residential

<table>
<thead>
<tr>
<th>Year</th>
<th>Type</th>
<th>ACH&lt;sub&gt;50&lt;/sub&gt;</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993 - 1995</td>
<td>n = 496</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>1996 - 2000</td>
<td>n = 8,268</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2002 - 2004</td>
<td>California</td>
<td>5</td>
<td>106</td>
</tr>
</tbody>
</table>

Commercial (office buildings)

<table>
<thead>
<tr>
<th>Source</th>
<th>Year</th>
<th>ACH&lt;sub&gt;50&lt;/sub&gt;</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIST&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1993 - 1995</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>FSEC&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1996 - 2000</td>
<td>5</td>
<td>88</td>
</tr>
<tr>
<td>Camroden&lt;sup&gt;e&lt;/sup&gt;</td>
<td>1996 - 2000</td>
<td>3</td>
<td>23</td>
</tr>
<tr>
<td>ACoE&lt;sup&gt;f&lt;/sup&gt;</td>
<td>1996 - 2000</td>
<td>3</td>
<td>79</td>
</tr>
<tr>
<td>PSU&lt;sup&gt;f&lt;/sup&gt;</td>
<td>1996 - 2000</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Average: 7.9 L/(s·m<sup>2</sup>) at 50 Pa

Average: 2.0 L/(s·m<sup>2</sup>) at 75 Pa

**Notes:**

- a. Sherman and Matson 2002
- b. Offermann 2009
- c. Persily and Grot 1986; Persily et al. 1991; Musser and Persily 2002
- d. Cummings et al. 1996; Cummings et al. 2000
- e. Brennan et al. 1992
- f. Bahnfleth et al. 1999

ACoE: US Army Corps of Engineers
FSEC: Florida Solar Energy Center
NIST: National Institute of Standards and Technology
PSU: Penn State University
- Cost-effective means to meet and exceed IECC 2012 requirements

- Evaluate the eight typical air barrier types

- Tests

- Membranes
  - Interior
  - Mechanically-fastened
  - Self-adhered
  - Fluid-applied non-foaming

- Sheathings
  - Non-insulating
  - Insulating

- Sealants
- Spray-applied foam

- Field test
- Sub-assembly tests
- Material characterization
Phase 2: Field Tests

- **Effect of air leakage on energy and durability**
  - **Material:** Level 1 $\rightarrow$ 0.02 L/(s·m$^2$) @ 75 Pa → **Baseline**
  - **Assembly:** Level 2 $\rightarrow$ 0.2 L/(s·m$^2$) @ 75 Pa
  - **Enclosure:** Level 3 $\rightarrow$ 2 L/(s·m$^2$) @ 75 Pa

- **Eight air barrier types**

<table>
<thead>
<tr>
<th>Membranes</th>
<th>Sheathings</th>
<th>Seals</th>
<th>Spray-applied foam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interior</td>
<td>Non-insulating</td>
<td>Sealants</td>
<td>Non-insulating</td>
</tr>
<tr>
<td>Mechanically-fasted</td>
<td>Insulating</td>
<td>Fluid-applied non-foaming</td>
<td>Spray-applied foam</td>
</tr>
<tr>
<td>Self-adhered</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluid-applied</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>non-foaming</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Three wall samples per air barrier type**
  - Representative of residential or commercial construction
  - Simulated imperfections

- **Data collection started in November 2011**
Field Tests: Wall Assembly

General Material Layout
Horizontal Cross Section of Wall

- Vinyl or fiber cement siding
- 1/2" air gap
- Furring strip
- R-7.5 XPS rigid foam insulation w/ unsealed joints and edges
- Air barrier (placement varies with type)
- Exterior sheathing
- Unpainted drywall
- Electrical outlet
- R-13 faced fiberglass insulation
- Wood or steel studs

General Sensor Layout
Vertical Cross Section of Wall

- T, RH, P, MP
- T, RH, HF
- T, RH, P
- T, RH
- T, RH, HF
- T, MP

HF: heat flux
MP: moisture pin
P: pressure
RH: relative humidity
T: temperature
Field Tests: Heat Flux Data

Air barrier type: non-insulating sheathing (south facing walls)
Imperfection: unsealed OSB joint at stud

