HIGH PERFORMANCE BUILDING ENVELOPES

Dave Seifert

Design

Construction

Commissioning
PRESENTATION OVERVIEW

• About BCRA
• How Did We Get Here...?
• What is a High Performance Building Envelope?
• Energy Conservation Considerations
• Durability Considerations
• High Performance Building Standards & Certifications
• Envelope Commissioning
• Air Leakage Testing
BCRA BUILDING ENVELOPE GROUP

• High Performance Envelope design
• Independent technical reviews
• Hygrothermal analysis/modeling
• Water and air leakage performance testing
• Exterior envelope commissioning
• 2D/3D thermal modeling
• Forensic investigation
• Air Barrier design and testing
BCRA - AIR BARRIERS

• Air barrier design and testing nationwide for over 1 billion dollars of construction across the U.S. in the past 5 years
• Building air leakage performance testing results as low as 0.07 CFM/SF, all below 0.25 CFM/SF, majority below 0.20 CFM/SF
• Results of High Performance Envelope design with substantial energy savings being reported, as high as 46%
FEDERAL LEGISLATION

Energy Policy Act of 2005
• Energy Efficient Commercial Buildings Tax Deduction

• Energy Savings in Buildings and Industry
• High Performance Commercial Buildings
STATE LEGISLATION

Senate Bill 5854 - 2009
- Climate Pollution Reduction - Energy Efficiency

RCW 19.27A - Energy-Related Building Standards
RCW 19.27A.130 - FINDING

The legislature finds that energy efficiency is the cheapest, quickest, and cleanest way to meet rising energy needs, confront climate change, and boost our economy. More than thirty percent of Washington's greenhouse gas emissions come from energy use in buildings. Making homes, businesses, and public institutions more energy efficient will save money, create good local jobs, enhance energy security, reduce pollution that causes global warming, and speed economic recovery while reducing the need to invest in costly new generation. Washington can spur its economy and assert its regional and national clean energy leadership by putting efficiency first. Washington can accomplish this by: Promoting super efficient, low-energy use building codes; requiring disclosure of buildings’ energy use to prospective buyers; making public buildings models of energy efficiency; financing energy saving upgrades to existing buildings; and reducing utility bills for low-income households.
RCW 19.27A.160 - Residential and nonresidential construction — Energy consumption reduction

...residential and nonresidential construction permitted under the 2031 state energy code must achieve a seventy percent reduction in annual net energy consumption, using the adopted 2006 Washington state energy code as a baseline.

- 2009 Energy Code – 13% reduction for commercial buildings
- 2012 Energy Code – 18% reduction for commercial buildings
- 2030 – 70% reduction in energy consumption over the 2006 State Energy Code
Definition - High Performance Building

**High Performance Building** - a building that integrates and optimizes on a life cycle basis all major high performance attributes, including:

- Energy Conservation
- Environment
- Safety
- Security
- Durability
- Accessibility
- Cost-Benefit
- Productivity
- Sustainability
- Functionality
- Operational Considerations

*SOURCE: ENERGY INDEPENDENCE AND SECURITY ACT OF 2007*
High Performance Building Envelope Goals

Primary Goal
• Reduce Energy consumption while increasing Durability

Secondary Considerations
• Security
• Sustainability
• Acoustical Performance

Secondary Benefits
• Increased Occupant Comfort & Productivity
• Cost-Benefit (Life Cycle Performance)
• Reduced Maintenance & Operational Cost
Energy Conservation Considerations

1. Building Shape and Orientation
2. Building Floor to Enclosure Ratio
3. Window-to-Wall Ratio
4. Window Performance (U-Value and SHGC)
5. Air Leakage
6. Thermal Bridging
7. Thermal Insulation
8. Thermal Mass
9. Shading and Overhangs
10. Entrances
11. Color of Exterior Surfaces
Energy Conservation Considerations
Building Shape and Orientation

• 1,550 sf building
• Differences in annual energy use for same floor area but different shape

![Diagram showing differences in heating loads and energy consumption for buildings with different shapes.

