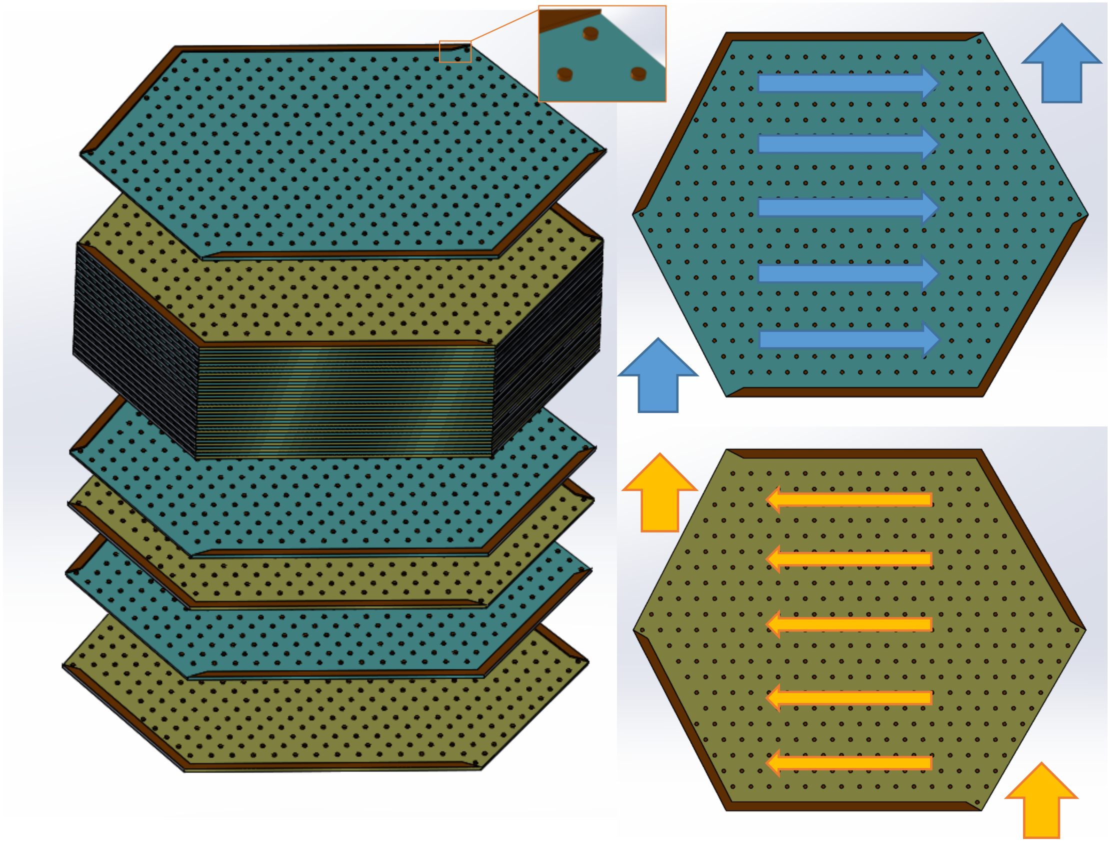
Building-Integrated Heat & Moisture Exchange

2016 Building Technologies Office Peer Review



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Project Summary

Timeline:

Start date: June 17, 2011

Planned end date: July 27, 2016

Key Milestones

1: Demo. Manufacturing at Target Cost July'16

2: Alternate Design At 8% Lower Cost July'17

3: Assembly w/ 28% Fewer Parts July'17

Budget:

Tot. Project $ to Date:

- DOE: $1288590
- Cost Share: $878833

Total Project $: $3,185,199

- DOE: $2,047,811
- Cost Share: $1,137,388

Key Partners:

Oregon State University-Research Institution
dPoint Technologies-Material Supplier
Boost Consulting LLC - commercialization
BasX Solutions* - production
Hunter Douglas Facades* - sales

*not included in current DOE work scope

Project Outcome:

The subject is a hybrid HVAC/Building Envelope technology (BTO MYPP Priorities 2.2 & 2.3) demonstrated in prior phases to reduce HVAC-related energy by 25-50%.