<table>
<thead>
<tr>
<th>Compared air leakage levels</th>
<th>Sensor location</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 3 vs. Level 1</td>
<td>½ height</td>
<td>54</td>
<td>39</td>
<td>48</td>
<td>37</td>
<td>44</td>
<td>19</td>
</tr>
<tr>
<td>Level 2 vs. Level 1</td>
<td></td>
<td>11</td>
<td>7</td>
<td>9</td>
<td>7</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Level 3 vs. Level 1</td>
<td>¼ height</td>
<td>97</td>
<td>67</td>
<td>90</td>
<td>71</td>
<td>80</td>
<td>43</td>
</tr>
<tr>
<td>Level 2 vs. Level 1</td>
<td></td>
<td>13</td>
<td>8</td>
<td>13</td>
<td>11</td>
<td>12</td>
<td>8</td>
</tr>
</tbody>
</table>
Field Tests: Moisture in Wall Cavities

Air barrier type: mechanically-fastened membrane
South facing walls
Imperfection: penetration through air barrier

<table>
<thead>
<tr>
<th>Level 1 – Baseline</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.07 L/(s·m²)</td>
<td>0.28 L/(s·m²)</td>
<td>0.73 L/(s·m²)</td>
</tr>
</tbody>
</table>

@ ΔP = 75 Pa

Air barrier type: insulating sheathing
East facing walls
Imperfection: gaps between top/bottom track & stud

<table>
<thead>
<tr>
<th>Level 1 – Baseline</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.03 L/(s·m²)</td>
<td>0.36 L/(s·m²)</td>
<td>0.5 L/(s·m²)</td>
</tr>
</tbody>
</table>

@ ΔP = 75 Pa
Field Tests: Moisture in Wall Cavities

<table>
<thead>
<tr>
<th>Air barrier type: mechanically-fastened membrane</th>
<th>Air barrier type: insulating sheathing</th>
</tr>
</thead>
<tbody>
<tr>
<td>South facing walls</td>
<td>East facing walls</td>
</tr>
</tbody>
</table>

**January 2012**

<table>
<thead>
<tr>
<th>Relative Humidity (%)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
</table>

- Airtightness can affect the drying potential of walls
- Condensation occurred despite the R-7.5 XPS exterior insulation
Phase 3: Sub-Assembly Tests

- **Characterize major air leakage paths**
  - Joints: wall / foundation, wall / roof, exterior sheathing
  - Penetrations: electrical outlets, pipes
  - ASTM E2357

- **Assess common sealing methods for each air barrier type**

- **Test matrix**

<table>
<thead>
<tr>
<th>Air barrier type</th>
<th>Wall framing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wood (8’×8’)</td>
</tr>
<tr>
<td>Fluid-applied non-foaming liquid</td>
<td>Complete</td>
</tr>
<tr>
<td>Insulating sheathing</td>
<td>Complete</td>
</tr>
<tr>
<td>Non-insulating sheathing</td>
<td>Complete</td>
</tr>
<tr>
<td>Interior air barrier</td>
<td>Complete</td>
</tr>
<tr>
<td>Mechanically-fastened membrane</td>
<td>Complete</td>
</tr>
<tr>
<td>Self-adhered membrane</td>
<td>Complete</td>
</tr>
<tr>
<td>Spray-applied foam</td>
<td>Complete</td>
</tr>
<tr>
<td>Sealants w/ backup structure</td>
<td>Complete</td>
</tr>
<tr>
<td>Interior drywall</td>
<td>Complete</td>
</tr>
<tr>
<td>Baseline (i.e., no air barrier)</td>
<td>Complete</td>
</tr>
<tr>
<td><strong>Number of tests</strong></td>
<td>10</td>
</tr>
</tbody>
</table>
Sub-Assembly Tests:
Characterization of Major Air Leakage Paths

**Air Leakage Effects**

<table>
<thead>
<tr>
<th>Joint Type</th>
<th>Leakage Rate</th>
<th>Contribution to IECC Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheathing / roof joint</td>
<td>1.7 (L/s)/m @ 50 Pa, 1.1 cfm/(ft) @ 50 Pa</td>
<td>6% 93%</td>
</tr>
<tr>
<td>Sheathing / foundation joint</td>
<td>1.7 (L/s)/m @ 50 Pa, 1.1 cfm/(ft) @ 50 Pa</td>
<td>8% 72%</td>
</tr>
</tbody>
</table>

- **2-Story house** (Floor area = 2,000 ft²)
  - Both joints unsealed                \( \approx 1 \text{ ACH}_{50} \)
    - Contribution to IECC requirement \( \approx 33\% \)
  - Both joints unsealed + bottom plate sealed to flooring + top plates continuously sealed \( \approx 0.96 \text{ ACH}_{50} \)
    - Contribution to IECC requirement \( \approx 32\% \)

IECC 2012 requirement = 3 ACH_{50}
Sub-Assembly Tests: Comparison of Air Barrier Types