Heating Loads:
- 12,415 kWh (Original)
- 13,289 kWh (+7%)
- 14,274 kWh (+7.4%)
- 14,302 kWh (+7.6%)
- 15,662 kWh (+17.9%)]
Energy Conservation Considerations
Building Floor-To-Enclosure Ratio (F/E)

- The more compact the building form, the higher the F/E ratio
- A higher F/E ratio provides a lower enclosure-to-floor area ratio
Energy Conservation Considerations

Building Floor-To-Enclosure Ratio

Six - 12 ft. stories
50' x 200'
Floor area: enclosure = 1.30

Six - 12 ft. stories
100' x 100'
Floor area: enclosure = 1.55
Energy Conservation Considerations

Window-To-Wall Ratio (WWR)

Design Considerations For High Performance Buildings:

1. Too high WWR, low energy performance
2. Too low WWR requires more interior lighting
3. Optimum WWR For HPE: 30% - 40% of area of above grade enclosure (walls and roof)
4. Higher WWR requires increased window performance (U-value)
5. State Energy Code prescriptive WWR requirement: No more than 30% of the above grade wall area
Energy Conservation Considerations
Window Performance (U-Value and SHGC)

1. **U-Value** (Btu/h∙ft²∙°F): A measure of the heat transmission through the window assembly, lower the U-value the better the insulating ability.

2. **Conversion**: $1/U$-value = R-value ($1/0.40 = 2.5$ R-value)

3. **SHGC** (Solar Heat Gain Coefficient): The measure of the solar radiation admitted through a window.

4. **SHGC** is expressed as a number between 0 to 1. A high coefficient signifies high heat gain; a low coefficient means low heat gain.
Energy Conservation Considerations
Window Performance (U-Value and SHGC)

Source: Efficient Windows Collaborative
# Energy Conservation Considerations

## Window Performance (U-Value and SHGC)

<table>
<thead>
<tr>
<th>ID</th>
<th>Glazing</th>
<th>Frame</th>
<th>U</th>
<th>SHGC</th>
<th>VT</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Single, clear</td>
<td>Metal</td>
<td>1.29</td>
<td>0.73</td>
<td>0.69</td>
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<tr>
<td>2</td>
<td>Double, clear</td>
<td>Metal</td>
<td>0.83</td>
<td>0.65</td>
<td>0.63</td>
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<tr>
<td>3</td>
<td>Double, tint</td>
<td>Metal</td>
<td>0.83</td>
<td>0.54</td>
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<tr>
<td>4</td>
<td>Double, low-e, high SHGC, argon</td>
<td>Metal</td>
<td>0.65</td>
<td>0.58</td>
<td>0.61</td>
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<tr>
<td>5</td>
<td>Double, low-e, medium SHGC, argon</td>
<td>Metal</td>
<td>0.64</td>
<td>0.38</td>
<td>0.56</td>
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<td>6</td>
<td>Double, low-e, low SHGC, argon</td>
<td>Metal</td>
<td>0.63</td>
<td>0.26</td>
<td>0.49</td>
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<tr>
<td>7</td>
<td>Double, clear</td>
<td>Metal, thermal break</td>
<td>0.60</td>
<td>0.62</td>
<td>0.63</td>
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<tr>
<td>8</td>
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<td>Metal, thermal break</td>
<td>0.60</td>
<td>0.51</td>
<td>0.47</td>
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<tr>
<td>9</td>
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<td>0.56</td>
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<tr>
<td>11</td>
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<td>Metal, thermal break</td>
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<td>0.23</td>
<td>0.49</td>
</tr>
<tr>
<td>12</td>
<td>Single, clear</td>
<td>Nonmetal</td>
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<td>0.64</td>
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<tr>
<td>13</td>
<td>Double, clear</td>
<td>Nonmetal</td>
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<td>0.57</td>
<td>0.59</td>
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<td>14</td>
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<td>Nonmetal</td>
<td>0.52</td>
<td>0.47</td>
<td>0.44</td>
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<td>15</td>
<td>Double, low-e, high SHGC, argon, improved</td>
<td>Improved nonmetal</td>
<td>0.29</td>
<td>0.50</td>
<td>0.57</td>
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<tr>
<td>16</td>
<td>Double, low-e, medium SHGC, argon, improved</td>
<td>Improved nonmetal</td>
<td>0.28</td>
<td>0.31</td>
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<td>Improved nonmetal</td>
<td>0.19</td>
<td>0.18</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Source: DOE - Measure Guideline: Energy Efficient Window Performance and Selection
Energy Conservation Considerations