The outcome of the current work will be a product manufactured with advanced additive technologies to meet unit cost targets enabling broad market adoption.

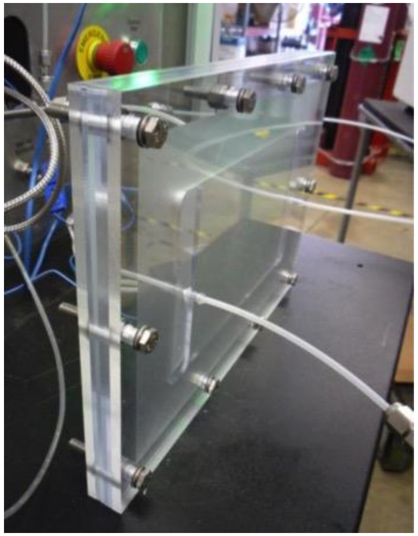
Purpose and Objectives

Problem Statement:
The strong benefits of the technology and resulting market demand have been clearly demonstrated in prior phases of this project.

The current Phase IIB proposal will enable this demand to be satisfied through broad market adoption by making this transformational product available at market-competitive prices.

Target Market and Audience:
The target market is owners, developers, designers, and operators of commercial buildings. Within this sector in ASHRAE Climate Zones 1a, 2a, 3a & 4a alone the technology has the potential so reduce energy use by 36% - or 0.85 Quads – below state-of-the-industry ERV products.

Purpose and Objectives– technology validation history



<u>2010-11</u>
bench-scale (≈1’ x 1’)
arpa-e
Berkeley, CA

LBNL
MTR
trl 4

<u>2011-12</u>
mid-scale (≈3’ x 4’)
doe sttr I
Berkeley, CA

LBNL
dPoint Technologies
trl 5

<u>2012-14</u>
full-scale (≈5’ x 12’)
doe sttr II
Berkeley, CA, Singapore

LBNL
dPoint Technologies
trl 7

Purpose and Objectives

Impact of Project:
The project output is demonstrated manufacturing of a unit at a target installed cost 48% lower than the current benchmark with equivalent performance. With accelerating market adoption, the installed cost premium of the technology will be further reduced through economies of manufacturing at scale.

This impact is aligned with *BTO MYPP* Sections 2.2 (HVAC/Water Heating/Appliances) and 2.3 (Windows and Building Envelope) which promote the development and deployment of Next Generation Technology tracking both energy performance improvement and installed cost.

TERM	YEAR	INSTALLED COST PREMIUM per SQ. FT. FLOOR	PRIMARY ENERGY SAVINGS	INSTALLED COST PREMIUM PER SQ. FT.	UNITS INSTALLED
Near	2016	1st Generation Manufacturing Methods	35%	$1.92	8
Intermediate	2018	2nd Generation Manufacturing Methods	35%	$0.99	100
Long	2020	2nd Generation Manufacturing Methods at Scale	35%	$0.31	1000+

Project Impact Targets

Approach – techno-economic modeling and cost targets

PRODUCT PRICE TARGET	
(Study for Replacement of Packaged DX VAV System within a Small Office Building)	
Reduced Cooling /Ventilation System Capacity	-$53,628
Reduced Ductwork/Distribution	-$35,752
Eliminated Spandrel Wall Area	-$28,600
NET CAP-EX REDUCTION TO CONVENTIONAL SYSTEM	**-$117,980**
TARGET PRICE FOR COST-NEUTRAL SYSTEM SUBSTITUTION (8 PANELS)	**$14,747.50**

TARGET PRODUCT COMPONENT COSTS	
Exchanger Core	$1,200
Balance of System Materials & Labor	$5,581
Margin	$5,764
Total Price	**$12,545**

3 major steps to meeting Cost Target:

1. **New Exchanger Architecture-**

   long deep channels → short shallow channels

2. **Printed Production Process-**

   corrugated spacer → printed spacer

3. **Balance of System Process-**

   many parts → fewer parts

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Approach – 1. new exchanger architecture

