## Passive Envelope Advancement

2017 Building Technologies Office Peer Review

### Baseline

<table>
<thead>
<tr>
<th>Concrete wythe</th>
<th>XPS insulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2” : 2” : 3”</td>
<td></td>
</tr>
</tbody>
</table>

Concrete density = 144 pcf  
Panel weight = 60 psf

### New Design

<table>
<thead>
<tr>
<th>Concrete wythe</th>
<th>XPS insulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1½” : 4” : 1½”</td>
<td></td>
</tr>
</tbody>
</table>

Concrete density = 100 pcf  
Panel weight = 25 psf

### Next Generation of Architectural Precast Concrete Wall Panels for New Construction

- 50% lighter
- 50% higher thermal performance
- Cost neutral design

### Assessment of Techniques to Retrofit Commercial Building Envelopes

**Before Retrofit**

**Rendering of Retrofitted Building**

### U.S.-China Clean Energy Research Center  
Building Energy Efficiency (CERC-BEE)

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Project Summary

Timeline
Start date: 4/1/16
Planned end date: 3/30/21

Key Milestones
1. 3/31/17: Designed and manufactured 1 - 2 prototypes of composite accessories
2. 3/31/17: Designed 5 - 6 concrete formulations that could achieve $\geq 600$ psi flexural strength at 12 hours and 100 pcf density

Budget
Total Project to Date
- DOE: $545K
- Cost Share: $983K

Total Project
- DOE: $2.7M
- Cost Share: $4.3M

Key Partners

Project Outcomes
- Next-gen architectural precast insulated walls
- Cost-effectiveness evaluation of commercial building envelope retrofits
- New air sealing technologies
Purpose

Problem Statement

1. New commercial buildings:
Envelope energy saving technologies typically take longer and cost more to install properly in onsite than offsite construction

2. Existing commercial buildings:
~50% of buildings lack or have minimal insulation and lack an air barrier system because built before energy codes

3. Air sealing technologies:
Easy-to-install air barrier technologies needed to increase airtightness in new and existing buildings

Target Market and Audience

• Market: new and existing commercial buildings in the US and China
• Audience: architects, designers, general contractors

2030 total energy market for commercial buildings
• Precast insulated walls for new construction
  US = 35 TBtu     China = 320 TBtu
• Retrofit of existing envelopes
  US = 120 TBtu    China = 140 TBtu
• Air sealing technologies
  US = 43TBtu      China = 49 TBtu

Envelopes contribute >50% of space heating and cooling loads


Lux Research, Dec 2012.
## Logic Model of Project’s Objectives

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Activities</th>
<th>Key Outputs</th>
<th>Short-term Outcome</th>
<th>Mid-term Outcome</th>
<th>Long-term Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Develop next-gen architectural precast insulated wall panels that are 50% lighter and have 50% higher thermal performance with same installed cost</td>
<td>R&amp;D • Concrete mixes • Advanced composites • Insulation boards • Additive manufacturing • Panel joints</td>
<td>Prototypes of • Concrete mixes for 1½” wythes • Non-corroding accessories for 1½” wythes • 3D-printed molds • Air/water tight panel joints</td>
<td>PCI has technologies for panels that are 50% lighter, have 50% higher thermal performance, and have complex molds made 30% faster w/o increasing installed cost</td>
<td>PCI obtains approval from International Code Council on developed technologies</td>
<td>PCI and its members deploy the developed technologies</td>
</tr>
<tr>
<td>2. Improve techniques to retrofit commercial building envelopes</td>
<td>Retrofit case studies to collect cost and performance data</td>
<td>Energy savings and return on investment estimates</td>
<td>Better informed construction industry</td>
<td>Building owners are less uncertain about retrofitting envelopes</td>
<td>Existing commercial buildings use less energy</td>
</tr>
<tr>
<td>3. Advance easy-to-install air barrier materials</td>
<td>Laboratory evaluations</td>
<td>Performance data</td>
<td>Market deployment</td>
<td>Market adoption</td>
<td>Commercial buildings use less energy due to infiltration</td>
</tr>
</tbody>
</table>
Approach: Precast Walls

Tasks to develop new system

1. Reduce weight by $\geq 50\%$ to decrease transportation and installation cost $\rightarrow$ 1½”-thick concrete wythes
   a. High performance concrete mix: 600 psi flexural strength at 12 hours
   b. Lower concrete density: 100 pcf
   c. Non-corroding accessories made of composites: lifting inserts, panel-to-building connectors, reinforcement

2. Double thermal performance
   a. Non-corroding accessories with low thermal conductivity
   b. Airtight panel joints
   c. No increase in panel thickness

3. 3D print molds for concrete
   a. ~30% faster manufacture of complex molds

4. Improve air/water tightness of panels joints
   a. New joint designs or sealants

Key Issues
Success of new system depends on success of new components

Distinctive Characteristics
• Multi-disciplinary team designing new precast system
• Design developed with guidance from precasters
Approach: Envelope Retrofit & Air Sealing Technologies