Air Leakage

Air Leakage Can Cause:

- 50% - 60% reduction in thermal value of fiberglass batt insulation due wind washing
- Solution: Continuous air barrier
- State Energy Code requires air barrier
- Air leakage rate of at least 0.25 cfm/sf is recommended
Energy Conservation Considerations

Thermal Bridging

Light Gauge Steel Framed Wall

- 50% reduction in R-Value due to thermal bridging
- Solution: Continuous rigid insulation

<table>
<thead>
<tr>
<th>Actual Cavity Depth, inch</th>
<th>Rated R-Value</th>
<th>Effective R-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5 inch depth</td>
<td>R-11</td>
<td>R-6.6</td>
</tr>
<tr>
<td></td>
<td>R-13</td>
<td>R-7.2</td>
</tr>
<tr>
<td></td>
<td>R-15</td>
<td>R-7.8</td>
</tr>
<tr>
<td>6.0 inch depth</td>
<td>R-11</td>
<td>R-6.6</td>
</tr>
<tr>
<td></td>
<td>R-13</td>
<td>R-7.2</td>
</tr>
<tr>
<td></td>
<td>R-19</td>
<td>R-7.4</td>
</tr>
<tr>
<td></td>
<td>R-21</td>
<td>R-7.4</td>
</tr>
<tr>
<td>3.5 inch depth</td>
<td>R-11</td>
<td>R-5.5</td>
</tr>
<tr>
<td></td>
<td>R-13</td>
<td>R-6.0</td>
</tr>
<tr>
<td></td>
<td>R-15</td>
<td>R-6.4</td>
</tr>
<tr>
<td>6.0 inch depth</td>
<td>R-19</td>
<td>R-6.0</td>
</tr>
<tr>
<td></td>
<td>R-21</td>
<td>R-8.6</td>
</tr>
</tbody>
</table>

Source: ASHRAE 90.1
Energy Conservation Considerations

Thermal Insulation

• Problem: A 70% reduction in building energy consumption by 2030 is not possible by only increasing insulation thermal value
• Problem: The design of the building envelope may not conform to all of the high performance thermal recommendations
• Solution: Adjust insulation thermal values in the walls and roof to allow building to achieve its target EUI
  – Energy modeling of multiple scenarios is required to balance the energy performance of the building
  – Energy modeling needs to occur in Schematic Design Phase
Energy Conservation Considerations

Thermal Insulation

STATE ENERGY CODE
ENERGY EFFICIENCY COMPLIANCE

Glazing WWR <30%

Required if Glazing WWR >40%

Prescriptive
Component
Modeling

Prescriptive: R-Value, U-Value

Component: UA Calculations

Modeling: Analyze Total Building Performance Using Approved Software Programs
Durability Considerations

1. Impact
2. Fire
3. Liquid Water
4. Air Leakage
5. Vapor Diffusion
6. Condensation
7. Heat
8. Ultraviolet Light (UV)

Termite Mound, Australia
Durability Considerations

“Simplicity is a great virtue but it requires hard work to achieve it and education to appreciate it. And to make matters worse: complexity sells better.”