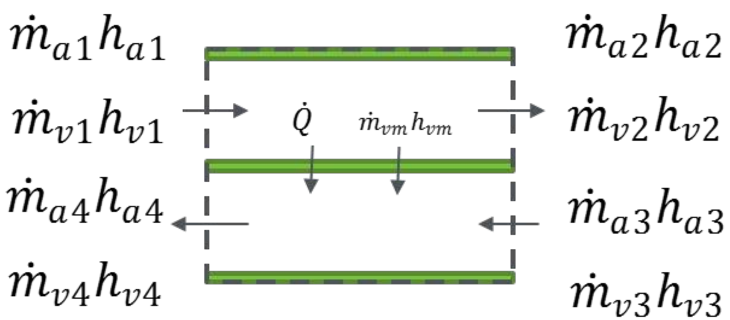
Conservation of mass and energy :

$$0 = \dot{m}_{v1} - \dot{m}_{v2} - \dot{m}_{vm}$$

$$0 = \dot{m}_{v3} - \dot{m}_{v4} + \dot{m}_{vm}$$

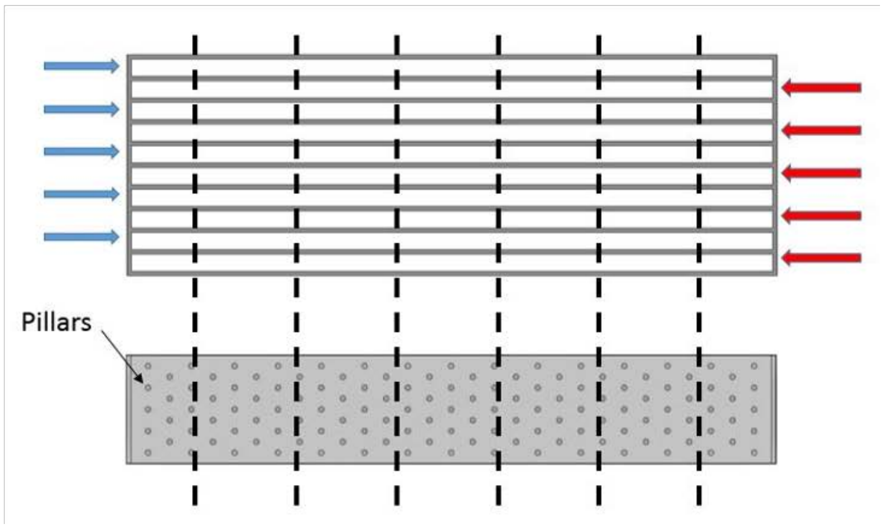
$$0 = -\dot{Q} + \dot{m}_{aS}[(h_{a1} + \omega_1 h_{v1}) - (h_{a2} + \omega_2 h_{v2}) - h_{vm}(\omega_1 - \omega_2)]$$

$$0 = \dot{Q} + \dot{m}_{aE}[(h_{a3} + \omega_3 h_{v3}) - (h_{a4} + \omega_4 h_{v4}) + h_{vm}(\omega_4 - \omega_3)]$$

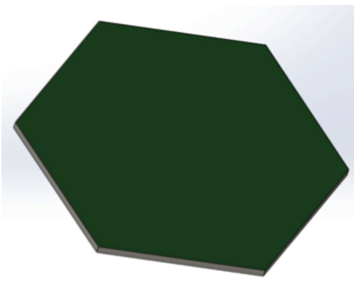


$$\dot{m}_{aS} = \dot{m}_{a1} = \dot{m}_{a2}$$

$$\dot{m}_{aE} = \dot{m}_{a3} = \dot{m}_{a4}$$

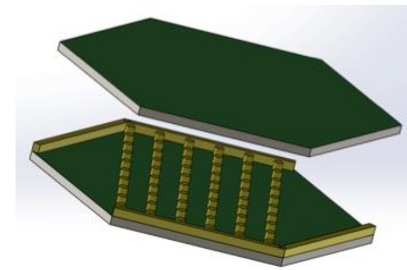


Approach– 2. additively printed spacer process



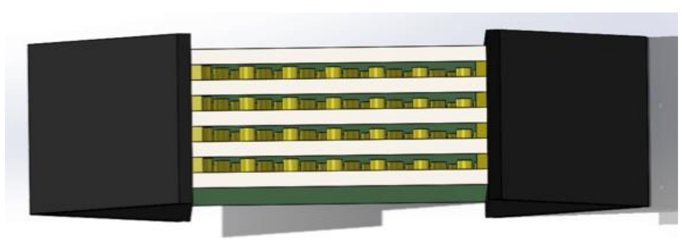
1. Point membrane (shown already diced)