Tasks to generate retrofit case studies
1. Gather before and after retrofit data: blower door tests, thermal insulation, energy bills
2. Estimate energy savings thru simulations
3. Estimate return on investment

Key Issues
Slowly increasing network of potential sources

Distinctive Characteristics
Using actual data to estimate energy savings and ROI

Tasks to develop new air sealing technologies
1. Dow and 3M designing new formulations
2. ORNL evaluates performance per manufacturer’s/market needs

Distinctive Characteristics
Dow and 3M focusing on developing easier-to-install technologies
Progress: Precast Walls – High Performance Concrete

• Requirements for 1½”-thick wythes
  – ≥600 psi flexural strength at 12 hours
    • Low-cost chopped and recycled carbon fibers
    • Polypropylene and polyvinyl alcohol (PVA) fibers
    • Basalt mini bars
  – 100 pcf density
    • Lightweight aggregate
    • Hollow microspheres

• Selected results from ≥8 non-optimized mix designs
  – Mix A: 610 psi and 99 pcf
  – Mix B: 720 psi and 99 pcf
  – Mix C: 750 psi and 103 pcf
  – Mix D: 720 psi and 102 pcf
Progress: Precast Walls – Non-Corroding Accessories

Accessories for 1½”-thick wythes

- Erection lifting insert (16,000 lbs)
- Stripping lifting insert (10,000 lbs)
- Tieback connection (10,000 lbs)
- Bearing connection (10,000 lbs)

Erection Lifting Insert Prototypes

- Installed carbon lifter at Gate precast
- Continuous glass fibers/PET
- Long discontinuous glass fibers/PPS
- Continuous glass fibers/vinyl resin
- Long discontinuous carbon fibers/PA6
- Long discontinuous carbon fibers/TPU

Mold Design for Lifting Stripping Insert Prototype

- Assembly
- Prototype
- Female Mold
- Male Mold
- Mold Assembly
Progress: 3D Printed Molds

- Complex molds take 1 to 2 weeks to assemble by hand
- Advanced manufacturing could decrease assembly time by ~30%

Building Elevation

1 Foot Long Cornice Mold Prototype

3D-printed and CNC-finished prototype mold (L) with cornice cross section (R)

Casted concrete
Progress: Cost-Neutral Installed Precast Walls

- Labor/plant cost reduced because complex molds are 3D printed offsite
- Delivery cost reduced because fewer trucks needed to deliver lighter wall panels
- Installation cost reduced by smaller cranes needed to hang lighter wall panels on a less expensive building structural frame

Material costs for insulation, concrete, and composite accessories will increase

Lower labor/plant, delivery, and installation costs offset higher materials costs
Progress: Retrofit of Dundee Theater

- Omaha, NE
- Circa 1925
- ~4,000 ft²
- Uninsulated exterior masonry walls
- No air barrier system
- Retrofit schedule: February to October 2017
- Proposed envelope retrofit
  - Spray closed-cell foam on interior of masonry
  - Increases number of freeze/thaw cycles
  - WJE
    - Evaluation of existing masonry
    - Recommendations to lower freeze/thaw risk
- Before retrofit blower door test in March
Progress: Air Sealing Technologies

• Dow’s LIQUIDARMOR™ LT
  – Silicone-based liquid flashing that can be applied as low as -20°F
  – Lab tests: performance after 20°F installation
  – Launched in October 2016

• Dow’s LIQUIDARMOR™ QS
  – Spray-applied liquid flashing 3-4× faster install than tape
  – ~4 times faster drying time than LIQUIDARMOR™ CM
  – Lab tests: performance on different substrates
  – To be launched in ~Spring 2017

• 3M’s 3015VP
  – Primer-less self-adhered membrane
  – Up to 50% faster installation than membranes that require priming
  – High vapor permeance
  – Lab tests: performance after exposure to 20-115°F and 20-80% RH cycles

• Lab tests
  – ASTM E381, E2357, E1424, E331, E2268
Integration and Collaboration within US Team

- Precast walls
  - ORNL/PCI finalizing Collaborative R&D Agreement (CRADA)
  - PCI
    - Coordinate pilot project
    - Deploy technologies

- Envelope retrofit

- Air sealing

- Publications
  - The case for retrofitting building envelopes, D+D In Depth
  - Building Envelope Advancement under the US-China Clean Energy Research Center for Building Energy Efficiency, Interface

2016 Organizational Members

- Producer
- Erector
- Services Assoc
- Supplier Assoc
- Supporting Org

Precast/Prestressed Concrete Institute

Classification of Organizational Members:
- 38.83% Producer
- 26.60% Erector
- 24.47% Services Assoc
- 7.71% Supplier Assoc
- 2.39% Supporting Org
Integration and Collaboration with Chinese Team

• China State Construction Engineering Corp (CSCEC)

• Largest construction company in the world
  – Excellent mechanism to deploy new technologies

• Performs construction and R&D
  – Precast construction
  – 3D printing
  – Retrofit
  – Air sealing