- Airtight drywall approach (ADA)
  - Economical
  - Time consuming

- Mechanically-fastened membrane
  - Economical
  - Air leaked at nailed fasteners
  - Will repeat test with screwed fasteners

- Non-insulating sheathing
  - Easier to meet wall assembly airtightness requirements
  - More expensive than ADA

- Fluid-applied membrane
  - Easier to meet wall assembly airtightness requirements
  - More expensive than other tested systems
## Project Plan & Schedule

### Project Name: Air Barriers for Residential and Commercial Buildings

**Complete CRADA with ABAA**

**Interim report for Phase 2**

**Current work and future research**

- **Q1:** Heat-air-moisture chamber quality assurance test and delivery to ORNL
- **Q2:** Complete first year of Phase 2
- **Q3:** Commissioning of heat-air-moisture chamber
- **Q4:** Continue Phase 3
  - Continue Phase 2 tests
  - Airtightness assessment of Flexible Research Platform (FRP) facilities

### Milestones & Deliverables (Original Plan)

<table>
<thead>
<tr>
<th>Task / Event</th>
<th>FY2012</th>
<th>FY2013</th>
<th>FY2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete CRADA with ABAA</td>
<td></td>
<td></td>
<td>$\diamond$</td>
</tr>
<tr>
<td>Interim report for Phase 2</td>
<td></td>
<td>$\diamond$</td>
<td></td>
</tr>
<tr>
<td>Heat-air-moisture chamber quality assurance test and delivery to ORNL</td>
<td>$\diamond$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complete first year of Phase 2</td>
<td></td>
<td>$\diamond$</td>
<td></td>
</tr>
<tr>
<td>Commissioning of heat-air-moisture chamber</td>
<td></td>
<td>$\diamond$</td>
<td></td>
</tr>
<tr>
<td>Continue Phase 3</td>
<td></td>
<td>$\diamond$</td>
<td></td>
</tr>
<tr>
<td>Continue Phase 2 tests</td>
<td></td>
<td>$\diamond$</td>
<td></td>
</tr>
<tr>
<td>Airtightness assessment of Flexible Research Platform (FRP) facilities</td>
<td></td>
<td>$\diamond$</td>
<td></td>
</tr>
</tbody>
</table>

### Milestones & Deliverables (Actual)

- **Q1 (Oct-Dec)**: Complete CRADA with ABAA
- **Q2 (Jan-Mar)**: Interim report for Phase 2
- **Q3 (Apr-Jun)**: Heat-air-moisture chamber quality assurance test and delivery to ORNL
- **Q4 (Jul-Sep)**: Continue Phase 2 tests
- **FY2013**
  - **Q1 (Oct-Dec)**: Commissioning of heat-air-moisture chamber
  - **Q2 (Jan-Mar)**: Continue Phase 3
- **FY2014**
  - **Q1 (Oct-Dec)**: Airtightness assessment of Flexible Research Platform (FRP) facilities
Project Budget

Project budget
- FY13 project budget is $275K ($150K from ET and $125K from RBI)

Variances
- No variances from planned budget

Cost to date
- As of 20 March, $115K or 42% of budget expended

Additional funding
- No other funding sources beyond in-kind contributions

<table>
<thead>
<tr>
<th></th>
<th>FY2010</th>
<th>FY2011</th>
<th>FY2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE</td>
<td>$550K</td>
<td>$400K</td>
<td>$400K</td>
</tr>
<tr>
<td>Cost-share</td>
<td>$300K</td>
<td>$300K</td>
<td>$600K</td>
</tr>
</tbody>
</table>
Project Integration, Collaboration & Market Impact

Partners and Technology Transfer

Communications
- Hun and Desjarlais (2011) Update to ABAA research participants, Syracuse, NY
- Hun and Desjarlais (2012) Air Barrier Conference, Chicago, IL
- Hun and Desjarlais (2013) Durability + Design Journal
- Hun and Desjarlais (2013) Air Barrier Conference, Chicago, IL
- Hun and Desjarlais (2013) Update to ABAA research participants, Indianapolis, IN
- Hun et al. (2013) Buildings XII Conference, Clearwater, FL
Next Steps and Future Plans: Continue CRADA with ABAA

- Continue monitoring some of the Phase 2 panels
- Finish sub-assembly tests
- Airtightness retrofits of Flexible Research Platforms
  - Simulate light commercial buildings from the 1980s
  - 1-story FRP: Metal Building Manufacturers Association (MBMA)
  - 2-story FRP: Energy Efficient Buildings Hub (EEB Hub)