2. Heated Adhesive Dispense



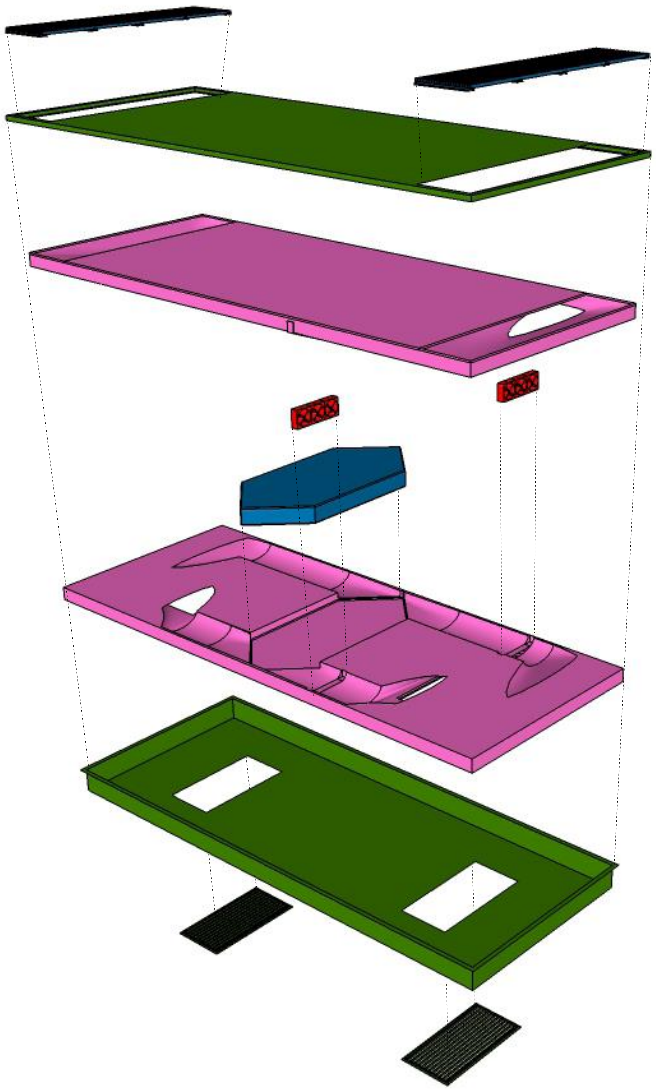
3. Second membrane layered on top of adhesive pillars

4. Repeated adhesive deposition + membrane stacking



5. Insertion into exchanger frame

Approach– 3. balance of system manufacturing



Concept for a formed panel interior.

- site-formed or pre-formed
- meets smoke and flame-spread requirements
- provides sufficient thermal insulation levels

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Approach

Key Issues:

A. Adhesive Selection

Category	Current Requirement	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Adhesive Type		[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Vendor	None	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Primary composition	None	PSA (Rubber Based)	Amorphous Poly-alpha olefin (APAO)	Polyurethane (1 part)	3M Low Surface Energy Acrylic Adhesive 300LSE (PSA) + Polyester release liner	Polyurethane (1 part)
Deposition method	Below 80°C or 150°C localized	149 - 191°C dispense + RT set to tacky PSA state	171 - 191°C dispense (lower?) RT set	121 °C dispense RT set	Application of tape between 21 - 38°C to substrate using pressure	110 °C dispense & RT set to tacky state
Adhesion / bond strength	Porous PP and sulfonated PEEK without primer (at least 0.4 N/mm)	✓	✓	(On non-metallic substrate) After cure (?): 1,625 – 4,200 psi	After 15 min. @ RT: 0.75 – 1.26 N/mm After 72 hrs. @ RT: 0.81 – 1.49 N/mm	(On polycarbonate) After 1 hr.: 60 psi After 24 hrs.: 850 psi
Non-slump	125,000 cP @ 25 °C (shear rate of $2\ s^{-1}$)	1,000 cP @ 177°C	3,000 cP @ 149°C	3,000 – 16,000 cP @ 121°C	N/A	4,000 - 9,000 cP @ 110 °C
Presence of solvent	Adhesive should not be solvent based	✓	✓	✓	✓	✓
Working time	Long enough for adhesive deposition and membrane stacking	Needs to stay hot in order to adhere to top layer	Needs to stay hot in order to adhere to top layer (longer open time than HMT 6400)	1.5 - 10 min	Long working time w release liner	1.5 - 4 min. open time
Cure method	non-UV energy source below 80°C or 150°C localized	Tacky PSA state. No cure?	No cure	Slow moisture cure	Removal of release liner + application of top membrane using pressure. Bond strength can be improved with additional heating (38 - 54°C)	Slow moisture cure
Cure time	Nearly instantaneous with application of energy source (heat, IR, etc…)	Depends on application procedure (especially pressure), but generally <1 min.	Takes <1 min to solidify	Initial set: 15 -150 sec. Full moisture cure: 12-24 hrs.	Nearly instantaneous bond with pressure application	Initial set: 1.5 - 4 min. Full moisture cure: 12 – 24 hrs.
Moisture resistance		✓	✓	✓	✓	✓
Anti-microbial resistance	Adhesive contains no nutrients for fungal / bacterial growth	✓	✓	✓	✓	✓
Cost		\$3.26 - \$2.61 / lb. (\$5.58 - \$7.04 / L)	\$2.88 - \$2.30 / lb. (\$4.92- \$6.22 / L)			
Comments			Lower temp. (<300 °F) dispense may be possible, but bond may be affected. Requires expt. w/ application T between softening point and max. membrane T		Thickness of active adhesive offered: 2, 3.5, 5 mil (50, 88, 127 um). 3M may have thicknesses less than 2 mil for experimental batches	

B. Codes and Standards

- Smoke & Flame Spread (NFPA 285, UL 1812)
- Energy Recovery performance (AHRI 1060)
- Intake Location Restrictions (ASHRAE 62.1/62.2)

C. Space Constraints

- Membrane span capability vs. adhesive spacing
- Fan clearance dimensions vs. acoustics
- Intake geometry vs. pressure drop
- Assembly thickness vs. commercial envelope systems

Approach

Distinctive Characteristics:

i. Hybrid, next-generation building product (wall-integrated, high eff.)

ii. Additive manufacturing process

iii. Micro-channel membrane exchanger

Accomplishments:

i. techno-economic models to determine cost targets

ii. fully discretized numerical model established

iii. adhesive product and dispensing technology screened and identified (in collaboration with industry)

Progress and Accomplishments

Market Impact:

Acceleration of Impact:

Sales: Sales calls in major US markets (Chicago, Atlanta, San Francisco, Houston)
Sales calls with Hunter Douglas Facades in Singapore, Hong Kong)

Education & Outreach:

Presentations to ≈ 4,000 professionals to date
First product sale, 2015 (first generation product)
Active sales pipeline ≈ 15 live projects

Progress Toward Impact Targets:

TERM	YEAR	PRIMARY ENERGY SAVINGS		INSTALLED COST PREMIUM PER SQ. FT.		UNITS INSTALLED	
Near	2016	35%	✓	$1.92	✓	8	13%
Intermediate	2018	35%	✓	$0.99	–	100	–
Long	2020	35%	✓	$0.31	–	1000+	–

in progress

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Progress and Accomplishments

Awards/Recognition:

Finalist -	International Ocean Exchange, 2015
Finalist -	Asia-Pacific Clean Energy Summit, 2012
Finalist –	NOVA INNOVATION Competition,2012
Finalist -	NREL Industry Growth Forum, 2011
Awardee –	ARPA-E BEETIT Program, 2010

Lessons Learned: Performance criteria of adhesive and dispensing are more limiting than originally anticipated.