• CSCEC recently submitted its research proposal

• ORNL and CSCEC to define collaboration
Global Benefits

• Worldwide forecast
  – Precast construction market worth $177B by 2021
    (Markets and Markets, 2017)
    • Asia-Pacific region will be the largest market
    • ≥30% of new buildings in Beijing will be prefabricated by 2020
    • ~8,000 production plants in Europe
  – Global revenue for energy efficiency commercial building retrofits expected to grow from $71.4 in 2016 to >$100B in 2025
    (Navigant Research, 2016)

• US advances in passive envelope will have international outcomes

• Partnership with CSCEC should promote deployment of new technologies worldwide
Next Steps: Precast Walls

• High performance concrete mix
  – Optimize mix based on mechanical properties and cost
  – Replace max amount of Portland cement without compromising mechanical properties and cost
  – Scale up mix at precast plant and further optimize

• Non-corroding composite accessories
  – Produce prototypes, evaluate performance, and optimize designs

• 3D printed molds
  – Print prototypes from actual projects and perform cost analysis

• Panel joints
  – Develop/test new sealants/details at panel joints

• Insulation boards
  – Dow to continue efforts using low-GWP blowing agents

• ORNL/PCI complete CRADA

• Finalize collaboration plan with CSCEC
Next Steps: Envelope Retrofit & Air Sealing Technologies

• Envelope retrofit
  – Expand network of potential sources for case studies
  – Target consultants that specialize in renovations
  – Continue data collection

• Air sealing technologies
  – Continue evaluations of LIQUIDARMOR™ to launch as an air barrier system

• Finalize collaboration plan with CSCEC
Variances: Will have 1 demonstration retrofit project instead of 2 because masonry retrofit requires more in-depth evaluations

Cost to Date: ~80%

Additional Funding: none
# Project Plan and Schedule

- **Start date:** 4/1/16
- **Planned end date:** 3/31/21
- **Slipped milestones because funds arrived 1.5 months late or slow identification of demos**

## Deliverables/Milestones

<table>
<thead>
<tr>
<th>Task 1: Architectural Precast Insulated Concrete</th>
<th>BTO FY16</th>
<th>BTO FY17</th>
<th>BTO FY18</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1.1.1 – Revised Tasks 1.3, 1.4 and 1.5 of this Gantt chart if needed.</td>
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<tr>
<td>D1.2 – Completed modification of ORNL’s facilities.</td>
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<tr>
<td>D1.3.1.1.1 – Held at least 3 meetings between ORNL and PCI.</td>
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<tr>
<td>D1.3.1.1.2 – Selected 3 to 5 potential composite materials for inserts and connectors.</td>
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<tr>
<td>M1.3.1.1.4 – Developed 1 to 2 prototypes and gathered feedback from PCI.</td>
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<tr>
<td>D1.3.2.1 – Summarized requirements and standard tests to be followed in the design of high performance concrete.</td>
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<tr>
<td>M.1.3.2.4.1 – Selected a component for each of those listed under Subtask 1.3.2.2 for concrete testing.</td>
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<tr>
<td>D.1.3.2.4.2 – Designed 5 or 6 concrete formulations that meet or exceed properties using regular quantities of cement.</td>
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<tr>
<td>M.1.3.2.5.1 – Selected a component for each of those listed under Subtask 1.3.2.3 for concrete testing.</td>
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<tr>
<td>D1.4.1 – Produced CAD models of 3D printed mold.</td>
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<tr>
<td>M1.4.2 – Produced two 3D molds and four concrete precast samples.</td>
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<tr>
<td>M1.3.1.1.6 – Manufactured ≥50 samples of 2-ton erection lifting inserts w/ near net shape aluminum mold.</td>
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<tr>
<td>M1.3.1.1.8 – Manufactured ≥50 samples of 10,000 lbs. stripping lifting inserts w/ near net shape aluminum mold.</td>
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<tr>
<td>M1.3.2.6.2 – Designed the most economical concrete mix for the outer wythe that reaches the required mechanical properties.</td>
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<tr>
<td>D1.3.2.7.2 – Measured baseline length change of mortars for the outer wythe and confirmed acceptability with PCI advisory board.</td>
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</tbody>
</table>

## Task 2: Retrofits

| D2.1 – Methodology to gather data from retrofitted buildings. |             |
| D2.2 – Selected two demonstration buildings. |             |
| M2.3.1 – Estimated energy savings due to building envelope retrofits from 1st demo. |             |
| M2.4.2 – Measured the air leakage rate of two building envelopes before they are retrofitted. |             |
| D2.4.4 – Estimated energy savings from the retrofit of two building envelopes. |             |

## Task 3: Air Sealing

| M3.1 – Dow to determine if readily available LIQUIDARMOR formulation can be utilized in below freezing temperatures. |             |
| M3.2 – 3M to determine if readily available 3015VP membrane can be utilized in below freezing temperatures. |             |
| D3.5.2.1 – Issued interim report on 1st wall evaluation. |             |
| M3.5.3 – Issued suggestions to Dow on how to improve the LIQUIDARMORM™ air barrier system. |             |

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### Not all milestone/deliverable are shown due to lack of space