Edsger Wybe Dijkstra
Durability Considerations
Exterior Barrier Functions

1. SECURITY BARRIER
2. VISUAL (LIGHT) BARRIER
3. ULTRAVIOLET (UV) BARRIER
4. SOUND BARRIER
5. HEAT (THERMAL) BARRIER
6. AIR BARRIER
7. MOISTURE BARRIER (LIQUID)
8. MOISTURE BARRIER (VAPOR)
# Durability Considerations

**Exterior Barrier Functions**

1. SECURITY BARRIER
2. VISUAL (LIGHT) BARRIER
3. ULTRAVIOLET (UV) BARRIER
4. SOUND BARRIER
5. HEAT (THERMAL) BARRIER
6. AIR BARRIER
7. MOISTURE BARRIER (LIQUID)
8. MOISTURE BARRIER (VAPOR)
Durability Considerations

Exterior Barrier Functions

Listed in order of importance:

1. WATER BARRIER
2. AIR BARRIER
3. VAPOR BARRIER
4. THERMAL BARRIER

Improving the thermal barrier is a waste of resources if the water, air and vapor barriers are not properly designed and constructed.
HIGH PERFORMANCE BUILDING ENVELOPES

**AIRBORNE MOISTURE**

*Air leakage* will transport as much as 90 times more moisture than *diffusion*.

- **Diffusion**
  - 4x8 sheet of gypsum board
  - Interior at 70°F and 40% RH
  - 1/3 quart of water

- **Air Leakage**
  - 4x8 sheet of gypsum board with a 1 sq inch hole
  - Interior at 70°F and 40% RH
  - 30 quarts of water
Durability Considerations
Exterior Barrier Functions

FACE SEALED BARRIER CLADDING SYSTEMS

RAINSCREEN CAVITY CLADDING SYSTEMS
Durability Considerations
Exterior Barrier Functions

TYPICAL SECTION AT EXTERIOR FRAMED WALL

HIGH PERFORMANCE BUILDING ENVELOPES
Durability Considerations
Exterior Barrier Functions

HPE DESIGN CHALLENGES

Location Of Vapor Barrier

**Problem:**
- Locating the vapor barrier to avoid trapped moisture in wall cavity

**Solutions:**
- Dew point in continuous insulation
- Use spray foam insulation instead
- Use continuous insulation exterior of framing

OPTIMAL SOLUTION
Dew point occurs on exterior side of sheathing

Vapor Movement (drying) occurs in both directions

HIGH PERFORMANCE BUILDING ENVELOPES

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Durability Considerations

Exterior Barrier Functions

HPE DESIGN CHALLENGES

Location Of Vapor Barrier

**Problem:**
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- Dew point in continuous insulation
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**High Performance Building Envelopes**

BCRA
Durability Considerations
Exterior Barrier Functions

AIR LEAKAGE

AIR LEAKAGE

CONVECTIVE AIR LOOPS
REASONS WHY - FAILURES

FORENSIC INVESTIGATION:

SLIDE 1 of 14

• Construction: Stucco cladding over wood framing
• Time of Year: Summer
• Weather: Dry
REASONS WHY - FAILURES

FORENSIC INVESTIGATION:
SLIDE 2 of 14

• Construction: Stucco cladding over wood framing
• Cut opening in stucco
REASONS WHY - FAILURES

FORENSIC INVESTIGATION:
SLIDE 3 of 14

- Construction: Stucco cladding over wood framing
- Stucco removed to expose building paper behind
- Wet Building Paper
REASONS WHY - FAILURES

FORENSIC INVESTIGATION:
SLIDE 4 of 14

- Construction: Stucco cladding over wood framing
- Building paper cut away to expose Tyvek Home Wrap
REASONS WHY - FAILURES

FORENSIC INVESTIGATION:
SLIDE 6 of 14

• Construction: Stucco cladding over wood framing
• Cut opening in OSB sheathing
FORENSIC INVESTIGATION:

• Construction: Stucco cladding over wood framing
• Opening in OSB sheathing to expose insulated wall cavity
• **Stud cavity is hot and very humid**
REASONS WHY - FAILURES

FORENSIC INVESTIGATION:
SLIDE 8 of 14

• Construction: Stucco cladding over wood framing
• Insulation pulled back to expose plastic sheet vapor barrier
• Water vapor condensed on plastic sheet vapor barrier
REASONS WHY - FAILURES

FORENSIC INVESTIGATION:
SLIDE 9 of 14

- Construction: Stucco cladding over wood framing
- Measure moisture content of wood wall framing
- Wall framing moisture content is 20% at exterior side of wall
REASONS WHY - FAILURES

FORENSIC INVESTIGATION:
SLIDE 10 of 14
• Construction: Stucco cladding over wood framing
• Measure moisture content of wood wall framing
• Wall framing moisture content increases to 20.5% at 1/3 depth of wall
REASONS WHY - FAILURES

FORENSIC INVESTIGATION:

SLIDE 11 of 14

• Construction: Stucco cladding over wood framing

• Measure moisture content of wood wall framing

• Wall framing moisture content increases to 21.5% at 2/3 depth of wall
REASONS WHY - FAILURES

FORENSIC INVESTIGATION:
SLIDE 12 of 14
• Construction: Stucco cladding over wood framing
• Measure moisture content of wood wall framing
• Wall framing moisture content increases to 23.3% at 7/8 depth of wall
REASONS WHY - FAILURES

FORENSIC INVESTIGATION:
SLIDE 13 of 14

• Construction: Stucco cladding over wood framing
• Measure moisture content of wood wall framing
• Wall framing moisture content increases to 26.8% at interior edge of wall framing
REASONS WHY - FAILURES

FORENSIC INVESTIGATION:
SLIDE 14 of 14
• Construction: Stucco cladding over wood framing
• Measure moisture content of interior GWB
• GWB Moisture Content: 16.9%
REASONS WHY - FAILURES

FORENSIC INVESTIGATION:
• Construction: Stucco cladding over wood framing
• Parallam column framing
• It got worse...
REASONS WHY - FAILURES

FORENSIC INVESTIGATION:
- Construction: Stucco cladding over wood framing
- It got a lot worse...
High Performance Buildings

Termite Mound, Africa

Portcullis House, Westminster, London
High Performance Building Standards & Certifications

2. U.S. Dept. of Homeland Security - Owner Project Requirements (OPR) Tool
3. ASHRAE – Building Energy Quotient
4. Living Building Challenge
5. Architecture 2030 – The 2030 Challenge
6. Passive House
Energy Star Program

HIGH PERFORMANCE BUILDING ENVELOPES
Energy Star Program

DOE - Building Performance Database

- 36,493 commercial buildings in the U.S.
- Median EUI is 171
- 679 commercial buildings in Washington State
- Median EUI is 141

**EUI** = Energy Use Intensity
Annual Energy Used Per Square Foot (kBtu / sf / year)
High Performance Buildings

Ben Franklin Elementary School, Kirkland, WA
Lake Washington School District
56,800 sf
Energy Use - 19.8 kBtu/ft²/yr

High Performance Buildings in Washington State
Source: Dept. of Energy Building Database
High Performance Buildings

Bremerton Bachelors Enlisted Quarters, Bremerton, WA
Naval Base Kitsap-Bremerton
99,800 sf
Energy Use – 46.2 kBtu/ft²/yr
LEED Certified

High Performance Buildings in Washington State
Source: Dept. of Energy Building Database
High Performance Buildings

Denny Park Apartments, Seattle, WA
39,700 sf
Energy Use – 31.8 kBtu/ft²/yr

High Performance Buildings in Washington State
Source: Dept. of Energy Building Database
High Performance Buildings