(dispense temperature, cure time, peel strength, etc.)

Project Integration and Collaboration

<u>Supply Chain</u>: a2 connections with materials supplier (3M) to identify adhesives.

OSU connections with contract manufacturing (Hisco, Nordsen) to consult of dispense technology and process.

dPoint Technologies (supplier) input on prior adhesive use and new membrane properties.

BasX Solutions input on efficient balance of system manufacturing.

<u>Sales:</u> Hunter Douglas Facades integration of technology with industry-standard systems and products

Project Integration and Collaboration

Partners, Subcontractors, and Collaborators:

Oregon State University
Microproducts Breakthrough Institute (MBI)
Project STTR Research Institute

As a part of the Department of Manufacturing, the MBI has a deep expertise in developing cost-effective production methods for micro-channel exchangers and devices. They have a track record of successful low-cost/high efficiency exchanger manufacturing using additive printed approaches.*

*(e.g. cost target achievement for a kidney dialysis membrane exchanger technology marketed by Home Dialysis Plus)

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Project Integration and Collaboration

Partners, Subcontractors, and Collaborators:

dPoint Technologies, Inc.

Membrane manufacturer, supplier, and consulting advisors.

BasX Solutions

Experienced contract HVAC manufacturer and advisor.

Hunter Douglas Facades

Sales channel partner, a $2.6B multinational company.

Boost Consulting

Commercialization consultant with industry experience.

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Project Integration and Collaboration

Communications:

Educational Institutions: Stanford University, 2010-15
University of Oregon, 2013

Professional Events: Façade Tectonics World Congress, Los Angeles
Ocean Exchange, Savannah

Next Steps and Future Plans:

1. Demonstration of manufacturing at target cost (per Milestones)
2. Creation of exchanger production line (capital required, used equipment available)
3. Complete required product certifications
4. Complete 3 additional demonstration installations by 2018
5. Build sales pipeline
6. Engage partners in global sales & distribution

REFERENCE SLIDES

Project Budget

Current Project Phase	Total Project	Expended To Date
PERSONNEL	$94,968	$54,310
TRAVEL	$8,486	$301
MATERIALS/SUPPLIES	$153,820	$12,920
CONSULTANT (Boost)	$10,000	$0
SUBAWARD (OSU)	$445,758	$100,782
INDIRECT	$231,547	$60,778
TOTAL	$1,009,999	$250,778

Variances:

None to date.

Additional Funding:

a2	$119,975
ONAMI	$ 44,575
Tower Labs	$ 17,000

Budget History					
6/17/2011– FY 2015 (past)		FY 2016 (current)		FY 2017 – 7/27/17 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1,137,791	$858,838	$504,999	$139,275	$505,000	$139,275

Project Plan and Schedule

The project plan, with key dates and milestones, is described in the graphic below. A key GO / NO GO milestone is scheduled for late June, 2016 (end of Project Q4), at which time we will have demonstrated the adhesive-printed membrane exchanger process at a cost-feasible target. This milestone should provide a strong basis for success on completing the project objectives.

Project Schedule								
Project Start: 07/28/2015		Completed Work						
Projected End: 07/27/2017		Active Task (in progress work)						
		Milestone/Deliverable (Originally Planned)						
		Milestone/Deliverable (Actual)						
	2015	FY2016				FY2017		
Task	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)
Past Work								
2.1 Governing Exchanger Parameters Characterized								
3.1 Properties of Membrane/Adhesive Spec								
3.2 Techno-Economic Models and Targets Established								
Current/Future Work								
1.1 Demonstration of Adhesive Printing & Curing								
1.4 Validation of Multilayer Exchanger Prototype								
2.3 Numerical Validaton of New Exchanger Atchitecture								
4.2 Demonstration of Simplified B.O.S. Production								
4.2 Full Uit Production Field Demonstration								