Pierce County Environmental Services Building
Chambers Creek, WA
50,000 sf
Energy Use – 81.7 kBtu/ft²/yr

High Performance Buildings in Washington State
Source: Dept. of Energy Building Database
High Performance Buildings

Seattle Justice Center, Seattle, WA
288,000 sf
Energy Use – 77.8 kBtu/ft²/yr LEED Silver

High Performance Buildings in Washington State
Source: Dept. of Energy Building Database
High Performance Buildings

Seattle Terminal Radar Approach Control, SeaTac, WA
52,100 sf
Energy Use – 128 kBtu/ft²/yr
LEED Gold

High Performance Buildings in Washington State
Source: Dept. of Energy Building Database
Owner Project Requirements (OPR) Tool

OPR is a web-based tool that allows analysis of:

- Safety
- Security
- Energy Conservation and Renewal
- Environmental Sustainability
- Durability
- Continuity of Operations
- Cost Benefit
Building Energy Quotient (bEQ)

- Requires a bEQ qualified practitioner.
- Determines the *as-designed* building energy potential.
- Improves energy performance and efficiency with an *in-operation* assessment.
Living Building Challenge offers 3 Certification options:

- ‘Living’ Status – Full Certification
- Petal Certification (partial certification)
- Net Zero Energy Building Certification
Architecture 2030 - The 2030 Challenge

U.S. Energy Consumption by Sector

The 2030 Challenge
Passive House Performance Characteristics

- Annual Energy Consumption - $\leq 38.1 \text{ kBtu/sf/yr}$
- Annual Heating Requirement - $\leq 4.75 \text{ kBtu/sf/yr}$
- Super-Insulated Envelope
- Ultra-High-Performance Windows
- Airtight Envelope Construction - $\leq 0.6$ air changes/hr at 50 Pa
- Eliminate Thermal Bridging in Envelope
- Heat-Recovery Ventilation
COMMISSIONING: a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, systems, and assemblies meets defined objectives and criteria.
WHAT IS HPE COMMISSIONING?

• Provides HPE installation accountability
• Can be separate or part of the commissioning contract for M & E
• Confirms that the specified products/systems are used
• Confirms installation conforms to manufacturer’s installation instructions
• Provides testing of installed systems to confirm performance
• Provides documentation of the HPE installation
AIR LEAKAGE TESTING

2012 WASHINGTON STATE ENERGY CODE

C402.4.1.2.3 Building Test. The completed building shall be tested and the air leakage rate of the building envelope shall not exceed 0.40 cfm/ft² at a pressure differential of 0.3 inches water gauge (2.0 L/s m² at 75 Pa) in accordance with ASTM E779 or an equivalent method approved by the code official.
AIR LEAKAGE TESTING

2012 WASHINGTON STATE ENERGY CODE

C402.4.1.2.3 Building Test. The completed building shall be tested and the air leakage rate of the building envelope shall not exceed 0.40 cfm/ft² at a pressure differential of 0.3 inches water gauge (2.0 L/s m² at 75 Pa) in accordance with ASTM E779 or an equivalent method approved by the code official.

A report that includes the tested surface area, floor area, air by volume, stories above grade, and leakage rates shall be submitted to the building owner and the Code Official.

If the tested rate exceeds that defined here, a visual inspection of the air barrier shall be conducted and any leaks noted shall be sealed to the extent practicable.

An additional report identifying the corrective actions taken to seal air leaks shall be submitted to the building owner and the Code Official and any further requirement to meet the leakage air rate will be waived.
AIR LEAKAGE TESTING
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AIR LEAKAGE TESTING

HIGH PERFORMANCE BUILDING ENVELOPES
AIR LEAKAGE TESTING
AIR LEAKAGE TESTING
3 STEPS TO MANAGING HIGH PERFORMANCE ENVELOPES

1. **DECIDE** on HPE at planning and funding phase
2. **TARGET** HPE options during design phase
3. **VERIFY** HPE during construction phase
Thank-you!